Lecture 1: Introduction to Soil and Water Conservation

Practical 1: General status of soil conservation in India

1.1 Why Soil and Water Conservation?

Soil and water are two important natural resources and the basic needs for agricultural production. During the last century it has been observed that the pressure of increasing population has led to degradation of these natural resources. In other words increase in agricultural production to feed the increasing population is only possible if there sufficient fertile land and water are available for farming. In India, out of 328 million hectares of geographical area, 68 million hectares are critically degraded while 107 million hectares are severely eroded. That's why soil and water should be given first priority from the conservation point of view and appropriate methods should be used to ensure their sustainability and future availability.

Water conservation is the use and management of water for the good of all users. Water is abundant throughout the earth, yet only three percent of all water is fresh water, and less than seven-tenths of freshwater is usable. Much of the usable water is utilized for irrigation. Detailed analysis will show that in about fifteen years, about two-thirds of the world's population will be living in some sort of water shortage. Water is used in nearly every aspect of life. There are multiple domestic, industrial and agricultural uses. Water conservation is rapidly becoming a hot topic, yet many people do not realize the importance of soil conservation.

Soil conservation is defined as the control of soil erosion in order to maintain agricultural productivity. Soil erosion is often the effect of many natural causes, such as water and wind. There are also human factors which increase the rate of soil erosion such as construction, cultivation and other activities. Some may argue that since it is a natural process, soil erosion is not harmful. The truth is that with the removal of the top layer of soil, the organic matter and nutrients are also removed.

Conservation is not just the responsibility of soil and plant scientists, hydrologists, wildlife managers, landowners, and the forest or mine owner alone.

All citizens should be made aware about the importance of natural resources as our lives depend on that and everyone should be involved in the process of caring of these resources properly and using them intelligently.

1.1.1 What is Soil Erosion?

The uppermost weathered and disintegrated layer of the earth's crust is referred to as soil. The soil layer is composed of mineral and organic matter and is capable of sustaining plant life. The soil depth is less in some places and more at other places and may vary from practically nil to several metres. The soil layer is continuously exposed to the actions of atmosphere. Wind and water in motion are two main agencies which act on the soil layer and dislodge the soil particles and transport them. The loosening of the soil from its place and its transportation from one place to another is known as soil erosion.

The word erosion has been derived from the Latin word 'erodere' which means eating away or to excavate. The word erosion was first used in geology for describing the term hollow created by water. Erosion actually is a two phase process involving the detachment of individual soil particle from soil mass, transporting it from one place to another (by the action of any one of the agents of erosion, viz; water, wind, ice or gravity) and its deposition. When sufficient energy is not available to transport a particle, a third phase known as deposition occurs. In general, finer soil particles get eroded more easily than coarse particles (silt is more easily eroded than sand). Hence soil erosion is defined as a process of detachment, transportation and deposition of soil particles (sediment). It is evident that sediment is the end product of soil erosion process. Sediment is, therefore, defined as any fragmented material, which is transported or deposited by water, ice, air or any other natural agent. From this, it is inferred that sedimentation is also the process of detachment, transportation and deposition of eroded soil particles. Thus, the natural sequence of the sediment cycle is as follows:

Soil $\longrightarrow$ detachment $\longrightarrow$ Transportation $\longrightarrow$ Deposition

Detachment is the dislodging of the soil particle from the soil mass by erosive agents. In case of water erosion, major erosive agents are impacting raindrops and runoff water flowing over the soil surface. Transportation is the entrainment and movement of detached soil particles (sediment) from their original location. Sediments move from the upland sources through the stream system and may eventually reach the ocean. Not all the sediment reaches the ocean; some are deposited at the base of the slopes, in reservoirs and flood plains along the way. Erosion is almost universally recognized as a serious threat to human well being. Erosion reduces the productivity of crop land by removing and washing away of plant nutrients and organic matter.

1.1.2 Problems Arising due to Soil Erosion

Balanced ecosystems comprising soil, water and plant environments are essential for the survival and welfare of mankind. However, ecosystems have been disturbed in the past due to over exploitation in many parts of the world, including some parts of India. The resulting imbalance in the ecosystem is revealed through various undesirable effects, such as degradation of soil surfaces, frequent occurrence of intense floods etc.

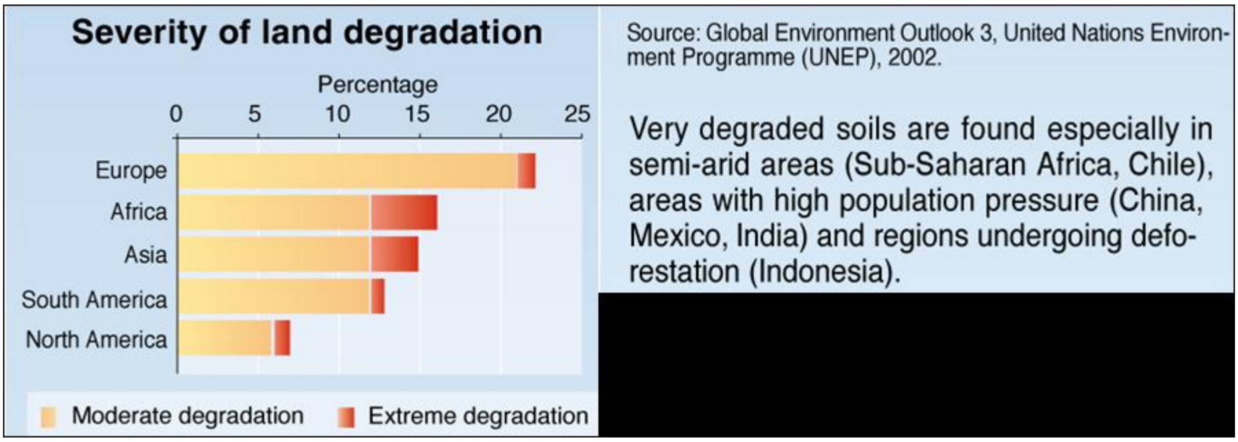


Fig. 1.1. Severity of land degradation at continental scale.

(Source: Peter H.G., 1983)

Vast tracts of land have been irreversibly converted into infertile surfaces due to accelerated soil erosion caused by the above and other factors. These degraded land surfaces have also become a source of pollution of the natural water. Deposition of soil eroded from upland areas in the downstream reaches of rivers has caused aggradation. This has resulted in an increase in the flood plain area of the rivers, reduction of the clearance below bridges and culverts and sedimentation of reservoirs. Severity of land degradation at a continental scale is shown in Fig. 1.1.

The major land degradation problems due to sedimentation are briefly discussed as below:

- Erosion by wind and water: Out of 144.12 M-ha areas affected by water and wind erosion. About 69 M-ha is considered to be critical and needs immediate attention. Wind erosion is mainly restricted to States of Rajasthan, Gujarat and Haryana. The severity of wind erosion is inversely related to the rainfall amount, lesser is the rainfall more would be the wind erosion.

- Gullies and Ravines: About 4 M-ha is affected by the problem of gullies and ravines in the country covering about 12 states. Ravines are mostly located in the states of Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat. Gullies on the other hand are seen in the plateau region of Eastern India, foot hills of the Himalayas and areas of Deccan Plateau.

- Torrents and Riverine Lands: Problem of Riverine and torrents is spread over an area of 2.73 M-ha in the country. Torrents are the natural streams which cause extensive damage to life and property as a result of frequent changes in their course and associated flash flows with heavy debris loads. The unfertile material or debris transported by torrents is sometimes deposited on the fertile plains, thus ruining the land for ever.

- Water logging: Water logging is caused either by surface flooding or due to rise of water table. An area of 8.53 M-ha has been estimated to be affected by water logging.

Water logging due to surface flooding is predominant in the states of West Bengal, Assam, Bihar, Orissa, Andhra Pradesh, Uttar Pradesh, Kerala, Punjab and Haryana.

- Shifting Cultivation: Shifting cultivation, also known as 'jhuming' is a traditional method of growing crops on hill slopes by slash and burn method. The method involves selection of appropriate site on hill slopes, cleaning of forest by cutting and burning, using the site for cultivation for few years and later on abandoning it and moving to a fresh site. The jhum cycle has gradually declined from 20-30 years to 3-6 years due to increasing population pressures. The problem is more serious in North Eastern region and in the states of Orissa and Andhra Pradesh.
- Saline soil including coastal areas: Saline soils are prevalent both in inland as well as coastal areas. About 5.5 M-ha area is affected by this problem in the country which includes arid and semi-arid areas of Rajasthan and Gujarat, black soil region and coastal areas. This problem is causing serious damage to agricultural lands, rendering fertile soil unproductive and turning groundwater brackish in the States of West Bengal, Tamil Nadu, Orissa, Maharashtra, Kerala, Karnataka, Gujarat and Andhra Pradesh as well as Union Territories of Pondicherry and Goa, Daman and Diu.
- Floods and Droughts: In India, among the major and medium rivers of both Himalayas and non-Himalayas catagories, 18 are flood prone which drain an area of 150 M-ha. In recent years, flash floods have caused extensive damage even in the desert areas of Rajasthan and Gujarat.

1.1.3 Importance of Soil Conservation

In India, out of the total geographical area of 329 M-ha, an area of about 150 M-ha is subjected to either water or wind erosion. A net area of about 140 M-ha is cropped at present. An area of 40 M-ha is considered to be flood prone. Area lost through ravines and gullies is estimated to be about 4 M-ha. As a whole, it is estimated that about 175 M-ha i.e., 53.3% of the total geographical area of the country is subjected to various soil and land degradation problems like saline-alkali soils, waterlogged areas, ravine and gullied lands, area under shifting cultivation, and desertification. By the year 2100 A.D, the projected population of the country is expected to be two billion, whereas the food grain production is almost stagnant at 211 million tons for the last 5 years. The per capita cropped area is shrinking every day; in the year 1950, it was 0.33 ha/capita, 0.2 ha in 1980 and it was 0.15 ha by 2000. This clearly shows that the limited land resource has to be managed very carefully by adopting total conservation measures for the survival of the huge population. A few suggestions to conserve soil and water resources in Indian context are discussed below.

- To prevent erosion of bare soil, it is important to maintain a vegetation cover, especially in the most vulnerable areas e.g. those with steep slopes, in a dry season or periods of very heavy rainfall. For this purpose, only partial harvesting forests (e.g.

alternate trees) and use of seasonally dry or wet areas for pasture rather than arable agricultural land should be permitted.

- Where intensive cultivation takes place, farmers should follow crop rotation in order to prevent the soil becoming exhausted of organic matters and other soil building agents. Where soils are ploughed in vulnerable areas, contour ploughing (i.e. round the hillside rather than down the hillside) should be used. Careful management of irrigation, to prevent the application of too much or too little water will be helpful to reduce the problem of soil salinity development. Livestock grazing must be carefully managed to prevent overgrazing.
- Construction of highways and urbanization should be restricted to areas of lower agricultural potential. With extractive industries, a pledge must be secured to restore the land to its former condition before permission for quarries or mines is granted.

1.1.4 History of Soil Erosion and Soil Conservation Programs in India

To meet the demand for food, fiber, fuel wood and fodder owing to increasing population pressures, the forest areas have been indiscriminately cleared resulting in enormous soil loss in many parts of the country. The human activities such as urbanization, road construction, mining etc. have further aggravated the problem. In the early years, the problem was more localized but now it has become more serious due to over exploitation of natural resources. However, various governmental plans have been implemented in the field of conservation of land, water and plant resources since pre-independence days.

(1) The Pre-Independence Era

In 1882, Sir Dietrich Brands, the Inspector General of Forests, commented on the possibility of soil erosion taking place and the need to counter it in the denuded slopes of the Nilgiri District of Madras Province of pre-independence India. He suggested planting of belts of trees in the midst of cultivation on hill slopes. Protection of land from the menace of 'Cho' (mountain torrents) also received early attention and one of the first enactments for prevention of soil deterioration was passed in Punjab in 1900 as Land Preservation Act. It provided for such measures as Wat Bandi (ridge formation), contour trenching, gully plugging, terracing, tree planting etc. for preventing the havoc caused by Chos. Soil conservation research in India was initiated during 1933-35 when the then Imperial (now Indian) Council of Agricultural Research decided to establish its regional centres for research in dry farming at Sholapur (Maharashtra), Bijapur, Raichur, Bellary (Karnataka) and Rohtak (Haryana). Holding rain water by construction of bunds, green manuring, cultivation of kharif crops on shallow soils and fallowing in deep black soils were important measures recommended by the research stations.

A real push to soil conservation was given when a separate Soil Conservation Wing in Agricultural Department was established in Maharashtra during 1940's and massive contour bunding programme was taken up following scientific guidelines and specifications. Field bunding was also practiced as part of famine relief programmes in the Deccan plateau during 1930's and 40's. Soil conservation was not confined to contour bunding alone but also included nala bunding (check dams of loose stones) and percolation dams for water harvesting.

A commission was appointed by the Gwalior State as far back as 1919 to consider ways and means of arresting further extension of ravines and suggest methods for improving production of economic plants in these areas. In the 1930's, ravine reclamation practices were applied in the Chambal ravines of the erstwhile state of Gwalior. In 1953, Board of Agriculture made a proposal for a systematic reconnaissance survey of Indian soils to assess the damage caused by erosion. The Bombay Land Improvement Act of 1942 provided for setting up in each division a Land Improvement Board for conservation, improvement and regulation of agriculture, forest and pasture lands.

In 1945, the Central Government obtained the services of Dr. Donald V. Shuhart of Soil Conservation Service, USDA to report on soil erosion problems in India and suggest remedial measures. A high powered seven member team visited United States in May, 1947 for exhaustive study of soil conservation practices and submitted a report to Government of India taking due cognizance of the conditions peculiar to the Indian Agriculture. The team suggested that the unit of planning should be a village or a group of villages or a watershed. The report also emphasized that there should be a close cooperation between the Department of Forest, Agriculture and Irrigation at the centre and in the provinces in initiating and developing different phases of the conservation programme.

(2) Post-Independence Period

A conference of state Ministers in-charge of agriculture and cooperation was held in New Delhi in September, 1953. The conference considered that at the state level, existing organizations and state development committees should be entrusted with the task of formulating soil conservation programmes. It also suggested that any state problem with regard to soil conservation should be concern of the Central Soil Conservation Board. The central Government in the Ministry of Food and Agriculture set up a Central Soil Conservation Board in 1953. Maharashtra state did pioneering work on problems of soil erosion and conservation measures in cultivated lands. It was realized that ultimate aim of soil conservation was not only to control erosion but also to maintain the productivity of soil.

(3) First Five Year Plan (1951-56)

During the First Five Year Plan (1951-56), considerable attention was given to soil and moisture conservation. With a view to develop a research base for soil conservation, a Soil Conservation Branch and a Desert Afforestation Research Station at Jodhpur were established under the control of Forest Research Institute, Dehra Dun. Consequently, the Central Soil Conservation Board established a chain of nine Soil Conservation Research, Demonstration and Training Centers at Dehra Dun, Chandigarh, Bellary, Ootacamund (now

Udhagamandalam), Kota, Vasad, Agra, Chatra (Nepal) and Jodhpur during the late First Five Year Plan and early Second Five Year Plan.

(4) Second Five Year Plan (1956-61)

In this plan, the Desert Afforestation and Soil Conservation Centre at Jodhpur were developed into the Central Arid Zone Research Institute (CAZRI) in 1959 with collaboration of UNESCO. A Centre was set up at Chatra in Nepal to take-up research on soil conservation problems of Kosi River Valley Project. The All India Soil & Land Use Survey Organization was established at central level.

(5) Third Five Year Plan (1961-66)

A centre at Ibrahimpatnam (Hyderabad) in the semi-arid red soil region was established in the third five year plan in 1962. The Government of India reorganized the Soil Conservation Division in the Ministry of Agriculture and redesignated the Senior Director as Advisor and entrusted him with the responsibility of coordinating the soil and water conservation development. After the reorganization of Agricultural Research and Education in India, all the Soil Conservation Research, Demonstration and Training Centres of the Government of India except Chatra (Nepal) were transferred to the Indian Council of Agricultural Research (ICAR) on the 1st October, 1967.

(6) Fourth Five Year Plan (1969-74)

Under this plan, All India Soil & Land Use Survey prepared a detailed analysis of different watersheds of the country. The concept of Integrated Watershed Management was successfully introduced at field level in different parts of the country.

(7) Fifth Five Year Plan (1974-79)

In this plan, the Government of India introduced many centrally sponsored programmers, viz; Drought Prone Area Programme (DPAP), Flood Prone Area Programme (FPAP), Rural Development Programme (RDP), and Desert Development Programme (DDP). In DPAP and DDP, the focus was on planting of trees on degraded lands and to drill tube wells to extract groundwater.

(8) Sixth Five Year Plan (1980-85)

In this plan period, more emphasis was given on the treatment of small watersheds varying in size up to 2000 hectare. An intensive programme for integrated management of about 200 sub-watersheds of 8 flood prone catchments of Ganga river basin was undertaken during this plan.

(9) Seventh Five Year Plan (1985-90)

In this plan, DDP in hot and cold desert areas took a major establishment and aforestation practices were adopted on a large scale following integrated watershed management approach. On the basis of the experience gained in various schemes, National Watershed Development Programme for Rainfed Areas (NWDPRA) was launched in the 7th Plan in 99 selected districts in the country. NWDPRA was implemented in about 2550 watersheds in 357 districts of 25 states and two Union Territories, viz; Andaman and Nicobar Islands and Dadra and Nagar Haveli. The watershed approach has the advantage of serving the twin objectives of restoration of ecological balance and socio-economic welfare of watershed community.

(10) Eighth Five Year Plan (1990-95)

During this period, Ministry of Agriculture, Department of Agriculture and Cooperation, New Delhi formulated the guidelines for the implementation of NWDPRA and published it in the form of a document commonly known as WARASA (Watershed Areas Rainfed Agriculture System Approach). The Ministry of Rural Development also brought out common guidelines for the implementation of DPAP, DDP and Integrated Wasteland Development Programme (IWDP) in the country so as to maintain uniformity in objectives, strategies and expenditure norms for various watershed development projects.

(11) Ninth Five Year Plan (1997-02)

The centrally sponsored scheme for reclamation of alkali soils was launched during the Seventh Five Year Plan in the states of Haryana, Punjab and Uttar Pradesh. It continued during the Eighth Five Year Plan and was extended to the states of Gujarat, Madhya Pradesh and Rajasthan. During 2000-01, it was extended to all other states where alkali soil problem exists. The scheme aimed at improving physical conditions and productivity status of alkali soils for restoring optimum crop production. The major components were assured irrigation water, on-farm development works like land leveling, bunding and ploughing, community drainage system, application of soil amendments, organic manures etc. During IX Plan, an area of 0.97 lakh ha, mostly occurring in isolated patches, was reclaimed at a cost of Rs. 14.99 crores (Govt. of India share).

Up to IX plan (1997-02), an area of 426 lakh ha had been covered under Priority Delineation Survey (PDS) and about 13.1 lakh ha under Detailed Soil Survey (DSS) by the All India Soil and Land Use Survey.

(12) Tenth Five Year Plan (2002-07)

The Tenth Five Year Plan (2002-2007) has put emphasis on natural resource management through rainwater harvesting, groundwater recharging measures and controlling groundwater exploitation, watershed development, treatment of waterlogged areas. The Government of India fully funded the Western Ghats Development Programme (WGDP), area affected due to erosion and water problem. In this programme, the State Governments were directed to adopt Integrated Watershed Approach in implementing the activities such as soil conservation, agriculture, horticulture, afforestation, fuel and fodder development, minor irrigation, animal husbandry etc. various soil conservation measures (engineering and agricultural) like construction of check dams, gully plugging, plantation of mixed species and contour trenching etc were taken up in sensitive Western Ghats areas of Sattari, Canacona and Sanguem talukas.

(13) Eleventh Five Year Plan (2007-12)

Watershed development projects, for the purpose of conserving soil and water, were funded through various schemes including National Watershed Development Projects in Rainfed Areas (NWDPRA), River Valley Projects (RVP), and Integrated Wasteland Development Programme (IWDP). Emphasis has been given to increase the water resources availability and their efficient use. Responsibility for ensuring adequate availability of water for agricultural use was divided between the Ministry of Water Resources (MoWR), which was responsible for major, medium, and minor irrigation, the Department of Land Resources, which was responsible for watershed management, the Department of Rural Development, which was responsible for the Mahatma Gandhi Rural Employment Guarantee Act (MGNREGA) and strongly oriented to deal with water conservation issues, and the Department of Agriculture, which deals with water use efficiency.

Lecture 2: Principles of Soil Erosion

2.1 Causes of Soil Erosion

No single unique cause can be held responsible for soil erosion or assumed as the main cause for this problem. There are many underlying factors responsible for this process, some induced by nature and others by human being. The main causes of soil erosion can be enumerated as:

(1) Destruction of Natural Protective Cover by

(i) Indiscriminate cutting of trees,

(ii) Overgrazing of the vegetative cover and

(iii) Forest fires.

(2) Improper Use of the Land

(i) Keeping the land barren subjecting it to the action of rain and wind,

(ii) Growing of crops that accelerate soil erosion,

(iii) Removal of organic matter and plant nutrients by injudicious cropping patterns,

(iv) Cultivation along the land slope, and

(v) Faulty methods of irrigation.

2.2 Types of Soil Erosion

2.2.1 According to Origin: Soil erosion can broadly be categorized into two types i.e. geologic erosion and accelerated erosion.

2.2.2 Geological Erosion: Under natural undisturbed conditions equilibrium is established between the climate of a place and the vegetative cover that protects the soil layer. Vegetative covers like trees and forests retard the transportation of soil material and act as a check against excessive erosion. A certain amount of erosion, however, does take place even under the natural cover. This erosion, called geologic erosion, is a slow process and is compensated by the formation of soil under the natural weathering process. Its effect are not of much consequence so far as agricultural lands are concerned.

2.2.3 Accelerated Erosion: When land is put under cultivation, the natural balance existing between the soil, its vegetation cover and climate is disturbed. Under such condition, the removal of surface soil due to natural agencies takes places at faster rate than it can be built by the soil formation process. Erosion occurring under this condition is referred to as accelerated erosion. Its rates are higher than geological erosion. Accelerated erosion depletes soil fertility in agricultural land.

2.2.4 According to Erosion Agents: Soil erosion is broadly categorized into different types depending on the agent which triggers the erosion activity. Mentioned below are the four main types of soil erosion.

(1) Water Erosion: Water erosion is seen in many parts of the world. In fact, running water is the most common agent of soil erosion. This includes rivers which erode the river basin, rainwater which erodes various landforms, and the sea waves which erode the coastal areas. Water erodes and transports soil particles from higher altitude and deposits them in low lying areas. Water erosion may further be classified, based on different actions of water responsible for erosion, as : (i) raindrop erosion, (ii) sheet erosion, (iii) rill erosion, (iv) gully erosion, (v) stream bank erosion, and (vi) slip erosion.

(2) Wind Erosion: Wind erosion is most often witnessed in dry areas wherein strong winds brush against various landforms, cutting through them and loosening the soil particles, which are lifted and transported towards the direction in which the wind blows. The best example of wind erosion is sand dunes and mushroom rocks structures, typically found in deserts.

(3) Glacial Erosion: Glacial erosion, also referred to as ice erosion, is common in cold regions at high altitudes. When soil comes in contact with large moving glaciers, it sticks to the base of these glaciers. This is eventually transported with the glaciers, and as they start melting it is deposited in the course of the moving chunks of ice.

(4) Gravitational Erosion: Although gravitational erosion is not as common a phenomenon as water erosion, it can cause huge damage to natural, as well as man-made structures. It is basically the mass movement of soil due to gravitational force. The best examples of this are landslides and slumps. While landslides and slumps happen within seconds, phenomena such as soil creep take a longer period for occurrence.

2.3 Agents of Soil Erosion

Soil erosion is the detachment of soil from its original location and transportation to a new location. Mainly water is responsible for this erosion although in many locations wind, glaciers are also the agents causing soil erosion. Water in the form of rain, flood and runoff badly affects the soil. Soil is in fact a composite of sand, silt and clay. When the rain falls along the mountains and bare soil, the water detaches the soil particles, and takes away the silt and clay particles along with the flowing water. Similarly, when wind blows in the form of storms, its speed becomes too high to lift off the entire soil upper layer and causes soil erosion.

Other factors responsible for soil erosion are human and animal activities. Vegetation is the natural cover of soil. When the animals continuously graze in the pastures, the vegetation is removed due to their walking and grazing. Bare lands left behind are easily affected by soil erosion. Activities of human like forest cutting, increased agriculture, and clearing of land for different purposes are the other agents that cause erosion of the soil. The soil erosion agent can be classified and summarized as shown in Fig. 2.1.

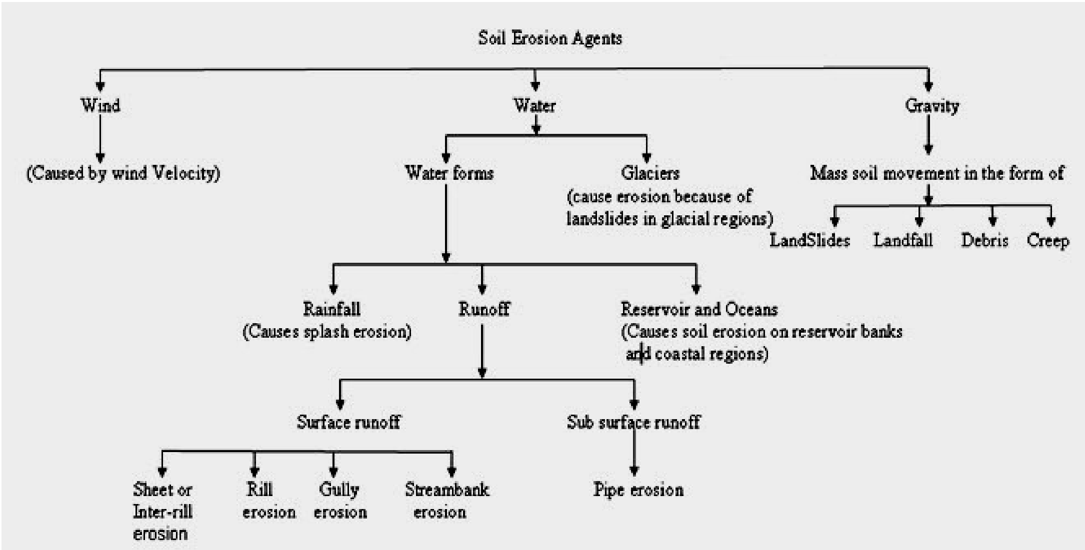


Fig. 2.1. Soil erosion agents, processes and effects

2.4 Factors Affecting Soil Erosion

Soil erosion includes the processes of detachment of soil particles from the soil mass and subsequent transport and deposition of those soil/sediment particles. The main factors responsible for soil erosion, in India, are excessive deforestation, overgrazing and faulty agricultural practices. Soil erosion is a very complicated problem as many complex factors affect the rate of erosion and therefore it is difficult to solve. These factors include:

1. Climatic Factor: The climatic factors that influence erosion are rainfall amount, intensity, and frequency. During the periods of frequent or continuous rainfall, high soil moisture or saturated field conditions are developed, a greater percentage of the rainfall is converted into runoff. This in turn results in soil detachment and transport causing erosion at high rate.

2. Temperature: While frozen soil is highly resistant to erosion, rapid thawing of the soil surface brought about by warm rains can lead to serious erosion. Temperature also influences the type of precipitation. Although falling snow does not cause erosion, heavy snow melts in spring can cause considerable runoff damage. Temperature also influences the amount of organic matter that gets collected on the ground surface and get incorporated with the topsoil layer. Areas with warmer climates have thinner organic cover on the soil. Organic matter cover on the surface protects the soil by shielding it from the impact of falling rain and helping in the infiltration of rainfall that would otherwise cause more runoff. Organic matter inside the soil increases permeability of the soil to cause more percolation and reduce runoff.

3. Topographical Factors: Among the topographical factors, slope length, steepness and roughness affect erodibility. Generally, longer slope increases the potential for erosion. The greatest erosion potential is at the base of the slope, where runoff velocity is the greatest and runoff concentrates. Slope steepness, along with surface roughness, and the amount and intensity of rainfall control the speed at which runoff flows down a slope. The steeper the slope, the faster the water will flow. The faster it flows, the more likely it will cause erosion and increase sedimentation. Slope accelerates erosion as it increases the velocity of flowing water. Small differences in slope make big difference in damage. According to the laws of hydraulics, four times increase in slope doubles the velocity of flowing water. This doubled velocity can increase the erosive power four times and the carrying (sediment) capacity by 32 times.

4. Soil: Physical characteristics of soil have a bearing on erodibility. Soil properties influencing erodibility include texture, structure and cohesion. Texture refers to the size or combination of sizes of the individual soil particles. Three broad size classifications, ranging from small to large are clay, silt, and sand. Soil having a large amount of silt-sized particles is most susceptible to erosion from both wind and water. Soil with clay or sand-sized particles is less prone to erosion.

Structure refers to the degree to which soil particles are clumped together, forming larger clumps and pore spaces. Structure influences both the ability of the soil to absorb water and its physical resistance to erosion. Another property is the cohesion which refers to the binding force between the soil particles and it influences the structure. When moist, the individual soil particles in a cohesive soil cling together to form a doughy consistency. Clay soils are very cohesive, while sand soils are the least cohesive.

5. Vegetation: Vegetation is probably the most important physical factor influencing soil erosion. A good cover of vegetation shields the soil from the impact of raindrops. It also binds the soil together, making it more resistant to runoff. A vegetative cover provides organic matter, slows down runoff, and filters sediment. On a graded slope, the condition of vegetative cover will determine whether erosion will be stopped or only slightly halted. A dense, robust cover of vegetation is one of the best protections against soil erosion.

6. Biological Factors of Soil Erosion: Biological factors that influence the soil erosion are the activities like faulty cultivation practices, overgrazing by animals etc. These factors may be broadly classified into following three groups:(i) Energy factors, (ii) Resistance factors, and (iii) protection factors.

(i) Energy Factors: They include such factors which influence the potential ability of rainfall, runoff and wind to cause erosion. This ability is termed as erosivity. The other factors which directly reduce the power of erosive agents are reduction in length/degree of slope through the construction of terraces and bunds in case of water eroded areas and creation of wind breaks or shelter belts in case of wind eroded areas.

(ii) Resistance Factors: They are also called erodibility factors which depend upon the mechanical and chemical properties of the soil. Those factors which enhance the infiltration of water into the soil reduce runoff and decrease erodibility, while any activity that pulverizes the soil increases erodibility. Thus, cultivation may decrease the erodibility of clay soils but increases that of sandy soil.

(iii) Protection Factors: This primarily focuses on the factors related to plant cover. Plant cover protects the soil from erosion by intercepting the rainfall and reducing the velocity of runoff and wind. Degree of protection provided by different plant covers varies considerably. Therefore, it is essential to know the rate of soil erosion under different land uses, degrees of length and slope, and vegetative covers so that appropriate land use can be selected for each piece of land to control the rate of soil erosion. The quantity of soil moved past a point is called soil loss. It is usually expressed in unit of mass or volume per unit time per unit area.

2.5 Mechanics of Soil Erosion

Soil erosion is initiated by detachment of soil particles due to action of rain. The detached particles are transported by erosion agents from one place to another and finally get settled at some place leading to soil erosion process. Different soil erosion processes are shown in Fig. 2.2.

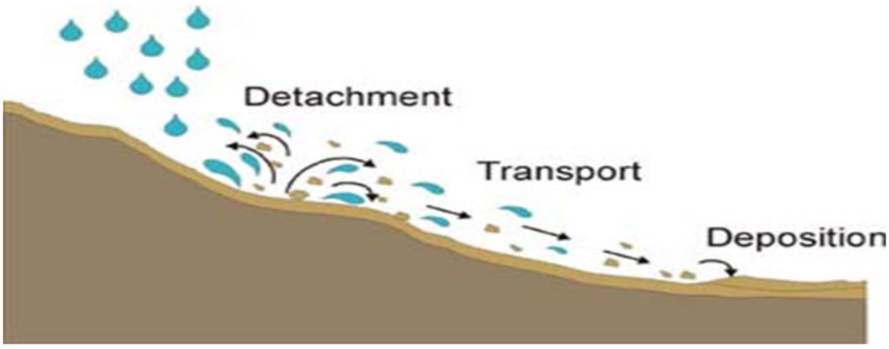


Fig. 2.2. Process of water erosion by the impact of raindrops.

Mechanics of soil erosion due to water and wind is discussed below.

2.5.1 Mechanics of Water Erosion

There are three steps for accelerated erosion by water:

i) Detachment or loosening of soil particles caused by flowing water, freezing and thawing of the top soil, and/or the impact of falling raindrops,

ii) Transportation of soil particles by floating, rolling, dragging, and/or splashing and

iii) Deposition of transported particles at some places of lower elevation.

Rain enhances the translocation of soil through the process of splashing as shown in Fig.2.2. Individual raindrops detach soil aggregates and redeposit them as particles. The dispersed particles may then plug soil pores, reducing water intake (infiltration). Once the soil dries, these particles develop into a crust at the soil surface and runoff is further increased.

2.5.2 Mechanics of Wind Erosion

Wind erosion occurs where soil is exposed to the dislodging force of wind. The intensity of wind erosion varies with surface roughness, slope and types of cover on the soil surface and wind velocity, duration and angle of incidence. Fine soil particles can be carried to great heights and for (may be) hundreds of kilometers. The overall occurrence of wind erosion could be described in three different phases. These are initiation of movement, transportation and deposition.

1. Initiation of Movement: The initiation of the movement of soil particles is caused by several factors acting separately in combination. In the course of collision of grains rolling and bumping on the surface, some particles may be bounced up. It occurs when the wind force or the impact of moving particles is strong enough to dislodge stationary soil particles.

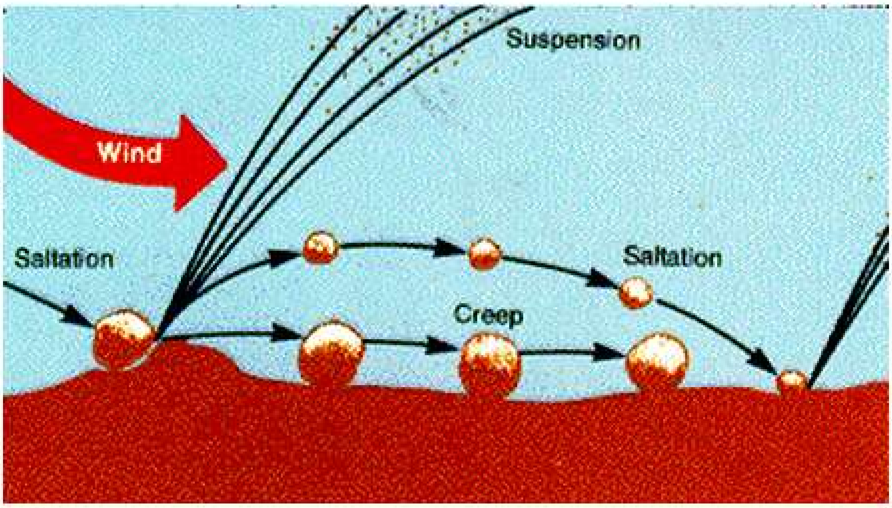
2. Transportation: The transportation of the particles once they are dislodged take place in three ways:

i) Saltation – In saltation soil particles of medium size (0.10-0.15 mm diameter) are carried by wind in a series of short bounces. These bounces are caused by the direct pressure of the wind on soil particles.

ii) Soil Creep – saltation also encourages soil creep (rolling or sliding) along the surface of the particles (0.5-1.0 mm diameter). The bouncing particles carried by saltation strike the large aggregates and speed up their movement along the surface.

iii) Suspension – When the particles of soil are very small (less than 0.1 mm) they are carried over long distances. Finer suspended particles are moved parallel to the ground surface and upward.

3. Deposition: Deposition of the particles occurs when the gravitational force is greater than the forces holding the particles in air. Deposition could occur when the wind velocity is decreased due to surface obstructions or other natural causes



Lecture 3: Water Erosion

Erosion of soil by water is caused by its two forms: liquid as the flowing water, and solid as the glaciers.

3.1 Forms of Water Erosion

The impact of rainfall causes splash erosion. Runoff water causes scraping and transport of soil particles leading to sheet, rill and gully erosion. Water waves cause erosion of bank sides of reservoirs, lakes and oceans. The subsurface runoff causes soil erosion in the form of pipe erosion, which is also called tunnel erosion. The glacial erosion causes heavy landsides. In India, glacial erosions are mainly confined to Himalayan regions. The various forms of water erosion are given below.

3.1.1 Hydraulic Action: The hydraulic action takes place when water runs over the soil surface compressing the soil, as a result of which the air present in the voids exerts a pressure on the soil particles and this leads to the soil detachment. The pressure exerted by the air voids is called hydraulic pressure. The soil particles so detached from their places, are scoured by the running water. The hydraulic action is more effective when the soil is in loose condition.

3.1.2 Abrasion: Soil particles mixed with the running water create an abrasive power in the water which increases the capacity of flowing water to scour more soil particles. Due to this effect, larger soil particles are eroded by the flowing water.

3.1.3 Attrition: This form includes mechanical breakdown of loads running along the moving water due to collision of particles with each other. The broken particles are moved along with the flow velocity, which generate abrasion effect on the bottom and banks of the water course. This effect pronounces the water erosion.

3.1.4 Solution: This form is associated with the chemical action between running water and soil or country rocks. This type condition is observed in areas where existing rocks or soils are easily dissolved in the running water.

3.1.5 Transportation: The process of soil transportation by running water is completed under the following forms:

1) **Solution:** the water soluble contents present in the water are transported by the water in solution form.
2) **Suspension:** it involves the transportation of finer soil particles, which are present in suspension form in the flowing water.
3) **Saltation and Surface Creep:** it involves transportation of medium size soil particles that are not able to stand in suspension form, but are mixed in water and flow over the stream bed in the form of mud. The surface creep action is responsible for transporting the coarser soil particles.

3.2 Factors Affecting Water Erosion

Water erosion is due to dispersive and transporting power of the water; as in case of water erosion first soil particles are detached from the soil surface by the raindrop force and then transported with surface runoff. There is a direct relationship between the soil loss and surface runoff volume. The water erosion process is influenced primarily by climate, topography, soils and vegetative cover. The factors influencing the water erosion are discussed below.

3.2.1 Climatic Factors: Climate includes rainfall, temperature and wind. The frequency, intensity and duration of rainfall are the principal aspects of rainfall influencing the volume of runoff, erosion and sediment (potential) from a given area. As the volume and intensity of rainfall increase, the ability of water to detach and transport soil particles increases. When storms are frequent, intense, and of long duration, the potential for erosion of bare soils is high. Temperature has a major influence on soil erosion. Frozen soils are relatively erosion resistant. However, bare soils with high moisture content are subject to uplift or "spew" by freezing action and are usually easily eroded upon thawing. Wind contributes to the drying of soil and increases the need for irrigation for new plantings and for applying wind erosion control practices.

3.2.2 Soil Characteristics: Soil characteristics include texture, structure, organic matter content and permeability. In addition, in many situations, compaction is significant. These characteristics greatly determine the erodibility of soil. Soils containing high percentages of sand and silt are the most susceptible to detachment because they lack inherent cohesive characteristics. However, the high infiltration rates of sands either prevent or delay runoff except where overland flow is concentrated. Clearly, well-graded and well-drained sands are usually the least erodible soils in the context of sheet and rill erosion. Clay and organic matter act as a binder to soil particles, thus reducing erodibility. As the clay and organic matter content of soils increase, the erodibility decreases. However, while clays have a tendency to resist erosion, they are easily transported by water once detached. Soils high in organic matter resist raindrop impact, and the organic matter also increases the binding characteristics of the soil. Sandy and silty soils on slopes are highly susceptible to gully erosion where flow concentrates because they lack inherent cohesiveness. Small clay particles, referred to as colloids, resist the action of gravity and remain in suspension for long periods of time. Colloids are potentially a major contributor to turbidity where they exist.

3.2.3 Vegetation Cover: Vegetative cover is an extremely important factor in reducing erosion at a site. It absorbs energy of raindrops, binds soil particles, slows down the velocity of runoff water, increases the ability of a soil to absorb water, removes subsurface water between rainfall events through the process of evapotranspiration and reduces off-site fugitive dust. By limiting the amount of vegetation disturbance and the exposure of soils to erosive elements, soil erosion can be greatly reduced. Vegetations create a surface obstruction for direct falling of raindrops on the land surface as well as in the flowing path of surface runoff. A good vegetative cover completely negates the effect of rainfall on soil erosion.

3.2.4 Topographic Effect: The main topographic factors which influence the soil erosion are land slope, length of slope and shape of slope. The land slope or slope inclination affects the erosion predominantly. As the slope increases, the runoff coefficient, kinetic energy and carrying capacity of surface runoff also increase thereby decreasing the soil stability. Critical slope length is the slope length at which the soil erosion begins. It is related to the critical land inclination. Lower the critical inclination larger will be the critical slope length. The slope shapes have greater bearing on erosion potential. The base of a slope is more susceptible to erosion than the top, because runoff has more momentum and is more concentrated as it approaches the base of slope. The slopes may be roughly convex or concave. On convex slope the above phenomena is magnified, whereas on concave slope it is reduced. It is because in convex slope, the steepness increases towards bottom, while it is flattened towards bottom in case of concave slope.

3.3 Types of Water Erosion

Water erosion can be classified as splash erosion, sheet erosion, rill erosion, gully erosion, stream bank erosion, sea-shore erosion and land slide erosion. They are discussed as follows.

3.3.1 Splash Erosion: It is also known as raindrop erosion (Fig. 3.1) because it is caused by the impact of raindrops on exposed soil surface. The process of raindrop erosion can be described as: when raindrop strikes on open soil surface it forms a crater. This is accomplished by forming a blast which bounces the water and soil up and returns back around the crater. The soil may be splashed into the air up to a height of 50 to 75 cm depending upon the size of rain drops. At the same time the soil particles also move horizontally as much as 1.50 m on level land surface. On sloping land, more than half of the splashed particles move down with the runoff.

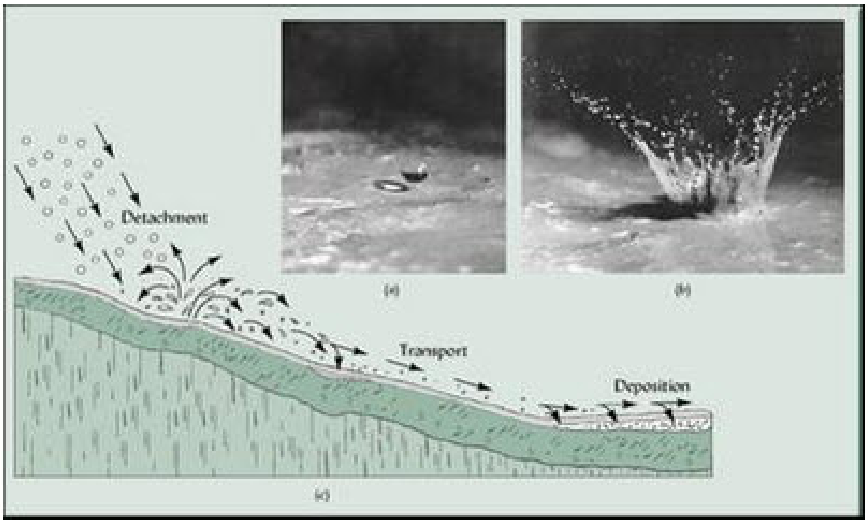


Fig. 3.1. Splash erosion.

3.3.2 Sheet Erosion: Sheet erosion may be defined as more or less uniform removal of soil in the form of a thin layer or in "sheet" form by the flowing water form a given width of sloping land (Fig. 3.2). It is an inconspicuous type of soil erosion because the total amount of soil removed during any storm is usually small. In the sheet erosion two basic erosion processes are involved. First process is the one in which soil particles are detached from the soil surface by falling of raindrop and in the second one the detached soil particles are transported away by surface runoff from the original place. The detached process is referred to as the splash erosion and transportation of detached particles by flowing water is considered as the wash erosion. When the rate of rainfall exceeds the infiltration rate of the soil, the excess water tends to flow over the surface of sloping land. This flowing water also detaches soil particles from the land surface and starts flowing in the form of thin layer over the surface. The erosion during these processes is called sheet erosion. The eroding and transporting power of sheet flow depends on the depth and velocity of flowing water for a given size, shape and density of soil particles.

Fig. 3.2. Sheet erosion

3.3.3 Rill Erosion: This type of water erosion is formed in the cultivated fields where the land surface is almost irregular. As the rain starts, the water tends to accumulate in the surface depressions and begins to flow following least resistance path. During movement of water large amount of soil particles are eroded from the sides and bottom of the flow path, which are mixed in the flowing water. This surface flow containing soil particles in suspension form moves ahead and forms micro channels and rills (Fig. 3.3).

Fig. 3.3. Rill erosion

3.3.4 Gully Erosion: Rills are small in size and can be leveled by tillage operations. When rills get larger in size and shape due to prolonged occurrence of flow through them and cannot be removed by tillage operation, these are called gullies (Fig. 3.4). Large gullies and their network are called ravines. It is the advanced and last stage of water erosion. In other words it is the advanced stage of rill erosion. If the rills that are formed in the field are overlooked by the farmers, then they tend to increase in their size and shape with the occurrence of further rainfall. Some of the major causes of gully erosion are: steepness of land slope, soil texture, rainfall intensity, land mismanagement, biotic interference with natural vegetation, incorrect agricultural practices, etc. Gully erosion gets initiated where the longitudinal profile of an alluvial land becomes too steep due to sediment deposition. Gullies advance due to the removal of soil by the flowing water at the base of a steep slope, or a cliff at the time of fall of stream. High intensity of flow of the runoff increases the gully dimensions. In the absence of proper control measures, slowly the gullies extend to nearby areas and subsequently engulf the entire region with a network of gullies of various sizes and shapes.

Fig. 3.4. Gully erosion

3.3.5 Stream Bank Erosion: Stream bank erosion is defined as the removal of stream bank soil by water either flowing over the sides of the stream or scouring from there (Fig.3.5). The stream bank erosion due to stream flow in the form of scouring and undercutting of the soil below the water surface caused by wave action is a continuous process in perennial streams. Stream bank erosion is mainly aggravated due to removal of vegetation, over grazing or cultivation on the area close to stream banks. Stream bank erosion is also caused by the occurrence of flood in the stream. Apart from scouring, the sloughing is also a form of stream bank erosion which is caused when the stream water subsides after reaching the peak. Sloughing is mainly due to movement of underground water from side into the stream due to pressure difference.

Fig. 3.5. Stream bank erosion

3.3.6 Sea-shore Erosion: It is also called coastal erosion. Sea shore erosion is the wearing away of land and the removal of beach or dune sediments by wave action, tidal currents, wave currents, or drainage (Fig. 3.6). Waves, generated by storms, wind or fast moving motor craft, cause coastal erosion which may take the form of long-term losses of sediment and rocks, or merely the temporary redistribution of coastal sediments. It may be caused by hydraulic action, abrasion, impact and corrosion.

Fig. 3.6. Sea-shore/ coastal erosion

3.3.7 Landslide Erosion: When gravity combines with heavy rain or earthquakes, whole slopes can slump, slip or slide (Fig. 3.7). Slips occur when the soil (topsoil and subsoil) on slopes becomes saturated. Unless held by plant roots to the underlying surface, it slides downhill, exposing the underlying material.

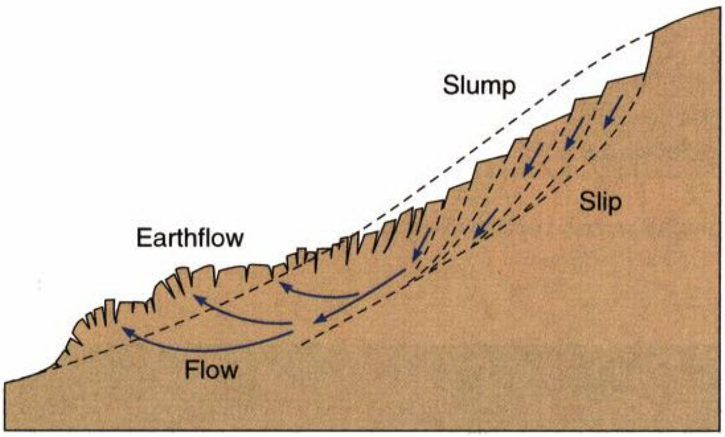


Fig. 3.7. Cross-section of landslide characteristics.

Lecture 4: Principles of Erosion Control

4.1 Agronomical Measures of Water Erosion Control

Soil conservation is a preservation technique, in which deterioration of soil and its losses are eliminated or minimized by using it within its capabilities and applying conservation techniques for protection as well as improvement of soil. In soil and water conservation, the agronomical measure is a more economical, long lasting and effective technique. Agronomic conservation measures function by reducing the impact of raindrops through interception and thus reducing soil erosion. They also increase infiltration rates and thereby reduce surface runoff. Widely used agronomic measures for water erosion control are listed below.

4.1.1 Contour Cropping

Contour Cropping is a conservation farming method that is used on slopes to control soil losses due to water erosion. Contour cropping involves planting crops across the slope instead of up and down the slope (Fig. 4.1). Use of contour cropping protects the valuable top soil by reducing the velocity of runoff water and inducing more infiltration. On long and smooth slope, contour cropping is more effective as the velocity of flow is high under such situation and contour cropping shortens the slope length to reduce the flow velocity. Contour cropping is most effective on slopes between 2 and 10 percent.

Fig. 4.1. Contour cropping

4.1.2 Strip Cropping

Strip cropping is the practice of growing strip of crops having poor potential for erosion control, such as root crop (intertilled crops), cereals, etc., alternated with strips of crops having good potentials for erosion control, such as fodder crops, grasses, etc., which are close growing crops (Fig. 4.2). Strip cropping is a more intensive farming practice than contour farming. The farming practices that are included in this type of farming are contour strip farming, cover cropping, farming with conservation tillage and suitable crop rotation. A crop rotation with a combination of intertilled and close growing crops, farmed on contours, provides food, fodder and conserves soil moisture. Close growing crops act as barriers to flow and reduce the runoff velocity generated from the strips of intertilled crops, and eventually reduce soil erosion. Strip cropping is laid out by using the following three methods:

Fig. 4.2. Strip cropping

i) **Contour strip cropping:** In contour strip cropping, alternate strips of crop are sown more or less following the contours, similar to contouring. Suitable rotation of crops and tillage operations are followed during the farming operations.

ii) **Field strip cropping:** In a field layout of strip cropping, strip of uniform width are laid out across the prevailing slope, while protecting the soil from erosion by water. To protect the soil from erosion by wind, strips are laid out across the prevailing direction of wind. Such practices are generally followed in areas where the topography is very irregular, and the contour lines are too curvy for strict contour farming.

iii) **Buffer strip cropping:** Buffer strip cropping is practiced where uniform strip of crops are required to be laid out for smooth operations of the farm machinery, while farming on a contour strip cropping layout. Buffer strip of legumes, grasses and similar other crops are laid out between the contour strips as correction strips. Buffer strips provide very good protection and effective control of soil erosion.

4.1.3 Mulching

Mulches are used to minimize rain splash, reduce evaporation, control weeds, reduce temperature of soil in hot climates, and moderate the temperature to a level conducive to microbial activity. Mulches help in breaking the energy of raindrops, prevent splash and dissipation of soil structure, obstruct the flow of runoff to reduce their velocity and prevent sheet and rill erosion (Fig. 4.3). They also help in improving the infiltration capacity by maintaining a conductive soil structure at the top surface of land.

Fig. 4.3. Mulching of cropped field.

4.2.3.1 Types of mulching material: To protect the land from erosion different types of materials are used as listed below.

1. Cut grasses or foliage
2. Straw materials
3. Wood chips
4. Saw dusts
5. Papers
6. Stones
7. Glass wools
8. Metal foils
9. Cellophanes
10. Plastics

Lecture 5: Terraces for Water Erosion Control

Practical 2: Design of Bench Terracing System

One of the most effective actions that can take to mitigate the problem of an eroding slope is to break up the rate of water decent by constructing terraces. The terraces for water erosion control consist of some mechanism to protect land surface as well as to reduce the erosive velocity of runoff water. It involves some land surface modification for retention and safe disposal of rainfall

5.1 Terraces and their Design

A Terrace is an earth-embankment, constructed across the slope, to control runoff and minimize soil erosion. A terrace acts as an intercept to land slope, and divides the sloping land surface into strips. In limited widths of strips, the slope length naturally available for runoff is reduced. It has been found that soil loss is proportional to the square root of the length of slope; i.e. by shortening the length of run, soil erosion is reduced. The soil eroded by the runoff scour and the raindrop splash flows down the slope, and gets blocked up by terraces. The scour of soil surface because of runoff water is initiated by the runoff at a velocity above the critical value, attained during a flow on long length of the sloping run. Thus, by shortening the length of run, the runoff velocity remains less than the critical value and therefore soil erosion owing to scour is prevented.

Terraces are classified into to two major types: broad-base terraces and bench terraces. Broad-base terraces are adapted where the main purpose is either to remove or retain water on sloping land suitable for cultivation whereas, the purpose of bench terraces is mainly to reduce the land slope. The classification of the terraces is given in Fig. 5.1.

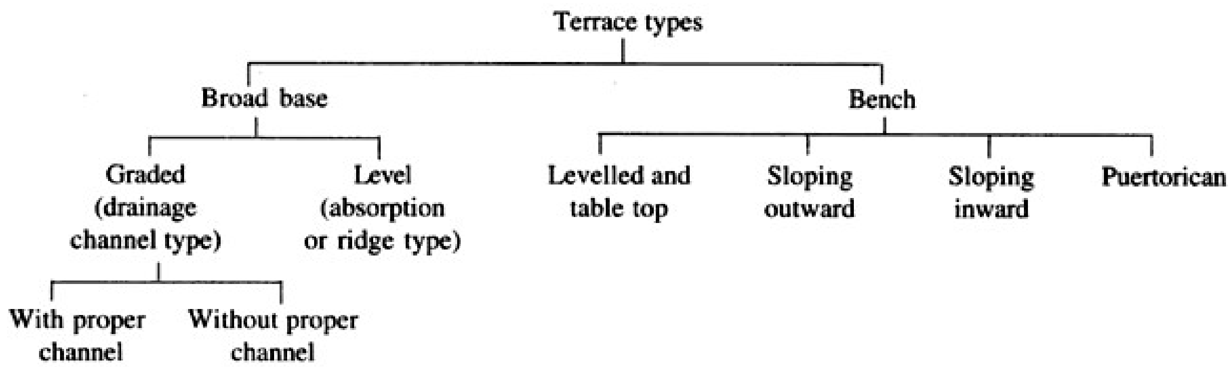


Fig. 5.1. Types of terraces

5.2 Bench Terracing

The original bench terrace system consists of a series of flat shelf-like areas that convert a steep slope of 20 to 30 percent to a series of level, or nearly level benches (Fig. 5.2). In other words, bench terracing consists of construction of series of platforms along contours cut into hill slope in a step like formation. These platforms are separated at regular intervals by vertical drop or by steep sided and protected by vegetation and sometimes packed by stone retaining walls. In fact, bench terrace converts the long un-interrupted slope into several small strips and make protected platform available for farming. In several hilly areas bench terraces have been used for the purpose of converting hill slopes to suit agriculture. In some areas where the climatic conditions favour the growing of certain cash crops like potato, coffee etc., the hill slopes are to be bench terraced before the area is put for cultivation of these crops. Bench terraces have also been adopted for converting sloping lands into irrigated fields or for orchard plantations.

Bench terracing is one of the most popular mechanical soil conservation practices adopted by farmers of India and other countries for ages. On sloping and undulating lands, intensive farming can be only adopted with bench terracing. It consists of construction of step like fields along contours by half cutting and half filling. Original slope is converted into level fields and thus all hazards of erosion are eliminated. All the manure and fertilizers applied are retained in the field. In sloping irrigated lands, bench terracing helps in proper water management. Bench terraces are normally constructed in lands having slope between 20 and 30%.

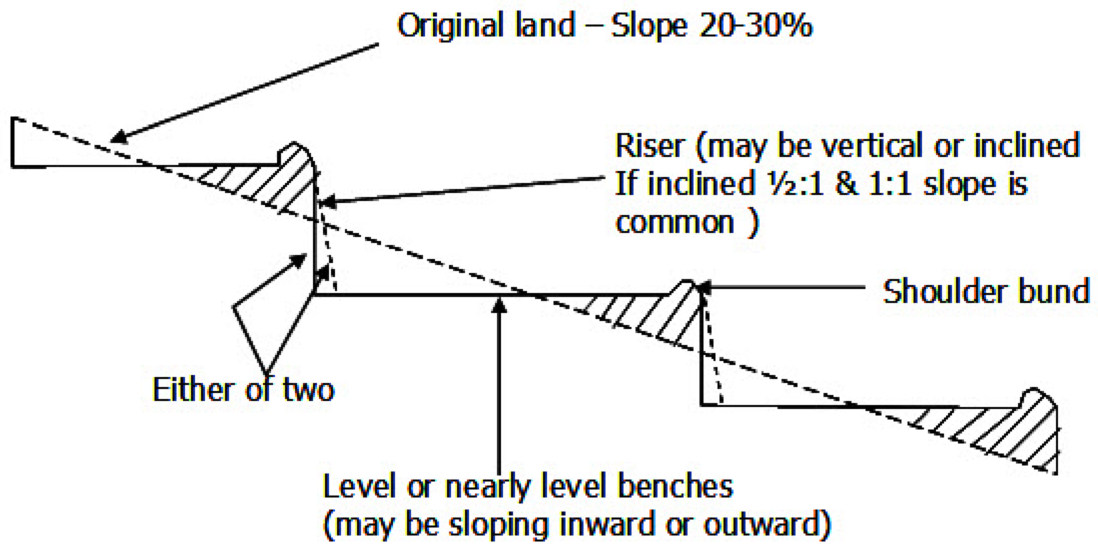


Fig. 5.2. Bench terrace and its different components.

5.3 Types of Bench Terraces and their adaptability

Depending on the purpose for which they are used, bench terraces are also classified as follows:

1. Level Bench Terrace: Paddy fields require uniform impounding of water. Level bench terraces are used for the same and to facilitate uniform impounding. Sometimes this type of terraces are termed as table top, or paddy terraces, conveying the same that such bench is as level as top of the table.

2. Inward Sloping Bench Terrace: Crops like potato are extremely susceptible to water logging. In that case the benches are made with inward slope to drain off excess water as quickly as possible. These are especially suited for steep slopes. It is essential to keep the excess runoff towards hill (original ground) rather than on fill slopes. These inwardly sloping bench terraces have a drain on inner side, which has a grade along its length to convey the excess water to one side, from where it is disposed-off by well stabilized vegetated waterway. These are widely used in Nilgiri hills of Tamilnadu state as well as on steep Himalayan slope in Himachal Pradesh and North-Eastern hill regions. Longitudinal slope of 1 in 120 and inward slope of 1 in 40 is adopted in Nilgris.

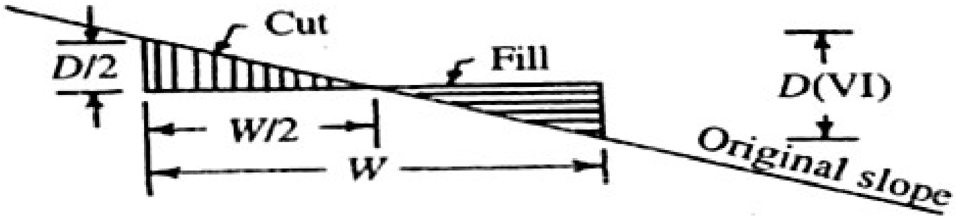
3. Outward Sloping Bench Terraces: Farmers many a times carry out the leveling process in phases, doing part of the job every year. As such outward sloping bench is usually a step towards construction of level or inward sloping bench terraces. In places of low rainfall or shallow soils, the outwardly sloping bench terraces are used to reduce the existing steep slope to mild slope. In this type of terraces constructed on soils not having good permeability, provision of graded channel at lower end has to be kept, to safely dispose off surplus water to some water way. In very permeable soils a strong bund with arrangement may take care for most of the rainfall events, while during heavy rainfall storm, the excess water may flow from one terrace to another. Attempt is usually made to dispose off this to some waterway at an earliest possible spot.

5.4 Design of Bench Terraces

For the designing of the bench terraces for a particular tract the average rainfall, the soil type, soil depth and the average slope of the area should be known. In addition the purpose for which the terraces are to be constructed should also be known. The design of bench terraces consists of determining the (1) type of the bench terrace, (2) terrace spacing or the depth of the cut, (3) terrace width, and (4) terrace cross section.

Selection of the type of bench terrace among the three types, described earlier, depen ds upon the rainfall and soil conditions.

Terrace spacing is generally expressed as the vertical interval between two terraces. The vertical interval (D) is dependent upon the depth of the cut and since the cut and fill are to be balanced, it is equal to double the depth of cut. The factors that limit the depth of cut are the soil depth in the area and the slope. The depth of cut should not be too high as to expose the bed rock which makes the bench terraces unsuitable for cultivation. In higher slopes greater depth of cuts result in greater heights of embankments which may become unstable. The width of the bench terraces (W) should be as per the requirement (purpose) for which the terraces are to be put after construction. Once the width of the terrace is decided, the depth of cut required can be calculated using the following formulae.



Case 1: When the terrace cuts are vertical

$$D = \frac{WS}{100} \qquad (5.1)$$

S is the land slope in percent; D/2 is the depth of cut and W is the width of terrace.

Case 2: When the batter slope is 1:1

$$\frac{D/2}{W/2 + D/2} = \frac{S}{100}$$

$$D = \frac{WS}{(100 - S)} \qquad (5.2)$$

Case 3: When the batter slope is ½: 1

$$\frac{D/2}{W/2 + D/4} = \frac{S}{100}$$

$$D = \frac{2WS}{(200 - S)} \qquad (5.3)$$

After deciding the required width, the depth of cut can be calculated from one of the above formulae.

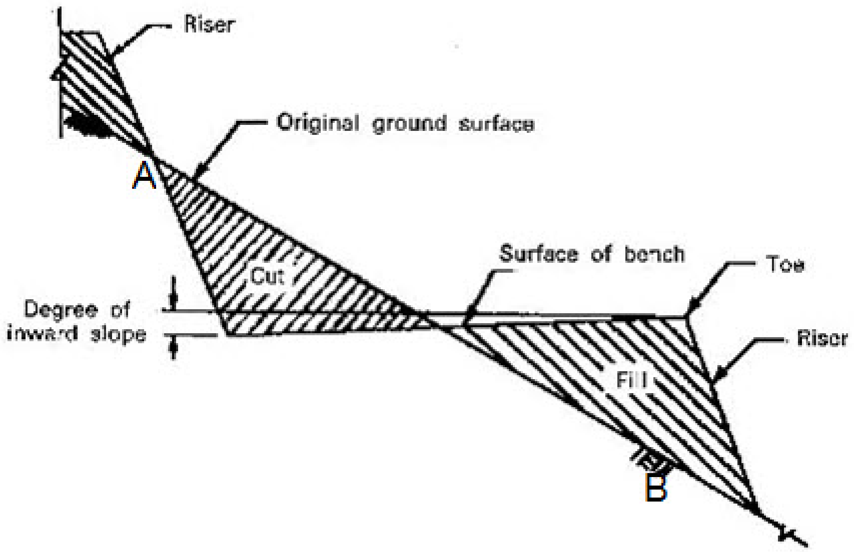


Fig: 5.3 Cross section of bench terraces.

The design of the terrace cross section consists of deciding (1) the batter slope, (2) dimensions of the shoulder bund, (3) inward slope of the terrace and the dimensions of the drainage channel in case of terraces sloping inward, and (4) outward slope in case of terraces sloping outward (Fig. 5.3). The batter slope is mainly for the stability of the fill or the embankment. The flatter the batter slope, the larger the area lost due to bench terracing. Vertical cuts are to be used in very stable soils and when the depth of the cut is small (up to 1 m). Batter slopes of ½: 1 can be used in loose and unstable soils. The size of the shoulder bunds in case of terraces sloping inward is nominal. In case of terraces with flat top and sloping outwards, larger sections of shoulder bunds are required as water stands against these bunds. The bund cross section depends upon the terrace width and soil conditions. The inward slope of the terrace may be from 1 in 50 to 1 in 10 depending upon the soil conditions. For these terraces a drainage channel is to be provided at the inner edge of the terrace to dispose of the runoff.

5.5 Alignment of Bench Terraces

Alignment of bench terraces should start from the ridge and progress towards the valley. The average land slope of the area to be terraced should be determined by taking levels and then the specifications of the terrace should be worked out. Contour lines may be marked with the help of a leveling instrument. Taking a contour line as the centre line, the terrace width may be marked on the ground. The alignment may now be examined and suitable adjustments should be made wherever necessary taking into considerations the local conditions like depressions, sharp turns, field boundaries etc. that exist at the site.

Construction of the bench terraces may be started from the highest terrace and proceeded downwards. By this method, the top soil and the subsoil get mixed up and the top soil may not be available for the terrace surface. In cases where the subsoil condition is not good, it is necessary to keep the top soil apart and again spread it on the terrace. This can be accomplished by starting the construction of the terraces from the lower most one. After the construction of the first terrace, the top soil from the second terrace may be spread on the first terrace and the process continued for subsequent terraces. In bench terraced areas, suitable outlets should be provided to dispose of the runoff safely. In most of the cases one of the sides of the hill slope where vegetation is well established can be used as the outlet. Where such outlets are not available or feasible, waterways are to be formed to dispose of the runoff.

5.6 Area Lost for Cultivation due to Bench Terracing

The area lost for cultivation due to bench terracing of a slope can be calculated as follows. Consider a batter slope of 1:1. Let D be the vertical interval of the benches to be laid out on a land with a slope of S %, along AB in Fig. 5.3 and the batter of the risers is 1:1. L is the horizontal interval between the benches i.e., projected length of AB on horizontal plane. Area lost in bench terracing (A_L) is given by:

$$= \frac{S + 200}{\frac{200}{S} + \frac{S}{100}}$$

The percentage width lost can be taken as the percentage area lost. When the batter is vertical, the length of bench terrace per hectare in metres will be 10000/W where W is in metres. When the batter slope is 1:1 the length per hectare in metres will be 10000/W + D; D and W being in meters.

When batter slope of 1/2:1, then Area lost in bench terracing (A_L) is given by:

$$= \frac{\boldsymbol{S + 100}}{\frac{200}{S} + \frac{S}{100}}$$

5.7 Examples of Terrace Design

Probl 1) On a 20% hill slope, it is proposed to constructed bench terraces. If the vertical interval of terrace is 2 m, calculate (i) length of terrace per hectare, (ii) earth work required per hectare, and (iii) area lost per hectare both for vertical cut and batter slope of 1:1. The cut should be equal to fill.

Solution

Using the equation for vertical cut, and estimating the width of bench terrace (W)-

$$W = \frac{100D}{S} = \frac{100*2}{20} = 10 \text{ m}$$

$$\text{Length of terrace per hectare} = \frac{10000}{10} = 1000 \text{ m}$$

$$\text{Earthwork } = \frac{1}{2}*5*\frac{2}{2}*1000 = 2500 \text{ m}^3.$$

$$\text{Area lost } = \frac{\sqrt{D^2+W^2}-W}{\sqrt{D^2+W^2}}*100 \text{ nearly } 2\%$$

When the batter slope is 1:1, using equation

$$W = \frac{D(100-S)}{S}$$

$$= \frac{2(100-20)}{20}$$

$$= 8 \text{ m}$$

$$\text{Length per hectare } = \frac{10000}{8+1+1}$$

$$= 1000 \text{ m}$$

Earthwork per hectare $=0.5(5*1-1*1)*1000$

$= 2000\ m^3$.

Area lost for cultivation using equation

$$= \frac{S+200}{\frac{200}{S}+\frac{S}{100}} = \frac{20+200}{\frac{200}{20}+\frac{20}{200}} = 21.57\%$$

Probl 2) A 15% hilly land is proposed for constructing the bench terrace. Calculate the following parameters of bench terrace using 2.5m as vertical interval and 1:1 as batter slope: (1) Width, (2) length per hectare, (3) earthwork per hectare and (4) area lost.

Lecture 6: Bunding Methods for Water Erosion Control

Practical 3: Design of Bunds

Bunding is a mechanical method for control of soil erosion. When agronomical measures alone are not sufficient, such and other mechanical measures should be adopted.

6.1 Mechanical Measures for Water Erosion Control

Mechanical practices are engineering measures used to control erosion from slopping land surfaces and thus land surface modification is done for retention and safe disposal of runoff water. In the design of such practices, the basic approach is (i) to increase the time of stay of runoff water in order to increase the infiltration time for water, (ii) to decrease the effect of land slope on runoff velocity by intercepting the slope at several points so that the velocity is less than the critical velocity, and (iii) to protect the soil from erosion caused by the runoff water. The mechanical measures adopted for soil and water conservation are: bunding, terracing etc.

6.2 Bunds (Contour Bunds, Graded Bunds) and their Design

Bund is an engineering measure of soil conservation, used for creating obstruction across the path of surface runoff to reduce the velocity of flowing water. It retains the running off water in the watershed and thus to helps to control soil erosion. Bunds are simply embankment like structures, constructed across the land slope. Different types of bunds are used for erosion control and moisture conservation in the watersheds. When the bunds are constructed along the contours with some minor deviation to adapt to practical situation, they are known as **contour bunds**. If the bunds are constructed with some slope, they are known as **graded bunds**. No farming is done on bunds expects at some places, where some types of stabilization grasses are planted to protect the bund. The choice of the types of bund is dependent on land slope, rainfall, soil type and the purpose of the bund in the area. The contour bunds are recommended for areas with low annual rainfall (< 600 mm) agricultural fields with permeable soils and having a land slope of less than 6%, while graded bunds are used for safe disposal of excess runoff in areas with high rainfall and relatively impervious soil.

In India, contour and graded bunding have been practiced for a long time and the Indian farmers have very good knowledge about it. From the experience, it has been found that bunds could stand well in shallow, medium and medium deep soils. In deep black soil, due to cracks in dry condition, the bunds fail. Through these cracks, water continues to flow and big breaches are usually created. This results in severe damage to the fields. Although various erosion problems exist in black cotton soils, contour bunding cannot be taken up in such soils successfully.

6.2.1 Contour Bunds

Contour bunds are laid out in those areas which have less rainfall and permeable soils. The major requirements in such areas are prevention of soil erosion and conservation of rain water in the soil for crop use. To maximize the conservation of rainwater in the soil, no longitudinal slope is provided to the field strip. In such a system of bunding, the bunds are designed to be laid out on contours with minor adjustments, wherever necessary.

The main functions of contour bunds are:

1. It reduces the length of slope which in turn reduces the soil erosion.
2. The water is impounded for some time and gets recharged into the soil which helps in crop cultivation.

The limitations of contour bunds are:

1. The contour bunds are suitable for those areas, which receive the annual rainfall less than 600 mm
2. It is not suitable for clayey soils
3. Contour bunding is not suitable on the land slopes greater than 6%.

6.2.2 Graded Bunds

Graded bunds are laid out in areas where the land is susceptible to water erosion, the soil is less permeable and the area has water logging problems. A graded bund system is designed to dispose of excess runoff safely form agricultural fields. A graded bund is laid out with a longitudinal slope gradient leading to outlet. The gradient can be either uniform or variable. The uniformly-graded bunds are suitable for areas where the bunds need shorter lengths and the runoff is low. The variable-graded bunds are required where bunds need longer lengths, owing to which the cumulative runoff increases towards the outlets. In these types of bunds, variations in the grade are provided at different sections of the bund to keep the runoff velocity within the desired limits so as not to cause any soil erosion.

The limitations of the system are:

- Due to crossing of farm implements, the bunds are disturbed and some soil is lost.
- Proper maintenance is required at regular interval.

6.3 Design Specification of Bunds

The following parameters should be considered for bund design:

1. **Type of Bund:** The type of bund (contour or graded bund) to be constructed depends upon the rainfall and soil condition. Contour bunds are preferred for construction in areas receiving annual rainfall less than 600 mm and where soil moisture is a limiting factor for crop production. Graded bunds are recommended in heavy and medium rainfall areas. The grade to be provided to the bund may vary from 0.2% to 0.3%.

2. **Spacing of the Bunds:** The basic principles to be adopted for deciding the spacing of bunds are: (1) the seepage zone below the upper bund should meet the saturation zone of the lower bund; (2) the bunds should check the water at a point where the water attains erosive velocity and (3) the bund should not cause inconvenience to the agricultural operations.

For determining the spacing of the bunds the following formula is used:

$$V.I. = \frac{S}{a} + b \quad (6.1)$$

where,

V.I. = vertical interval between consecutive bunds,

S = land slope (percent) and

a and b = constants, depend upon the soil and rainfall characteristics of the area.

The above equation is area specific. It can be modified for areas with different rainfall amounts.

1. For the areas of heavy rainfall:

$$V.I. = 10S + 60 \quad (6.2)$$

2. For the areas having low rainfall

$$V.I. = 15S + 60 \quad (6.3)$$

In which, VI is in cm and S is in percent.

The bund spacing can not be easily located on the ground on the basis of vertical interval. But the horizontal interval (spacing) can be easily measured on the land surface. For this purpose, the relationship between horizontal and vertical spacing is important and is given below.

H.I. = V.I. / S

Here, H.I. indicates the horizontal distance of the bund and V.I. is the vertical interval.

3. Size of the Bund: The size of bund includes its height, top width, side slopes and bottom width. The height of bunds mainly depends upon the slope of the land, spacing of the bunds and the maximum intensity of rainfall expected in the area. Once the height of the bund is determined, other dimensions of the bund viz., base width, top width and side slopes are determined using the information on the nature of the soil. Depending on the amount of water to be intercepted, the height of the bund can be calculated as given below (Fig. 6.1).

Let X = height of the bund, L = distance between bunds, V = vertical interval between bunds, and W = width of water spread.

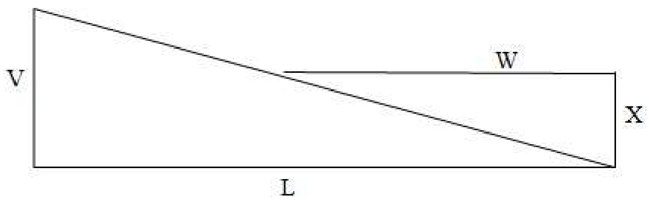


Fig. 6.1. Basic diagram for deriving the height of bund

$$\frac{W}{L} = \frac{X}{V} \quad or \quad W = \frac{LX}{V} \qquad (6.4)$$

Considering 1m length of the bund, amount of water stored = ½ WX

Substituting for W from Eqn. 6.4, amount of water stored

$$= 0.5\left(\frac{LX^2}{V}\right) \qquad (6.5)$$

Assuming that any time the maximum rainfall, which the bunds have to withstand, is 15 cm high; water retained by 1 m length of the bund

$$= \frac{15}{100}(L.1) = \frac{3L}{20} \qquad (6.6)$$

Now equating both these values:

$$0.5\left(\frac{LX^2}{V}\right) = \frac{3L}{20}$$

Height of the bund, $$X = \sqrt{\frac{3V}{10}} \qquad (6.7)$$

When, the land slope is expressed as S per cent.

V = LS/100

$$x = \sqrt{\frac{3LS}{1000}} \qquad (6.8)$$

L and X are in meters and S is the per cent slope. This is the theoretical height and suitable free board is added to arrive at the practical height of the bund.

Base width of the bund depends upon the hydraulic gradient of water in the soil. Side slopes are dependent upon the angle of repose of the soil. A general value of the hydraulic gradient assumed is 1:4. Side slopes of the bund recommended for different soils are given in Table 6.1.

Table 6.1. Side slopes of the bunds recommended for different soil types (Source: Murthy, 1994)

<table>
<tr><td>Side slopes</td><td>1.5 to 1</td><td>2 to 1</td><td>2.5 to 1</td></tr>
<tr><td rowspan="4">Soil types</td><td>Red Gravel</td><td>Light Sandy loam</td><td rowspan="4">Sand</td></tr>
<tr><td>Light red loam</td><td>Clay</td></tr>
<tr><td>Black loam</td><td>Black cotton soil</td></tr>
<tr><td>White gravel</td><td>Soft decomposed rock</td></tr>
</table>

Some of the typical cross sections of bunds are shown in Table 6.2. Usually a higher size of the bunds than required by the hydraulic considerations is adopted to allow for the settlement and poor maintenance by the cultivators.

Table 6.2. Typical bund cross-sections for scarcity areas (Source: Murthy, 1994)

Soil Types	**Top width (m)**	**Bottom width (m)**	**Height(m)**	**Side Slope**
Full maximum or soil layer up to 7.5 cm	0.45	1.95	0.75	1:1
Soil layer from 7.5 cm to 23 cm	0.45	2.55	0.83	1.25 :1
Full soil or soil layer from 23 cm to 45 cm	0.53	3.0	0.83	1.50: 1
Full soil 45 cm to 80 cm	0.60	4.2	0.90	2:1

4. Length of Bund. The length of bund is determined by calculating the horizontal interval of the bund formed. The length of bund per hectare area of land is given as:

$$L = 10000/H.I$$
$$= (10000*S)/(VI*100)$$
$$= 100(S/VI) \qquad (6.9)$$

5. Earth Work: The earth work of bunding system includes the sum of earthwork made in main bunds, side bunds and lateral bunds formed in the field. The earthwork of any bund is obtained by multiplying the cross-sectional area to its total length. The total earthwork can be given by the following equation.

$$E_t = E_m + E_s + E_l \qquad (6.10)$$

where, E_t = total earthwork, E_m = earthwork of main bunds, E_s = earthwork of side bunds, E_l = earthwork of lateral bunds, E_m = cross-sectional area * total length of bund = (100S/VI)* cross-sectional area.

Therefore, $E_s + E_l$ = ((100S/VI) * 30/100) * cross-sectional area

Therefore, total $E_t = E_m + E_s + E_t$

= (100S/VI + 30S/VI)* cross-sectional area

= 130S/VI * cross-sectional area

E_t = 1.3 * (100S/VI) * cross-sectional area of bund

In the above calculation the value of $E_s + E_l$ is taken as 30% earth work of main contour bund (E_m) by assuming that the length of side and lateral bund to be as 30% of the length of main bund and their cross-sectional area is also equal to main bund.

6. Area Lost due to Bunding: It is calculated by multiplying the length of contour bund per hectare with its base width. i.e

A_L = 10000/HI * b

= 100S/VI * b

Where, b is the base width of bund.

This equation computes only the area lost due to main contour bund and not the area lost due to side and lateral bunds. Usually, the area lost due to side and lateral bunds is taken as 30% of the area lost due to main contour bund. Thus, the total area lost due to contour bunding is:

$$\left(\left(\frac{100S}{VI}\right)*b+\left(\frac{100S}{VI}\right)*b*\frac{30}{100}\right)$$
$$=1.3*\frac{100S}{VI}*b$$

The above equation can also be written in the following form to compute the area lost in percentage due to bunding:

A_L (%) = 1.3*S*b/VI

6.4 Construction of Bunds

Construction of bunds should start from the ridge and continue down the valley. This will ensure protection of the bunds if rains occur during construction. The base width area of the bund should be cleared of vegetation and the soil in this area should also be slightly distributed so that good binding can be achieved when the bund is formed over it. The burrow pits for the soil are generally located on the upstream side of the bund. It should have a uniform depth of 30 cm and the width can be varied as per necessity. The burrow pits should be continuous and no breaks are to be left. The burrow pits should not be located in a gully or depression. When the soil is dug, the clods should not be put on the bund at a time. The earth should be put in layers of 15 cm and consolidated by trampling. The templates of the specified dimensions are used for checking the bund section. The bund section should be finally shaped, trimmed and slightly rammed on the top and the sides. After the bund formation, it is desirable to plough the field and the burrow pit.

Lecture 7: Gully Erosion and Control Measures

Gully erosion is an advance stage of rill erosion as rill erosion is the advanced stage of sheet erosion. It is the most spectacular form of erosion. Any concentration of surface runoff is a potential source of gully erosion. The Soil Conservation Society of America defines a gully as "a channel or miniature valley cut by concentrated runoff but through which water commonly flows only during and immediately after heavy rains. It may be dendritic or branching or it may be linear, rather long, narrow and of uniform width". In India, the rate of soil erosion from gullies is 33 t/ha/yr in ravine regions (Shekinah and Saraswathy, 2005). The distinction between ravine, gully and rills is that of size. A gully is too large to be filled by normal tillage practices. A ravine is a deep narrow gorge. It is larger than a gully and is usually worn down by running water. It is estimated that about 4 million ha of land in India are affected by gully erosion (Michael and Ojha, 2012).

7.1 Development of Gullies

The main processes in the development of gullies are waterfall erosion and channel erosion. These two erosions are commonly found in the same gully. The extension of the gully head is usually by waterfall erosion; while the scouring of bottom and sides which enlarges the depth and width of gullies is by channel erosion. Gullies usually start with channel erosion. When an overfall develops at the head of the gully, the gully continues to develop by waterfall erosion. The waterfall erosion at gully head and advancement of the gully towards the upper edge of the watershed is shown in Fig. 7.1.

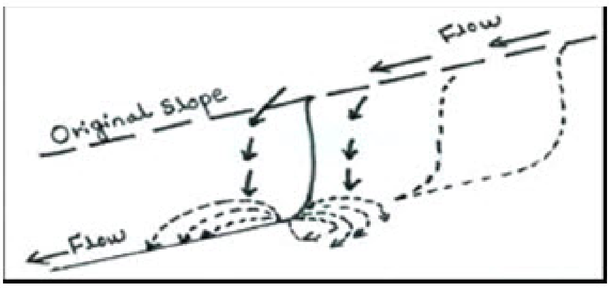


Fig. 7.1. Waterfall erosion at gully head.

The gully development is recognized in four stages:

Formation Stage: Scouring of top soil in the direction of general slope occurs as the runoff water concentrates. It normally proceeds slowly where the top soil is fairly resistant to erosion.

Development Stage: Causes upstream movement of the gully head and enlargement of the gully in width and depth. The gully cuts to the C-horizon of soil, and the parent materials are removed rapidly as water flows.

Healing Stage: Vegetation starts growing in the gully.

Stabilization Stage: Gully reaches a stable gradient, gully walls attain a stable slope and sufficient vegetation cover develops over the gully surface to anchor the soil and permit development of new topsoil.

7.2 Classification of Gullies

Gullies can be classified based on three factors viz. their size, shape (cross section) and formation of branches or continuation. The detailed classification is discussed below.

7.2.1 Based on Size (depth and drainage area)

Gully classification based on the size is presented in Table 7.1.

Table 7.1. Gully classification based on size

Classification	Depth (m)	Drainage area (ha)
Small	< 1	< 2
Medium	1 to 5	2 to 20
Large	> 5	> 20

7.2.2 Based on Shape

The classification of gullies based on shape is shown in Fig 7.2.

U-Shaped: These are formed where both the topsoil and subsoil have the same resistance against erosion. Because the subsoil is eroded as easily as the topsoil, nearly vertical walls are developed on each side of the gully.

V-Shaped: These gullies develop where the subsoil has more resistance than topsoil against erosion. This is the most common form of gully.

Trapezoidal: These gullies are formed where the gully bottom is made of more resistant material than the topsoil. Below the bottom of gully, the subsoil layer has much more resistance to get eroded and thus the development of further depth of gully is restricted.

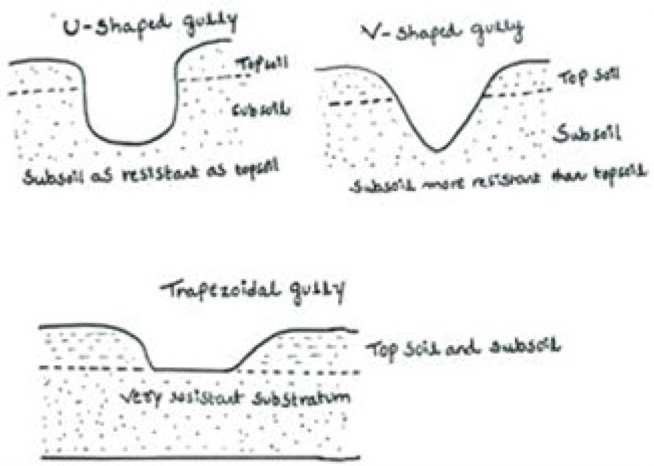


Fig. 7.2. Gully classes based on the shape of gully cross-section.

7.2.3 Based on the Formation of Branches or Continuation

Continuous Gullies: These gullies consist of many branches. A continuous gully has a main gully channel and many mature or immature branch gullies. A gully network is made up of many continuous gullies. A multiple-gully system may be composed of several gully networks.

Discontinuous Gullies: These may develop on hillsides after landslides. They are also called independent gullies. At the beginning of its development, a discontinuous gully does not have a distinct junction with the main gully or stream channel. Flowing water in a discontinuous gully spreads over a nearly flat area. After some time, it reaches the main gully channel or stream. Independent gullies may be scattered between the branches of a continuous gully, or they may occupy a whole area without there being any continuous gullies.

7.3 Principles of Gully Control

Generally, gullies are formed by an increase in surface runoff. Therefore, minimizing surface runoff is essential in gully control. The rate of gully erosion depends primarily on the runoff producing characteristics of the watershed, the watershed area, soil characteristics, size-shape and slope of gully etc. Watersheds deteriorate because of misuse of the land (man made changes), short intensive rainstorms, prolonged rains of moderate intensity, and rapid snow melts. The precipitation factors which turn into high runoff, develop flooding and form gullies. In gully control, the following three methods should be applied according to the order given:

- Improvement of gully catchments to reduce and regulate the runoff rates (peak flows).
- Diversion of surface water above the gully area.
- Stabilization of gullies by structural measures and accompanying re-vegetation.

When the first and/or second methods are applied in some regions of the countries with temperate climates, small or incipient gullies may be stabilized without having to use the third method. On the other hand, in tropical and subtropical countries which have heavy rains (monsoons, typhoons, tropical cyclones, etc.); all three methods have to be applied for successful gully control.

7.4 Gully Control Measures

Preventing the formation of gully is much easier than controlling it once it has formed. One of the major steps in a gully control programme is to plan the control of runoff from the drainage area. The various methods employed for controlling runoff may be considered in the following order:

- **Retention of Runoff on the Drainage Area:** It is possible through good crop management and applicable conservation practices such as contouring, strip cropping, bunding, terracing etc. Where contour bunds are used, runoff is greatly reduced. On cultivated areas, small and medium sized gullies can also be reclaimed by placing a series of earthfills across the gully.
- **Diversion of Runoff Around the Gullied Area:** The most effective control of gullies is by complete elimination of runoff from the gullied area. This can be obtained by diverting runoff from the gully, causing it to flow at a non- erosive velocity to a suitable outlet. Terraces and diversion ditches are generally used for diverting runoff from its natural outlet. Terraces are very effective in the control of small gullies on cultivated fields or even medium size shallow gullies. If the slope above a gully is too steep for terracing, or if the drainage area is pasture or woodland, diversion ditches may be used to keep the runoff out of the gully.
- **Conveyance of Runoff through the Gully:** If it is not possible to either retain or divert the runoff, then runoff must be conveyed through the gully itself. This is possible only if vegetation can be established in the gullies, or if soil conservation structures are built at critical points to give primary control.

7.5 Classification of Gully Control Measures or Structures

Basically gully control structures are used to reduce soil erosion, control sedimentation, and harvesting water. Gully control measures are mainly of two types.

7.5.1 Biological or Vegetative Measures

7.5.1.1 Anti-Erosion Crops

These crops stabilize gully. Crops produced provide supplementary income.

7.5.1.2 Changing Gully into Grassed Waterway

Small and medium size gullies can be converted into grassed waterways. In practice, gully is shaped and suitable species of grasses are grown. Channel cross-section should be broad and flat, to keep water spread uniform over a wide area.

7.5.1.3 Sod Flumes

It may be successfully used to control overfall in gullies with head < 3 m and area <10 ha. The design of sod flume is shown in Fig 7.3. It serves the purpose of preventing further waterfall erosion by providing a protected surface over which the runoff may flow into the gully. Slope varies with the soil type, size of watershed, height of overfall and type of sod used. 4:1 is the steepest slope considered for its design. To maintain a non-erosive velocity, flume should be wide enough. The maximum depth of flow over the flume should not exceed 30 cm.

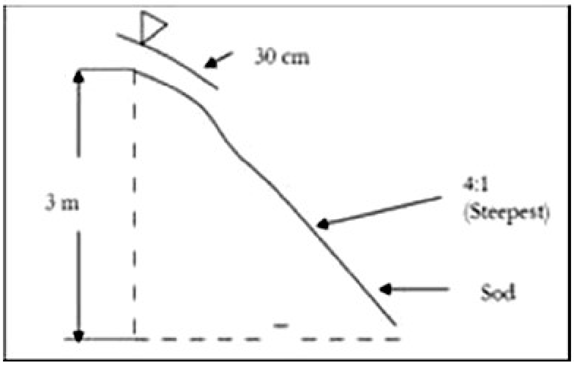


Fig. 7.3. Sod flume.

7.5.1.4 Sod Strip Checks

These checks are best adapted to small gullies with small to medium sized watersheds. These checks cannot be used in gullies with very steep grades. Strips are laid across gully channel (Fig. 7.4). Strips should have a minimum width of 30 cm and should extend up to gully sides at least 15 cm. Strip spacing usually varies from 1.5 to 2.0 m.

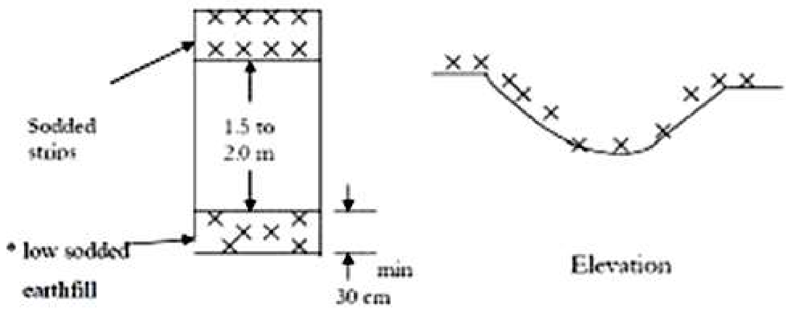


Fig. 7.4A. Sod strip checks.

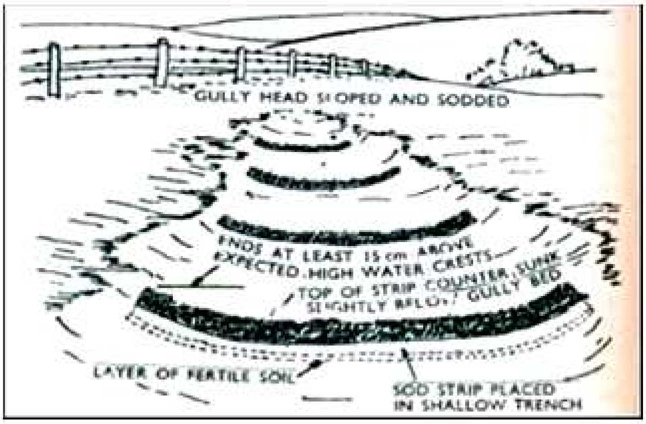


Fig. 7.4B. A series of sod-strip checks in a small gully. (Source: Agr. Handbook No. 61. USDA, SCS).

7.5.1.5 Low Sodded Earthfills

These are used as substitutes for temporary gully controlled structures in small and medium sized gullies. Already growing sods are cut along with soil mass and combined together to form earth fill dams (Fig. 7.5). They are constructed with a maximum height of 45 cm, upstream (u/s) side slope of 3:1 and downstream (d/S) side slope of 4:1.

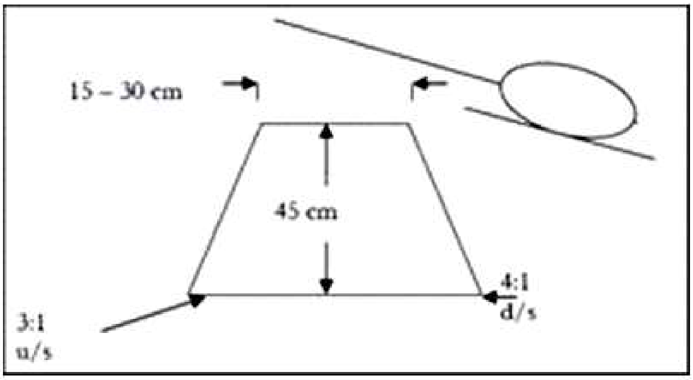


Fig. 7.5 Low sodded earthfills.

7.5.1.6 Trees, Shrubs etc.

Trees, shrubs etc. are used to stabilize severely eroded gullied area. Generally gullied area is fenced and trees are grown. A plant spacing of 1 × 1 m, 1.2 × 1.2 m or a maximum of 2 × 2 m should be maintained.

7.5.2 Engineering Measures (Temporary and Permanent)

7.5.2.1 Temporary Gully Control Structures (TGCS)

TGCS have a life span of 3 to 8 years and they are pretty effective where the amount of runoff is not too large. These are made of locally available materials. Basic purposes they serve are to retain more water as well as soil for proper plant growth and prevent channel erosion until sufficient vegetation is established on the upstream side of the gully. TGCS are of many types:

- Woven wire check dams
- Brush dams
- Loose rock dams
- Plan or slab dams
- Log check dams
- Boulder check dams

7.5.2.2 Permanent Gully Control Structures (PGCS)

If the erosion control programmer requires bigger structure, then PGCS are used. They include:

- Drop spillway
- Drop-inlet spillway
- Chute spillway
- Permanent earthen check dams

7.6 Design Criteria of TGCS

- The overall height of a temporary check shouldn't ordinarily be more than 75 cm. An effective height of about 30 cm is usually considered sufficient. Also, sufficient freeboard is necessary.
- Life of the check dams under ordinary conditions should be in between 3 to 8 years.
- Spillway capacity of check dams is generally designed to handle peak runoff that may be expected once in 5 to 10 year return period.
- Since the purpose of check dams in gully control is to eliminate grade in the channel, check dams theoretically should be spaced in such a way that the crest elevation of one will be same as the bottom elevation of the adjacent dam up-stream.
- As an integral part of most of the checks dams, an apron or platform of sufficient length and width must be provided at the down-stream end to catch the water falling over the top and to conduct it safely without scouring.

7.6.1 Woven Wire Check Dams

Woven-wire check dams are small barriers which are usually constructed to hold fine material in the gully (Fig. 7.6).

General:

- Used in gullies of moderate slopes (not more than 10 percent) and small drainage areas that do not have flood flows which carry rocks and boulders.
- Help in the establishment of vegetation for permanent control of erosion.
- Dam is built in half-moon shape with the open end up-stream.
- The amount of curvature is arbitrary: but an off-set equal to $1/6^{th}$ of the width of gully at the dam site is optimum.

Construction:

- To construct a woven-wire dam, a row of posts is set along the curve of the proposed dam at about 1.2 m intervals and 60-90 cm deep.
- Heavy gauge woven wire is placed against the post with the lower part set in a trench (15-20 cm deep), and 25-30 cm projected above the ground surface along the spillway width.
- Rock, brush or sod may be placed approximately up to a length of 1.2 m to form the apron.
- For sealing the structure, straw, fine brush or similar material should be placed against the wire on the upstream side upto the height of spillway.

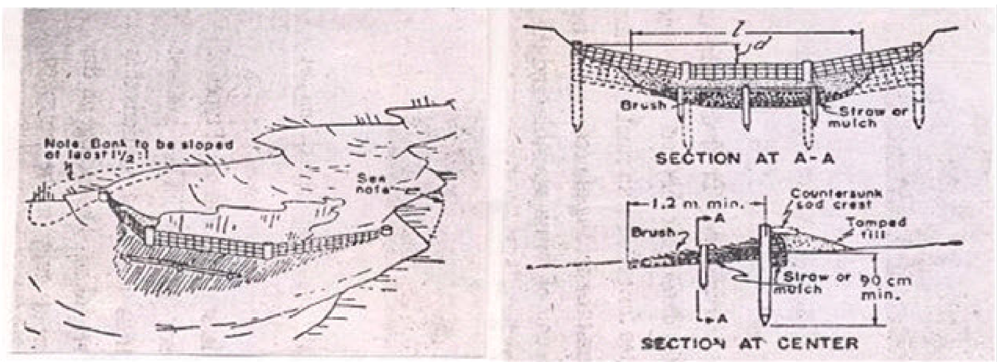


Fig. 7.6. Woven wire check dams. (Source: Agr. Handbook No. 61. USDA, SCS).

7.6.2 Brush Dams

General:

- Cheap and easy to build, but least stable of all types of check dams.

- Best suited for gullies with small drainage area.
- Center of the dam is kept lower than the ends to allow water to flow over the dam rather than around it (Fig. 7.7).

Construction:

- For a distance of 3-4.5 m along the site of the structure, sides and bottom of the gully are covered with thin layer of straw or similar fine mulch.
- Brushes are then packed closely together over the mulch to about one half of the proposed height of dam.
- Several rows of stakes are then driven crosswise in the gully, with rows 60 cm apart, and stakes 30-60 cm apart in the rows.
- Heavy galvanized wire is used to fasten the stakes in a row, as well as to firmly compress the brushes in places.
- Sometimes large stones are also placed on top of brush to keep it compressed and in close contact with the bottom of the gully.
- Major weakness is the difficulty of preventing the leaks and constant attention is required to plug openings of appropriate size with straw as they develop.

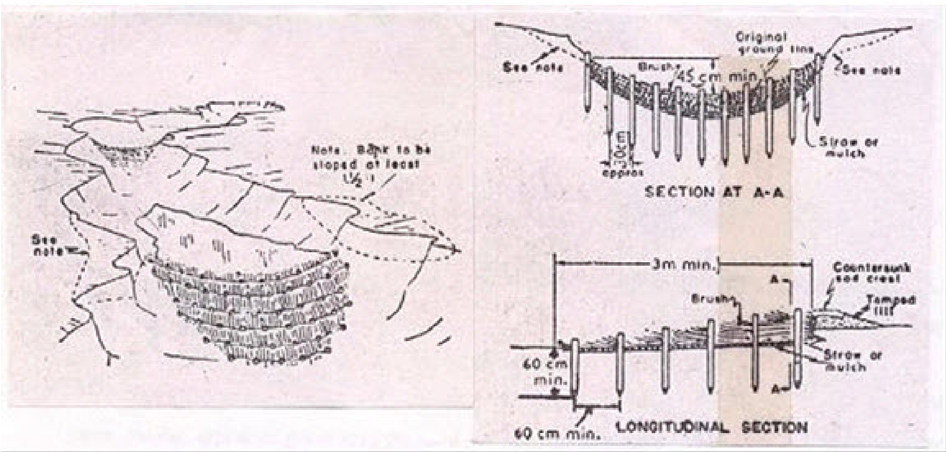


Fig. 7.7. Brush dam. (Source: Agr. Handbook No. 61. USDA, SCS).

7.6.3 Loose Rock Dams

Loose rock dams made of relatively small rocks are placed across the gully (Fig. 7.8). The main objectives for these dams are to control channel erosion along the gully bed, and to stop waterfall erosion by stabilizing gully heads. Loose stone check dams are used to stabilize the incipient and small gullies and the branch gullies of a continuous gully or gully network. The length of the gully channel is not more than 100 m and the gully catchment area is 2 ha or less. These dams can be used in all regions.

General:

- Suitable for gullies with small to medium size drainage area.
- Used in areas where stones or rocks of appreciable size and suitable quality are available.
- Flat stones are the best choice for dam making.
- Stones can be laid in such a way that the entire structure is keyed together.
- If round or irregular shaped stones are used, structure is generally encased in woven-wire so as to prevent outside stones from being washed away.
- If the rocks are small, they should be enclosed in a cage of woven-wire.

Construction:

- A trench is made across the gully to a depth of about 30 cm. This forms the base of the dam on which the stones are laid in rows and are brought to the required height.
- The center of the dam is kept lower than the sides to form spillway.
- To serve as an apron, several large flat rocks may be countersunk below the spillway, extending about 1 m down-stream from the base of the dam.

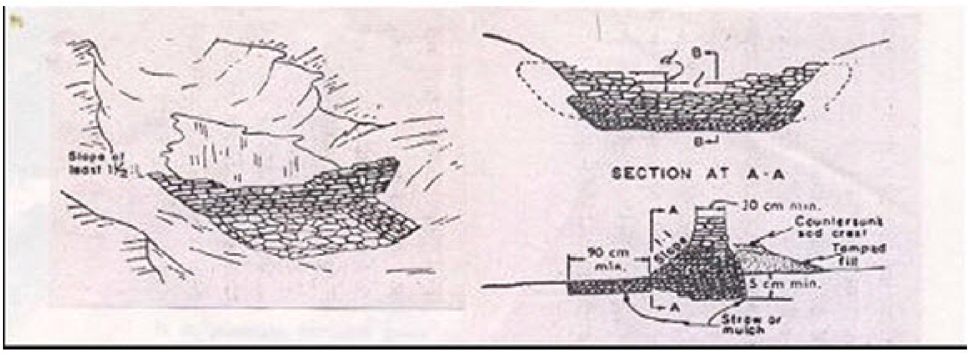


Fig. 7.8. Loose rock dam. (Source: Agr. Handbook No. 61. USDA, SCS).

7.6.4 Plank or Slab Dam

General:

- These dams are suitable in areas where timber is plentiful, and dam can be constructed with much less labor as compared to other types of temporary structures.
- These dams can generally be used in gullies with larger drainage area.

Construction:

- The planks are placed across the gully to form the dam. If the planks are not close fitting, straw or grass may be used for sealing purposes.
- A suitable opening for the spillway notch is made over the headwall. On the up-stream face, a well tempered earth fill is made.
- On the down-stream, the apron may be made of loose rock, brush, sod or planks.

7.6.5 Log Check Dam

They are similar to plank or slab dams. Logs and posts used for the construction are placed across the gully. They can also be built of planks, heavy boards, slabs, poles or old railroad ties. The main objectives of log check dams are to hold fine and coarse material carried by flowing water in the gully, and to stabilize gully heads. They are used to stabilize incipient, small and branch gullies generally not longer than 100 m and with catchment areas of less than two hectares. The maximum height of the dam is 1.5 m from the ground level. Both, its downstream and upstream face inclination are 25 percent backwards. The spillway is rectangular in shape. In general, the length and depth of spillway are one to two meters and 0.5 to 0.6 m respectively (Fig. 7.9).

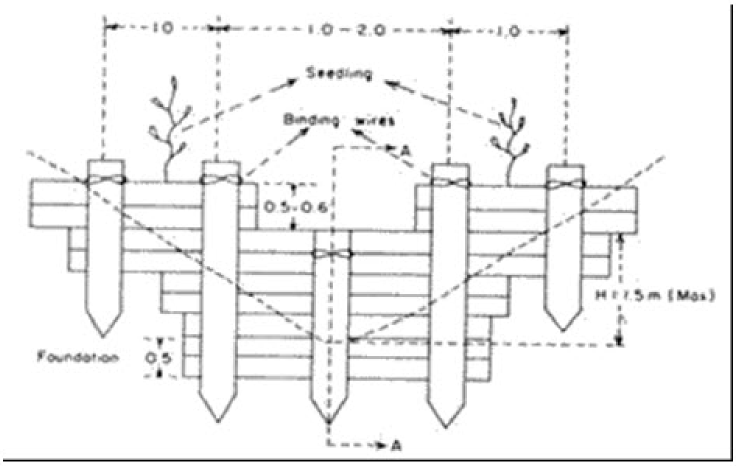


Fig. 7.9A. Front view of the first log check dam. (Source: Agr. Handbook No. 61. USDA, SCS).

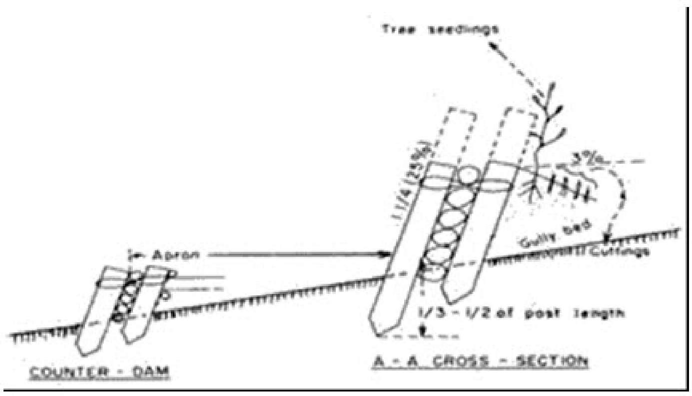


Fig. 7.9B. A-A cross-section of the first log check dam and counter dam. (Source: Agr. Handbook No. 61. USDA, SCS).

7.6.6 Boulder Check Dams

Boulder check dams placed across the gully are used mainly to control channel erosion and to stabilize gully heads. In a gully system or multiple-gully system all the main gully channels of continuous gullies (each continuous gully has a catchment area of 20 ha or less and its length is about 900 m) can be stabilized by boulder check dams. These dams can be used in all regions. The maximum total height of the dam is 2 m. Foundation depth must be at least half of the effective height. The thickness of the dam at spillway level is 0.7 to 1.0 m (average 0.85 m), and the inclination of its downstream face is 30 percent (1:0.3 ratio); the thickness of the base is calculated accordingly. The upstream face of the dam is usually vertical. If the above-mentioned dimensions are used, it is not necessary to test the stability of the dam against overturning, collapsing and sliding. The dimensions of the spillway (Fig. 7.10) should be computed according to the maximum discharge of the gully catchment area. The form of the spillway is generally trapezoidal.

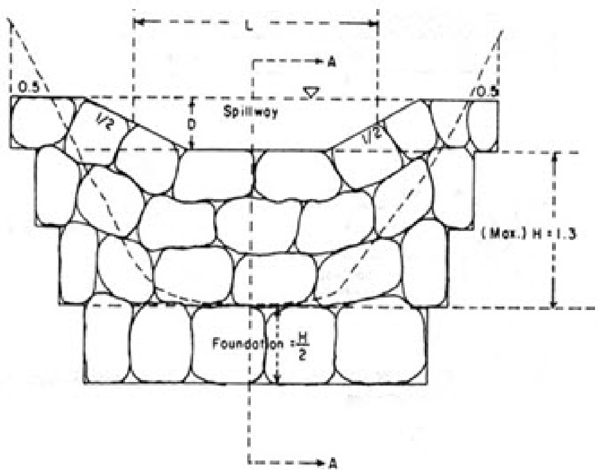


Fig. 7.10. Front view of the boulder check dam. (Source: Agr. Handbook No. 61. USDA, SCS).

Lecture 8: Grassed Waterways

Practical 4: Design of Grassed Waterways

Grassed waterways are natural or man made constructed channels established for the transport of concentrated flow at safe velocities from the catchment using adequate erosion resistant vegetation which cover the channels. These channels are used for the safe disposal of excess runoff from the crop lands to some safe outlet, namely rivers, reservoirs, streams etc. without causing soil erosion. Terraced and bunded crop lands, diversion channels, spillways, contour furrows, etc. from which excess runoff is to be disposed of, preferably use constructed grassed waterways for safe disposal of the runoff. The grassed waterways outlets are constructed prior to the construction of terraces, bunds etc. because grasses take time to get established on the channel bed. Generally, it is recommended that there should be a gap of one year so that the grasses can be established during the rainy season.

8.1 Purpose of Grassed Waterways

Grassed waterways are used as outlets to prevent rill and gully formation. The vegetative cover slows the water flow, minimizing channel surface erosion. When properly constructed, grassed waterways can safely transport large water flows to the down slope. These waterways can also be used as outlets for water released from contoured and terraced systems and from diverted channels. This best management practice can reduce sedimentation of nearby water bodies and pollutants in runoff. The vegetation improves the soil aeration and water quality (impacting the aquatic habitat) due to its nutrient removal (nitrogen, phosphorus, herbicides and pesticides) through plant uptake and sorption by soil. The waterways can also provide a wildlife habitat.

8.2 Design of Grassed Waterways

The designs of the grassed waterways are similar to the design of the irrigation channels and are designed based on their functional requirements. Generally, these waterways are designed for carrying the maximum runoff for a 10- year recurrence interval period. The rational formula is invariably used to determine the peak runoff rate. Waterways can be shorter in length or sometimes, can be even very long. For shorter lengths, the estimated flow at the waterways outlets forms the design criterion, and for longer lengths, a variable capacity waterway is designed to account for the changing drainage areas.

8.2.1 Size of Waterway

The size of the waterway depends upon the expected runoff. A 10 year recurrence interval is used to calculate the maximum expected runoff to the waterway. As the catchment area of the waterway increases towards the outlet, the expected runoff is calculated for different reaches of the waterway and used for design purposes. The waterway is to be given greater cross-sectional area towards the outlet as the amount of water gradually increases towards the outlet. The cross-sectional area is calculated using the following formula:

$$a = \frac{Q}{V}$$

where, a = cross-sectional area of the channel,

Q = expected maximum runoff, and

V = velocity of flow.

8.2.2 Shape of Water Way

The shape of the waterway depends upon the field conditions and type of the construction equipment used. The three common shapes adopted are trapezoidal, triangular, and parabolic shapes. In course of time due to flow of water and sediment depositions, the waterways assume an irregular shape nearing the parabolic shape. If the farm machinery has to cross the waterways, parabolic shape or trapezoidal shape with very flat side slopes are preferred. The geometric characteristics of different waterways are shown in Fig. 8.1 and Fig. 8.2 for trapezoidal and parabolic waterways respectively.

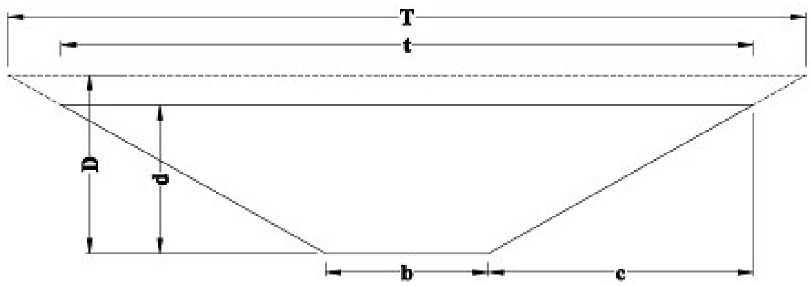


Fig. 8.1. Trapezoidal Cross-section. (Source: Murty, 2009)

In the figure, d is the depth of water flow, b is bottom width, t is the top width of maximum water conveyance, T is top width after considering free board depth, (D - d) is the free board and slope (z) is c/d.

The design dimensions for trapezoidal and parabolic waterways are given in Tables 8.1 and 8.2 respectively.

Table 8.1. Design Dimensions for Trapezoidal Cross-section

Cross-sectional Area, a	Wetted perimeter, P	Hydraulic Radius, $R = \frac{a}{p}$	Top width
$bd + zd^2$ Where, Z = c/d	$b + 2d\sqrt{Z^2 + 1}$	$\frac{bd + zd^2}{b + 2d\sqrt{z^2 + 1}}$	T = b + 2dz T = b + 2Dz

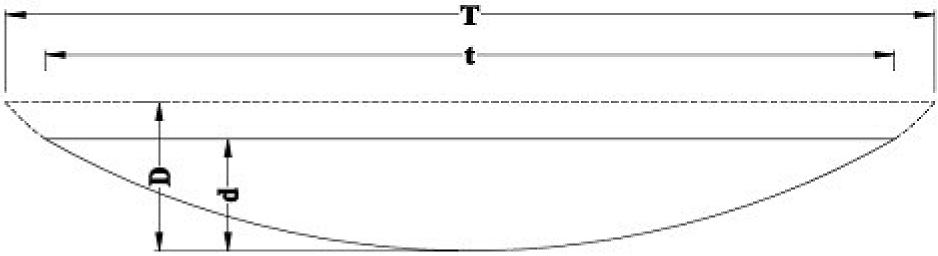


Fig. 8.2. Parabolic Cross-section. (Source: Murty, 2009)

Table 8.2. Design Dimensions for Parabolic Cross-Section

Cross-sectional Area, a	Wetted perimeter, P	Hydraulic Radius, $R = \frac{a}{p}$	Top width
$\frac{2}{3}td$	$t + \frac{8d^2}{3t}$	$\frac{t^2 \times d}{1.5t^2 + 4d^2}$ $\frac{2d}{3}approx$	$t = \frac{a}{0.67d}$ $T = t\left(\frac{D}{d}\right)^{\frac{1}{2}}$

8.2.3 Channel Flow Velocity

The velocity of flow in a grassed waterway is dependent on the condition of the vegetation and the soil erodibility. It is recommended to have a uniform cover of vegetation over the channel surface to ensure channel stability and smooth flow. The velocity of flow through the grassed waterway depends upon the ability of the vegetation in the channel to resist erosion. Even though different types of grasses have different capabilities to resist erosion; an average of 1.0 m/sec to 2.5 m/sec are the average velocities used for design purposes. It may be noted that the average velocity of flow is higher than the actual velocity in contact with the bed of the channel. Velocity distribution in a grassed lined channel is shown in Fig. 8.3. Recommended velocities of flow based on the type of vegetation are shown in Table 8.3.

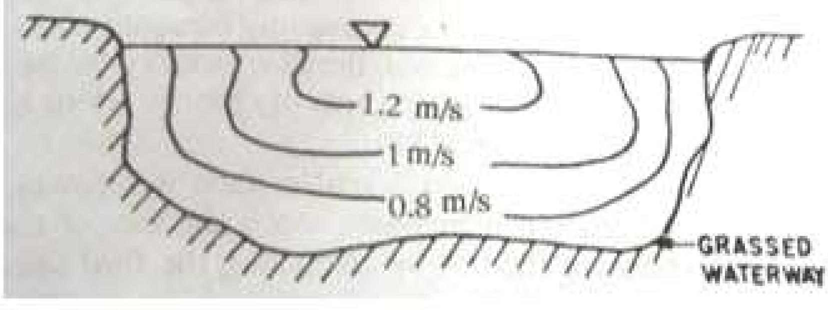


Fig. 8. 3. Velocity Distribution in Open Channel (Source: Murty, 2009)

Table 8.3. Recommend Velocities of Flow in a Vegetated Channel.

Type of vegetation cover	Flow velocity, (m/s)	
	Type	Magnitude
Spare green cover	Low velocity	1-1.15
Good quality cover	Medium velocity	1.5-1.8
Excellent quality cover	High velocity	1.8-2.5

8.2.4 Design of Cross-Section

The design of the cross-section is done using above given Equation in section 8.2.1 for finding the area required and Manning's formula is used for cross checking the velocity. A trial procedure is adopted. For required cross-sectional area, the dimensions of the channel section are assumed. Using hydraulic property of the assumed section, the average velocity of flow through the channel cross-section is calculated using the Manning's formula as below:

$$V = \frac{S^{1/2} R^{2/3}}{n}$$

where, V = velocity of flow in m/s; S = energy slope in m/m; R = hydraulic mean radius of the section in m and n = Manning's roughness coefficient.

The Manning's roughness coefficient is to be selected depending on the existing and proposed vegetation to be established in the bed of the channel. Velocity is not an independent parameter. It will depend on n which is already fixed according to vegetation, R which is a function of the channel geometry and slope S for uniform flow. Slope S has to be adjusted. If the existing land slope gives high velocity, alignment of the channel has to be changed to get the desired velocity.

Problem 8.1: Design a grassed waterway of parabolic shape to carry a flow of 2.6 m^3/s down a slope of 3 percent. The waterway has a good stand of grass and a velocity of 1.75 m/s can be allowed. Assume the value of *n* in Manning's formula as 0.04.

Solution: Using, Q = AV for a velocity of 1.75 m/s, a cross-section of 2.6/1.75 = 1.485 m^2 (~1.5 m^2) is needed.

Assuming, t = 4 m, d = 60 cm.

$$A = \frac{2}{3}t \times d = \frac{2}{3}4 \times 0.6 = 1.6 m^2$$

$$P = t + 8\frac{d^2}{3t} = 4 + 8\frac{(0.6)^2}{3 \times 4} = 4.24 m$$

$$R = \frac{A}{P} = \frac{1.6}{4.24} = 0.377 m$$

$$V = \frac{S^{1/2} R^{2/3}}{n} = \frac{(0.03)^{1/2} \times (0.377)^{2/3}}{0.04} = 2.26 m/s$$

The velocity exceeds the permissible limit. Assuming a revised

t = 6 m and d = 0.4 m

$$A = \frac{2}{3}t \times d = \frac{2}{3}4 \times 0.6 = 1.6 m^2$$

$$P = t + 8\frac{d^2}{3t} = 6 + 8\frac{(0.4)^2}{3 \times 6} = 6.45 m$$

$$V = \frac{S^{1/2} R^{2/3}}{n} = \frac{(0.03)^{1/2} \times (0.248)^{2/3}}{0.04} = 1.70 m/s$$

The velocity is within the permissible limit.

Q = 1.6 × 1.7 = 2.72 m^3/s

The carrying capacity (Q) of the waterway is more than the required. Hence, the design of waterway is satisfactory. A suitable freeboard to the depth is to be provided in the final dimensions.

8.2.5 Construction of the Waterways

It is advantageous to construct the waterways at least one season before the bunding. It will give time for the grasses to get established in the waterways. First, unnecessary vegetation like shrubs etc. are removed from the area is marked for the waterways. The area is then ploughed if necessary and smoothened. Establishment of the grass is done either by seeding or sodding technique. Maintenance of the waterways is important for their proper operation. Removal of weeds, filling of the patches with grass and proper cutting of the grass are of the common maintenance operations that should be followed for an efficient use of waterways.

8.3 Selection of Suitable Grasses

The soil and climate conditions are the primary factors in selection of vegetations to be established for construction of grassed waterways. The other factors to be considered for selection of suitable grasses are duration of establishment, volume and velocity of runoff, ease of establishment and time required to develop a good vegetative cover. Furthermore, the suitability of the vegetation for utilization as feed or hay, spreading of vegetation to the adjoining fields, cost and availability of seeds and redundancy to shallow flows in relation to the sedimentation are the important factors that should be considered for the selection of vegetation.

Generally, the rhizomatous grasses are preferred for the waterway, because they get spread very quickly and provide more protection to the channel than the brush grasses. Deep rooted legumes are seldom used for grassed waterways, because they have the tendency to loosen the soil and thus make the soil more erodible under the effect of fast flowing runoff water. Sometimes, a light seeding of small grain is also used to develop a quick cover before the grasses are fully established in the waterway.

8.4.1 Maintenance

The grasses grown in waterway should always be kept short and flexible, so that they shingle as water flows over them, but do not lodge permanently. For this purpose, the grass should be mowed two to three times in a year. The mowed grasses must be removed from the waterway, so that they do not get accumulated at some spots in the waterway and also should not obstruct the flow. The deposition of mowed grasses in the section of the waterway reduces the flow capacity of the waterway and also diverts the direction of flowing water which can cause turbulence and thus damage of the channel. It is also possible to keep the grasses short by light pasturing, which should not be done in wet condition. When the grass is pastured, it is necessary to apply manure to discourage grazing. The waterway should not be used as a road for livestock. After the vegetative cover is established and runoff passes through them for a long time, a light application of fertilizer should be done because the flowing runoff removes the plant food from the soil of waterway.

Similarly, if waterways are to be crossed by tillage implements, they should be disengaged, plough should be lifted and disc straightened. Tillage operation should also be done following nearly the contour. The waterway and its sides should not be touched during tillage operation. It is also essential that if there is any damage of the waterway, it should be quickly repaired so that the damage may not enlarge due to rainfalls. Overall, it should always be remembered that the waterways are an integral part of watershed conservation or land treatment system. If they fail to handle the peak discharge due to lack of proper maintenance, then the prolong flow of runoff through them can develop gullies in the area.

Briefly, the maintenance of waterways can be taken up using the following process.

a) The outlets should be safe and open so as not to impede the free flow.

b) Grassed waterways should not be used as footpaths, animal tracks, or as grazing grounds.

c) Frequent crossing of waterways by wheeled vehicles should not be allowed.

d) Newly established waterways should be kept under strict watch.

e) The large waterways should be kept under protection with fencing.

f) Waterways must be inspected frequently during first two rainy seasons, after construction.

g) If there is any break in the channel or structures, then they should be repaired immediately.

h) The bushes or large plants grown in the waterway should be removed immediately as they may endanger the growth of grasses.

i) The level of grass in waterway should be kept as low and uniform as possible to avoid turbulent flow.

Lecture 9: Soil Loss Estimation by Universal Soil Loss Equation (USLE)

Practical 5: Estimation of Soil Loss

For estimation of soil loss various methods were developed by different scientists over a period of time. Some of the most useful methods are presented in this chapter.

9.1 Estimation of Soil Loss

The control of erosion is essential to maintain the productivity of soil and to improve or maintain downstream water quality. The reduction of soil erosion to tolerable limits necessitates the adoption of properly planned cropping practices and soil conservation measures. Several methods exist for the measurement of soil loss from different land units. These include the measurements from runoff plots of various sizes for each single land type and land use, small unit source watersheds, and large watersheds of mixed land use. However, to estimate soil erosion, empirical and process based models (equations) are used. Universal Soil Loss Equation (USLE) is an empirical equation. It estimates the average annual mass of soil loss per unit area as a function of most of the major factors affecting sheet and rill erosions. Estimating soil loss is considerably more difficult than estimating runoff as there are many variables, both natural such as soil and rainfall and man-made such as adopted management practices. The soil loss considerably depends on the type of erosion. As a result, models, whether empirical or process-based, are necessarily complex if they are to include the effect of all the variables.

For some purposes, meaningful and useful estimates of sediment yield can be obtained from models, and the best example is the estimation of long-term average annual soil loss from a catchment by using the Universal Soil Loss Equation (USLE).

9.2 The Universal Soil Loss Equation (USLE)

The filed soil loss estimation equations development began in 1940 in USA. Zing (1940) proposed a relationship of soil loss to slope length raised to a power. Later in 1947, a committee chaired by Musgrave proposed a soil-loss equation having some similarity to the present day USLE. Based on nearly 10,000 plot year runoff plot data, Wischmeier and Smith (1965) developed the universal soil loss equation, which was later refined with more recent data from runoff plots, rainfall simulators and field experiences. It is the most widely used tool for estimation of soil loss from agricultural watersheds for planning erosion control practices. The USLE is an erosion prediction model for estimating long term averages of soil erosion from sheet and rill erosions from a specified land under specified conditions (Wischmeier and Smith, 1978).

It provides an estimate of the long-term average annual soil loss from segments of arable land under various cropping conditions. The application of this estimate is to enable farmers and soil conservation advisers to select combinations of land use, cropping practice, and soil conservation practices, which will keep the soil loss down to an acceptable level. The equation (USLE) is presented as below.

$$A = R \times K \times L \times S \times C \times P$$

where, A = soil loss per unit area in unit time, t ha^{-1} yr^{-1}, R = rainfall erosivity factor which is the number of rainfall erosion index units for a particular location, K = soil erodibility factor - a number which reflects the susceptibility of a soil type to erosion, i.e., it is the reciprocal of soil resistance to erosion, L = slope length factor, a ratio which compares the soil loss with that from a field of specified length of 22.6 meters, S = slope steepness factor, a ratio which compares the soil loss with that from a field of specified slope of 9%, C = cover management factor - a ratio which compares the soil loss with that from a field under a standard treatment of cultivated bare fallow, and P = support practice factor - a ratio of soil loss with support practice like contouring, strip cropping or terracing to that with straight row farming up and down the slope.

The factors L, S, C and P are each dimensionless ratios which allow comparison of the site for which soil loss is being estimated with the standard conditions of the database. Knowing the values of rainfall erosivity, soil erodibility and slope one can calculate the effectiveness of various erosion control measures with the purpose of introducing a cultivation system in an area with soil loss limited to the acceptable value.

Various factors associated with the above equation are discussed below.

Rainfall Erosivity Factor (R)

It refers to the rainfall erosion index, which expresses the ability of rainfall to erode the soil particles from an unprotected field. It is a numerical value. From the long field experiments it has been obtained that the extent of soil loss from a barren field is directly proportional to the product of two rainfall characteristics: kinetic energy of the storm and its 30-minute maximum intensity. The product of these two characteristics is termed as EI or EI_{30} or rainfall erosivity. The erosivity factor, R is the number of rainfall erosion index units (EI_{30}) in a given period at the study location. The rainfall erosion index unit (EI_{30}) of a storm is estimated as:

$$EI_{30} = \frac{KE \times I_{30}}{100} \quad EI_{30} = KE \times I_{30}$$

where, KE = kinetic energy of storm in metric tones /ha-cm, expressed as

$$KE = 210.3 + 89 \log I \; KE = 210.3 + 89 \log I$$

where, I = rainfall intensity in cm/h, and I_{30} = maximum 30 minutes rainfall intensity of the storm.

The study period can be a week, month, season or year and this I_{30} values are different for different areas. The storm EI_{30} values for that length of period is summed up. Annual EI_{30} values are usually computed from the data available at various meteorological stations and lines connecting the equal EI_{30} values (known as *Iso-erodent lines*) are drawn for the region covered by the data stations for ready use in USLE.

Soil Erodibility Factor (K)

The soil erodibility factor (K) in the USLE relates to the rate at which different soils erode. Under the conditions of equal slope, rainfall, vegetative cover and soil management practices, some soils may erode more easily than others due to inherent soil characteristics. The direct measurement of K on unit runoff plots reflect the combined effects of all variables that significantly influence the ease with which a soil is eroded or the particular slope other than 9% slope. Some of the soil properties which affect the soil loss to a large extent are the soil permeability, infiltration rate, soil texture, size and stability of soil structure, organic content and soil depth. These are usually determined at special experimental runoff plots or by the use of empirical erodibility equations which relate several soil properties to the factor K. The soil erodibility factor (K) is expressed as tons of soil loss per hectare per unit rainfall erosivity index, from a field of 9% slope and 22 m (in some cases 22.13 m) field length. The soil erodibility factor (K) is determined by considering the soil loss from continuous cultivated fallow land without the influence of crop cover or management.

The formula used for estimating K is as follows:

$$K = \frac{Ao}{S \times (\Sigma EI)} \; K = \frac{A_o}{S \times (\Sigma EI)}$$

where, K = soil erodibility factor, A_0 = observed soil loss, S = slope factor, and ΣEI = total rainfall erosivity index.

Based on runoff plot studies, the values of erodibility factor K have been determined for use in USLE for different soils of India as reported by Singh *et al.* (1981). Values of K for several stations are given in Table 9.1.

Table 9.1. Values of K for Several Stations (Source: K. Subramanya, 2008)

Station	Soil Type	Computed Values of K
Agra	Loamy sand, alluvial	0.07
Dehradun	Dhulkot silt, loam	0.15
Hyderabad	Red chalka sandy loam	0.08
Kharagpur	Soils from laterite rock	0.04
Kota	Kota clay loam	0.11
Ootakamund	Laterite	0.04
Rehmankhera	Loam, alluvial	0.17
Vasad	Sandy loam, alluvial	0.06

Topographic Factor (LS)

Slope length factor (L) is the ratio of soil loss from the field slope length under consideration to that from the 22.13 m length plots under identical conditions. The slope length has a direct relation with the soil loss, i.e., it is approximately equal to the square root of the slope length ($L^{0.5}$), for the soils on which runoff rate is not affected by the length of slope (Zing, 1940).

Steepness of land slope factor (S) is the ratio of soil loss from the field slope gradient to that from the 9% slope under otherwise identical conditions. The increase in steepness of slope results in the increase in soil erosion as the velocity of runoff increases with the increase in field slope allowing more soil to be detached and transported along with surface flow.

The two factors L and S are usually combined into one factor LS called ***topographic factor***. This factor is defined as the ratio of soil loss from a field having specific steepness and length of slope (i.e., 9% slope and 22.13 m length) to the soil loss from a continuous fallow land. The value of LS can be calculated by using the formula given by Wischmeier and Smith (1962):

$$LS = \frac{\sqrt{L}}{100}\left(0.76 + 0.53S + 0.076S^2\right)$$

$$LS = \frac{\sqrt{L}}{100}(0.76 + 0.53\,S + 0.076\,S^2)$$

where, L = field slope length in feet and S = percent land slope.

Wischmeier and Smith (1978) again derived the following equation for LS factor in M.K.S. system, based on the observations from cropped land on slopes ranging from 3 to 18% and length from 10 to 100 m. The derived updated equation is:

$$LS = \left(\frac{\lambda}{22.13}\right)^{m} [65.41\, Sin^2\theta + 4.56\, Sin\theta + 0.065]$$

where, λ = field slope length in meters, m = exponent varying from 0.2 to 0.5, and θ = angle of slope.

Crop Management Factor (C)

The crop management factor C may be defined as the expected ratio of soil loss from a cropped land under specific crop to the soil loss from a continuous fallow land, provided that the soil type, slope and rainfall conditions are identical. The soil erosion is affected in many ways according to the crops and cropping practices, such as the kind of crop, quality of cover, root growth, water use by plants etc. The variation in rainfall distribution within the year also affects the crop management factor, which affects the soil loss. Considering all these factors, the erosion control effectiveness of each crop and cropping practice is evaluated on the basis of five recommended crop stages introduced by Wischmeier (1960). The five stages are:

Period F (Rough Fallow): It includes the summer ploughing or seed bed preparation.

Period 1 (Seed Bed): It refers to the period from seeding to 1 one month thereafter.

Period 2 (Establishment): The duration ranges from 1 to 2 months after seeding.

Period 3 (Growing Period): It ranges from period 2 to the period of crop harvesting.

Period 4 (Residue or Stubble): The period ranges from the harvesting of crop to the summer ploughing or new seed bed preparation.

For determining the crop management factor the soil loss data for the above stages is collected from the runoff plot and C is computed as the ratio of soil loss from cropped plot to the corresponding soil loss from a continuous fallow land for each of the above five crop stages separately, for a particular crop, considering various combinations of crop sequence and their productivity levels. Finally, weighted C is computed. This factor reflects the combined effect of various crop management practices. Values of factor C for some selected stations of India are given in Table 9.2.

Table 9.2. Values of Crop Management Factors for Different Stations in India (Source: K Subramanya, 2008)

Station	Crop	Soil Loss, t $ha^{-1}y^{-1}$	Value of C
Agra	Cultivated fallow	3.80	1.0
	Bajra	2.34	0.61
	Dichanhium annualtu	0.53	0.13
Dehradun	Cultivated fallow	33.42	1.0
	Cymbopogon grass	4.51	0.13
	Strawberry	8.89	0.27
Hyderabad	Cultivated fallow	5.00	1.0
	Bajra	2.00	0.40

Support Practice Factor (P)

This factor is the ratio of soil loss with a support practice to that with straight row farming up and down the slope. The conservation practice consists of mainly contouring, terracing and strip cropping. The soil loss varies due to different practices followed. Factor P for different support practices for some locations of India is presented in Table 9.3.

Table 9.3. Different Values of Support Practice Factor (P) for Some Indian Locations (Source: K. Subramanya, 2008)

Station	Practice	Factor P
Dehradun	Contour cultivation of maize	0.74
	Up and down cultivation	1.00
	Contour farming	0.68
	Terracing and bunding in agricultural watershed	0.03
Kanpur	Up and down cultivation of Jowar	1.00
	Contour cultivation of Jowar	0.39
Ootacamund	Potato up and down	1.00
	Potato on contour	0.51

9.3 Use of USLE

There are three important applications of the universal soil loss equation. They are as follows:

- It predicts the soil loss;
- It helps in identification and selection of agricultural practices; and
- It provides the recommendations on crop management practices to be used.

USLE is an erosion prediction model and its successful application depends on the ability to predict its various factors with reasonable degree of accuracy. It is based on considerably large experimental data base relating to various factors of USLE.

Based on 21 observation points and 64 estimated erosion values of soil loss obtained by the use of USLE at locations spread over different regions of the country, soil erosion rates have been classified into 6 categories. Areas falling under different classes of erosion are shown in Table 9.4.

Table 9.4. Distribution of various erosion classes in India (Source: K Subramanya, 2008)

Range (Tones/ha/year)	Erosion Class	Area (km^2)
0-5	Slight	801,350
5-10	Moderate	1,405,640
10-20	High	805,030
20-40	Very high	160,050
40-80	Severe	83,300
>80	Very severe	31,895

9.4 Limitations of Universal Soil Loss Equation

The equation involves the procedure for assigning the values of different associated factors on the basis of practical concept. Therefore, there is possibility to introduce some errors in selection of the appropriate values, particularly those based on crop concept. Normally R and K factors are constants for most of the sites/regions in the catchment, whereas, C and LS vary substantially with the erosion controlled measures, used. The following are some of the limitations of the USLE:

1) Empirical

The USLE is totally empirical equation. Mathematically, it does not illustrate the actual soil erosion process. The possibility to introduce predictive errors in the calculation is overcome by using empirical coefficients.

2) Prediction of Average Annual Soil Loss

This equation was developed mainly on the basis of average annual soil loss data; hence its applicability is limited for estimation of only average annual soil loss of the given area. This equation computes less value than the measured, especially when the rainfall occurs at high intensity. The storage basin whose sediment area is designed on the basis of sediment yield using USLE should be inspected after occurrence of each heavy storm to ensure that the sedimentation volume in the storage basin is within the limit.

3) Non-computation of Gully Erosion

This equation is employed for assessing the sheet and rill erosions only but can not be used for the prediction of gully erosion. The gully erosion caused by concentrated water flow is not accounted by the equation and yet it can cause greater amount of soil erosion.

4) Non-computation of Sediment Deposition

The equation estimates only soil loss, but not the soil deposition. The deposition of sediment at the bottom of the channel is less than the total soil loss taking place from the entire watershed. Nevertheless, the USLE can be used for computing the sediment storage volume required for sediment retention structures., Also the USLE equation can be used as a conservative measure of potential sediment storage needs, particularly where sediment basins ranges typically from 2-40 ha and runoff has not traveled farther distance and basin is intended to serve as the settling area. Again, if the drainage on any site is improperly controlled and gully erosion is in extensive form, then this equation underestimates the sediment storage requirement of the retention structure.

During the estimation of contribution of hill slope erosion for basin sediment yield, care should be taken as it does not incorporate sediment delivery ratio. This equation cannot be applied for predicting the soil loss from an individual storm, because the equation was derived to estimate the long term mean annual soil loss. The use of this equation should be avoided for the locations, where the values of different factors associated with the equation, are not yet determined.

9.5 Revised Universal Soil Loss Equation (RUSLE)

Over the last few decades, a co-operative effort between scientists and users to update the USLE has resulted in the development of RUSLE. The modifications incorporated in USLE to result the RUSLE are mentioned as under (Kenneth *et.al.* 1991):

- Computerizing the algorithms to assists the calculations.
- New rainfall-runoff erosivity term (R) in the Western US, based on more than 1200 gauge locations.
- Some revisions and additions for the Eastern US, including corrections for high R-factor areas with flat slopes to adjust splash erosion associated with raindrops falling on ponded water.
- Development of a seasonally variable soil erodibility term (K).
- A new approach for calculating the cover management term (C) with the sub-factors representing considerations of prior land use, crop canopy, surface cover and surface roughness
- New slope length and steepness (LS) algorithms reflecting rill to inter-rill erosion ratio
- The capacity to calculate LS products for the slopes of varying shapes
- New conservation practices value (P) for range lands, strip crop rotations, contour factor values and subsurface drainage.

9.6 Modified Universal Soil Loss Equation (MUSLE)

The USLE was modified by Williams in 1975 to MUSLE by replacing the rainfall energy factor (R) with another factor called as 'runoff factor'. The MUSLE is expressed as

$$Y = 11.8\left(Q \times q_p\right)^{0.56} K(LS)CP$$

$$Y = 11.8\,(Q \times q_p)^{0.56} K(LS)CP$$

where, Y = sediment yield from an individual storm (in metric tones), Q = storm runoff volume in m^3 and q_p = the peak rate of runoff in m^3/s.

All other factors K, (LS), C and P have the same meaning as in USLE (equation 16.1). The values of Q and q_p can be obtained by appropriate runoff models. In this model Q is considered to represent detachment process and q_p is the sediment transport. It is a sediment yield model and does not need separate estimation of sediment delivery ratio and is applicable to individual storms. Also it increases sediment yield prediction accuracy. From modeling point of view, it has the advantage that daily, monthly and annual sediment yields of a watershed can be modeled by combining appropriate hydrological models with MUSLE.

Example 9.1: In an area subjected to soil erosion, the following information is available.

Rainfall erosivity index = 1200 metre tone ha^{-1}; Soil erodibility index = 0.20

Crop factor = 0.60; Conservation practice factor = 1.0

Slope length factor = 0.1

What will be estimated annual loss? Explain how this soil loss will decrease by adopting conservation practices.

Solution:

Using the Universal soil loss equation, the soil loss is obtained as,

A = 1200*0.20*0.60*1.0*0.1 = 14.4 tonnes ha^{-1} year^{-1}

To reduce the soil loss, if conservation practices are introduced, let us say the factor P is now 0.6.

$$A = 14.4 * 0.6 = \mathbf{10.44\ tonnes\ ha^{-1}\ year^{-1}}$$

Example 9.2: Determine the soil loss from a watershed. Following data are given:

Average watershed slope length = 150 m

Average watershed slope = 10% (angle = 5.7°)

Rainfall erosivity factor = 6000 [(t - m)/ha] (mm/h) per year

Soil erodibility factor = 0.02 t/ha/rainfall erosivity factor

Cropping management factor = 0.2

Conservation practice factor for contour farming = 0.5

Slope gradient factor = 1.168

Exponent (m) = 0.53.

Lecture 10: Calculation of Erosion Index

Practical 6: Calculation of Erosion Index

10.1 Erosivity of Rainfall

Rainfall erosivity is a term that is used to describe the potential for soil to be washed off from disturbed, de-vegetated areas and move with into surface waters during storms. It may also be defined as the potential ability of rain to cause the erosion. It is dependent upon the physical characteristics of rainfall, which include raindrop size, drop size distribution, kinetic energy, terminal velocity, etc. For a given soil condition, the potential of two storms can be compared quantitatively, regarding soil erosion to be caused by them. The power of overland runoff flow to erode soil material is partly a property of the rainfall, and partly of the soil surface. Rainfall erosivity is highly related to soil loss. Increased rain erosivity indicates greater erosive capacity of the overland water flow. Soil erosion by running water occurs where the intensity and duration of rainstorms exceeds the capacity of the soil to infiltrate the rainfall. The potential for erosion is based on many factors which include including soil type, slope, and the energy or force of precipitation expected during the period of surface disturbance.

10.1.1 Factors Affecting Rainfall Erosivity

The various factors, which affect the erosivity of rain storm, are given as under:

1) Rainfall Intensity

Rainfall intensity refers to the rate of rainfall over the land surface. It is one of the most important factors responsible for the erosive nature of rainfall. The rainfall intensity is assumed as the force, by which an individual water droplets strikes over the soil surface. The kinetic energy is related to the intensity of rainfall by the equation proposed by Wischmeier and Smith (1958) as follows:

$$KE = 210.3 + 89\log_{10} I \, E_K = 210.3 + 89\log_{10} I$$

where, KE = kinetic energy of rainfall, tons per ha per cm of rainfall, and I = rainfall intensity (cm/h).

2) Drop Size Distribution

The drop size distribution in a particular rainstorm influences the energy, momentum and erosivity of the rain in cumulative way. The increases in median drop size, increases the rainfall intensity. The relationship between the median drop size (D_{50}) and rainfall intensity, is given as under (Laws and Parsons, 1943):

$$D_{50} = 2.23 I^{0.182}$$

In which, D_{50} is the median drop size (inch) and I is the intensity (inch/h).

3) Terminal Velocity

The effect of terminal velocity of falling raindrops is counted in terms of kinetic energy of respective rain drops at the time of their impact over the soil surface. It is the function of drop size. A rainstorm composed of large proportion of bigger size raindrops, has greater terminal velocity and vice-versa. The kinetic energy of rain storm has following relationship with terminal velocity, as:

$$E_k = \frac{IV^2}{2}$$

where,

E_k = rainfall energy (watts /m^2)^3, I = Intensity of rainfall (mm/s), and V = Terminal velocity of rainfall before impact (m/s).

Ellison (1947) developed an empirical relationship among the terminal velocity, drop diameter and rainfall intensity, for computing the amount of soil detached by the rainfall as:

$$E = K.V^{4.33} d^{1.07} I^{0.65}$$

where, E = relative amount of soil detached, K = a constant, depends upon the soil characteristics, V = velocity of raindrop (feet/s), d = drop diameter (mm), and I = rainfall intensity (inch/h).

4) Wind Velocity

Wind velocity affects the power of rainfall to cause soil detachment, by influencing the kinetic energy of rain storm. Tropical regions experience the occurrence of windy storm most of the times. Wind driven storms are more effective than anticipated for breaking the aggregates. The effect of wind velocity on soil detachment by rain storm is shown in Table 1.

Table 10.1. Effect of Wind Velocity on Soil Detachment at Different Intensities of Rain Storm. (Source: Lyles et.al, 1969)

Wind Velocity (m/s)	**Intensity of Rain (cm/h)**		
	1.6	2.84	5.61
	% Soil Detachment (arbitrary unit)		
0	56	93	97
6.7	95	98	97
13.4	97	100	100

5) Direction of Slope

The direction of land slope also develops significant effect on rainfall erosivity. Slope direction in the direction of the rain storm, effectively alters the actual kinetic energy of the rain drop. It increases the impact force of the raindrop as the velocity component in the direction of slope becomes more.

10.1.2 Estimation of Erosivity from Rainfall Data

The rainfall erosivity is related to the kinetic energy of rainfall. The following two methods are widely used for computing the erosivity of rainfall.

1. EI_{30} Index method and

2. KE > 25 Index method.

1. EI_{30} Index Method

This method was introduced by Wischmeier (1965). It is based on the fact that the product of kinetic energy of the storm and the 30-minute maximum rainfall intensity gives the best estimation of soil loss. The greatest average intensity experienced in any 30 minute period during the storm is computed from recording rain gauge charts by locating the maximum amount of rain which falls in 30 minute period and later converting the same to intensity in mm/hour. This measure of erosivity is referred to as the EI_{30} index and can be computed for individual storms, and the storm values can be added over periods of time to give weekly, monthly or yearly values of erosivity.

The rainfall erosivity factor EI_{30} value is computed as follows:

$$EI_{30} = KE \times I_{30}$$

$$EI_{30} = KE \times I_{30}$$

where *KE* is rainfall kinetic energy and I_{30} is the maximum rainfall intensity for a 30-minute period. Kinetic energy for the storm is computed from Eqn. 17.1.

Limitation

The EI_{30} index method was developed under American condition and is not found suitable for tropical and sub-tropical zones for estimating the erosivity.

2. KE > 25 Index Method

This is an alternate method introduced by Hudson for computing the rainfall erosivity of tropical storms. This method is based on the concept that erosion takes place only at threshold value of rainfall intensity. From experiments, it was obtained that the rainfall intensities less than 25 mm/h are not able to yield the soil erosion in significant amount. Thus, this method takes care of only those rainfall intensities, which are greater than 25 mm/h. That is why the name is K.E. > 25 Index method. It is used in the same manner as the EI_{30} index and the calculation procedure is also similar.

Calculation Procedure

The estimation procedure is same for both the methods. However, K.E. > 25 method is more advantageous, because it sorts out many data less than 25 mm/h, hence uses less rainfall data. For both the methods, it is important to have data on rainfall amount and its intensity.

The procedure involves the multiplication of rainfall amounts in each class of intensity to the computed kinetic energy values and then all these values are added together to get the total kinetic energy of the storm. The K.E. so obtained, is again multiplied by the maximum 30-minute rainfall intensity to determine the rainfall erosivity value.

Solved Example

1. Find out the total kinetic energy of rainfall and also its erosivity using EI_{30} and K.E.> 25 index methods for the following given rainfall amount and intensity values.

Solution:

1. EI_{30} Index Method:

Intensity (cm/h)	Amount (cm)	Energy (metric tones/ha/cm)	Total (col.2 × col.3)
(1)	(2)	(3)	(4)
1.5	3	231.97	695.91
2.5	0.75	245.71	184.28
3.5	1.25	258.72	323.40
4.5	2.58	268.43	692.56
5.5	3.57	276.19	986.00
			2882.15(metric tones/ha.)

Kinetic energy is calculated by the Eqn. 17.1;

Let I_{30} is taken to be 45 cm/h, the rainfall erosivity is given as

EI_{30} = 2882.15 × 45 = 129696.75 metric tonnes/ha.cm/hr. **Ans.**

2. K.E. > 25 Method:

Intensity (cm/h)	Amount (cm)	Energy (tons/ha cm)	Total (col.2 × col. 3)
(1)	(2)	(3)	(4)
0.015	0.5	47.97	23.98
1.5	2.52	225.97	569.44
1.67	0.021	230.12	4.83
0.025	0.75	67.71	50.78
			569.44 m tons/ha

For calculation of total kinetic energy, corresponding terms for rainfall intensity of less than 25 mm/h have not been considered. According to this method,

EI_{30} = 569.44 × 45 = 25624.28 t/ha cm/h **Ans.**

Lecture 11: Principles of Wind Erosion and its Control Measures

Wind erosion is the process of detachment, transportation and deposition of soil particles by the action of wind. It occurs in all parts of the world and is a cause of serious soil deterioration. In India, Rajasthan has severe wind erosion problem. A large part of area the state is affected by sand dune formation. Some parts of coastal areas also have such problems. It most commonly occurs in the regions where soil is loose, finely divided and dry, soil surface is smooth and bare, and where wind is strong to detach the soil particles from the surface.

11.1 Wind Erosion Control

A suitable surface soil texture is the best key to wind erosion protection. Properly managed crop residues, carefully timed soil tillage, and accurately placed crop strips and crop barriers can all effectively reduce wind erosion. Proper land use and adaptation of adequate moisture conservation practices are the main tools which help in wind erosion control. In arid and semiarid regions where serious problem of wind erosion is common, several cultural methods can help to reduce the wind erosion. In the absence of crop residue, soil roughness or soil moisture can reduce the wind erosion effectively.

Three basic methods can be used to control wind erosion:

- Maintain Vegetative Cover (Vegetative Measures)
- Roughen the Soil Surface by Tillage Practices (Tillage Practices or may be called Tillage Measures)
- Mechanical or Structural Measures (Mechanical Measures)

There is no single recipe for erosion control as many factors affect the outcome. However, with an understanding of how soil is eroded, strategies can be devised to minimize erosion.

11.2 Vegetative Measures

Vegetative measures can be used to roughen the whole surface and prevent any soil movement. The aim is to keep the soil rough and ridged to either prevent any movement initially or to quickly trap bouncing soil particles in the depressions of the rough surface. A cover crop with sufficient growth will provide soil erosion protection during the cropping season. It is one of the most effective and economical means to reduce the effect of wind on the soil. It not only retards the velocity near the ground surface but also holds the soil against tractive force of wind thereby helping in reduction of soil erosion.

From the basic concept, the velocity of wind decreases near the ground surface because of the resistance offered by the vegetation. The variation in wind velocity with respect to height above the land surface increases exponentially.

Vegetative measures can be of two types:

1. Temporary Measures

2. Permanent Measures

The use of these measures depends upon the severity of erosion.

11.3 Tillage Practices

The tillage practices, such as ploughing are importantly adopted for controlling wind erosion. These practices should be carried out before the start of wind erosion. Ploughing before the rainfall helps in moisture conservation. Ploughing, especially with a disc plough is also helpful in development of rough soil surface which in turn reduces the impact of erosive wind velocity. Both the above effects are helpful in controlling the wind erosion.

Surface roughening should only be considered when there is insufficient (less than 50%) vegetation cover to protect the soil surface or when the soil type will produce sufficient clods to protect the surface. Roughening can be used in both crop and pasture areas. Surface roughening alone is inadequate for sandy soils because they produce few clods. Tillage ridges, about 100 mm high, should be used to cover the entire area prone to erosion. Ridges that are lower than 100 mm get quickly filled with sand, whilst the crest of the ridge that is higher than 100 mm tends to erode very quickly.

The common tillage practices used for wind erosion control are as under:

- Primary and Secondary Tillage
- Use of Crop Residues
- Strip Cropping

11.4 Mechanical Measures

This method consists of some mechanical obstacles, constructed across the prevailing wind, to reduce the impact of blowing wind on the soil surface. These obstacles may be fences, walls, stone packing etc., either in the nature of semi-permeable or permeable barriers. The semi-permeable barriers are most effective, because they create diffusion and eddying effects on their downstream face. Terraces and bunds also obstruct the wind velocity and control the wind erosion to some extent. Generally, in practice two types of mechanical measures are adopted to control the wind erosion; i) wind breaks and ii) shelter belts.

11.4.1 Wind Breaks

This is a permanent vegetative measure which helps in the reduction of wind erosion. It is most effective vegetative measure used for controlling severe wind erosion. The term wind break is defined as any type of barrier either mechanical or vegetative used for protecting the areas like building apartments, orchards or farmsteads etc. from blowing winds. The wind break acts as fencing wall around the affected areas, normally constructed by one row or maximum up to two rows across the prevailing wind direction.

A further use for "windbreaks" or "wind fences" is for reducing wind speeds over erodible areas such as open fields, industrial stockpiles, and dusty industrial operations. As erosion is proportional to the cube of wind speed, a reduction in wind speed by 1/2 (for example) will reduce erosion by over 80%. The largest one of these windbreaks is located in *Oman* (28 m high by 3.5 km long) and was created by Mike Robinson from Weather Solve Structures.

11.4.2 Shelter Belts

A shelterbelt is a longer barrier than the wind break, is installed by using more than two rows, usually at right angle to the direction of prevailing winds. The rows of belt can be developed by using shrubs and trees. It is mainly used for the conservation of soil moisture and for the protection of field crops, against severe wind erosion.

Shelterbelt is more effective for reducing the impact of wind movement than the wind break. Apart from controlling wind erosion, it provides fuel, reduces evaporation and protects the orchard from hot and cold winds.

Woodruff and Zingg (1952) developed the following relationship between the distance of full protection (d) and the height (h) of wind break or shelter belt.

$$d = 17h\left(\frac{v_m}{v}\right)\cos\theta$$

Where, d is the distance of full protection (m), h is the height of the wind barrier (wind break or shelter belt) (m), v_m is the minimum wind velocity at 15 m height required to move the most erodible soil fraction (m/s), v is the actual velocity at 15 m height, and θ is the angle of deviation of prevailing wind direction from the perpendicular to the wind barrier.

This relationship (equation) is valid only for wind velocities below 18 m/s. This equation may also be adapted for estimating the width of strips by using the crop height in the adjoining strip in the equation. The value of v_m for a bare smooth surface after erosion has been initiated and before wetting by rainfall and subsequent surface crusting is about 9.6 m/s.

11.5 Sand Dunes Stabilization

A 'Dune' is derived from English word 'Dun' means hilly topographical feature. Therefore a sand dune is a mount, hill or ridge of sand that lies behind the part of the beach affected by tides. They are formed over many years when windblown sand is trapped by beach grass or other stationary objects. Dune grasses anchor the dunes with their roots, holding them temporarily in place, while their leaves trap sand promoting dune expansion. Without vegetation, wind and waves regularly change the form and location of dunes. Dunes are not permanent structures.

Sand dunes provide sand storage and supply for adjacent beaches. They also protect inland areas from storm surges, hurricanes, flood-water, and wind and wave action that can damage property. Sand dunes support an array of organisms by providing nesting habitat for coastal bird species including migratory birds. Sand dunes are also habitat for coastal plants. For example: 'The Seabrook dunes' are home to 141 species of plants, including nine rare, threatened and endangered species.

There are three essential prerequisites for sand dune formation:

(1) An abundant supply of loose sand in a region generally devoid of vegetation (such as an ancient lake bed or river delta);

(2) A wind energy source sufficient to move the sand grains.

(3) A topography whereby the sand particles lose their momentum and settle down.

The best method by which the sand dunes can be stabilized is to reduce the erosive velocity. Therefore, various methods which are employed for sand dune stabilization are based on the principle to dissipate the erosive power of wind, so that the detachment and transportation of soil particles cannot take place. Some methods employed for sand dune stabilization are:

- Vegetation/Vegetative Measures
- Mechanical Measures
- Straw (Checkerboard and Bales)/Mats and Netting
- Chemical Spray

11.5.1 Vegetative Measures

This method is most common and preferred worldwide for sand dune stabilization. It is a most effective, least expensive, aesthetically pleasing method which mimics a natural system with self-repairing provision. However, it has some disadvantages as the plant establishment phase is critical, it needs irrigation and maintenance until self-sustaining system is developed. Most common practices adopted under this are:

11.5.1.1 Raising of Micro Wind Breaks

It is preferred in those areas where wind velocity is intensive and rainfall is less than 300 mm per year. The raising of wind break should be completed before the onset of monsoon. Twigs or brush woods are inserted into the soil parallel to one another at about 5 m spacing. The spacing depends on the intensity of erosive wind velocity, if the velocity is more spacing is less and vice versa. The fencing of dunes using brush woods reduces evaporation loss and also enriches the humus content in the soil.

11.5.1.2 Retreating the Dunes

In this, the micro wind breaks are treated again by planting tree saplings and grasses in the space left. The grasses grown in the intersection of plants of wind break reduce the soil loss from the dune surface significantly.

11.5.2 Mechanical Measures

Wind breaks, shelterbelts, stone pitching, fences etc., either manmade or natural barriers are helpful to reduce the wind velocity thereby favoring the stabilization of sand dunes.

11.5.3 Straw Checker Boards

This technique of sand dunes stabilization is extensively used in China since 1950's. Wheat or rice straw or reeds (50 – 60 cm in length) are placed vertically to form the sides of the checkerboard, which are typically 10 to 20 cm high. Optimum grid size of checker ranges from 1 x 1 m to 2 x 2 m, depending on local wind and sand transport conditions. Smaller grids are used in areas where winds are stronger.

11.5.4 Chemical Spray

Sometimes crude oils are used for the successful stabilization of sand dune. The oil is heated to 50 °C and sprayed on the dune at the rate of 4 m^3/ha. It is a temporary measure, lasting only for 3-4 years and during those years, it is expected that the vegetation growth will take place in that area. This method is costly and suitable only for small areas.

Solved Problems:

1. Determine the spacing between windbreaks that are 15 m high. 5 year return period wind velocity at 15 m height is 15.6 m/s and the wind direction deviates 10° from the perpendicular to the field strip. Assume a smooth, bare soil surface and a fully protected field.

Solution:

Given: h = 15 m

V = 15.6 m/s

$\theta = 10°$

Vm = 9.6 m/s (for smooth, bare soil surface)

Spacing = distance of full protection by a windbreak,

Therefore,

$$d = 17h\left(\frac{V_m}{V}\right)\cos\theta \quad = 17x15\left(\frac{9.6}{15.6}\right)\cos 10^{o}$$
$$= 154.54\, m$$

Thus, the spacing between windbreaks = 154.54 m.

2. Determine the full protection strip width for field strip cropping if the crop in the adjacent strip is wheat, 0.9 m tall, and the wind velocity at 15 m height is 8.9 m/sec at 90° with the field strip.

Solution:

Given: h = 0.9 m

v = 8.9 m/s

$\theta = 0°$

Assuming v_m = 8.9 m/sec (Because theoretical v_m = 9.6 m/sec which is greater than the prevailing wind velocity). Since the field conditions are not specified taking $v_m = v$.

Full protection width-

$$d = 17h\left(\frac{V_m}{V}\right)\cos\theta \quad = 17x0.9\left(\frac{8.9}{8.9}\right)\cos\theta$$
$$= 15.3\, m$$

Thus, strip width = 15.30 m.

Lecture 12: Water Harvesting and its Techniques

12.1 Importance of Water Harvesting

Rainwater harvesting, in its broadest sense, is a technology used for collecting and storing rainwater for human use from rooftops, land surfaces or rock catchments using simple techniques such as jars and pots as well as engineered techniques. Rainwater harvesting has been practiced for more than 4,000 years, owing to the temporal and spatial variability of rainfall. It is an important water source in many areas with significant rainfall but lacking any kind of conventional, centralised supply system. It is also a good option in areas where good quality fresh surface water or ground water is lacking. Water harvesting enables efficient collection and storage of rainwater, makes it accessible and substitute for poor quality water. There are a number of ways by which water harvesting can benefit a community.

- Improvement in the quality of ground water,
- Rise in the water levels in wells and bore wells that are drying up,
- Mitigation of the effects of drought and attainment of drought proofing,
- An ideal solution in areas having inadequate water resources,
- Reduction in the soil erosion as the surface runoff is reduced,
- Decrease in the choking of storm water drains and flooding of roads and
- Saving of energy to lift ground water.

12.2 Types of Water Harvesting

Rainwater Harvesting: Rainwater harvesting is defined as the method for inducing, collecting, storing and conserving local surface runoff for agriculture in arid and semi-arid regions. Three types of water harvesting are covered by rainwater harvesting.

- Water collected from roof tops, courtyards and similar compacted or treated surfaces is used for domestic purpose or garden crops.
- Micro-catchment water harvesting is a method of collecting surface runoff from a small catchment area and storing it in the root zone of an adjacent infiltration basin. The basin is planted with a tree, a bush or with annual crops.
- Macro-catchment water harvesting, also called harvesting from external catchments is the case where runoff from hill-slope catchments is conveyed to the cropping area located at foothill on flat terrain.

Flood Water Harvesting: Flood water harvesting can be defined as the collection and storage of creek flow for irrigation use. Flood water harvesting, also known as 'large catchment water harvesting' or 'Spate Irrigation', may be classified into following two forms:

- In case of 'flood water harvesting within stream bed', the water flow is dammed and as a result, inundates the valley bottom of the flood plain. The water is forced to infiltrate and the wetted area can be used for agriculture or pasture improvement.
- In case of 'flood water diversion', the wadi water is forced to leave its natural course and conveyed to nearby cropping fields.

Groundwater Harvesting: Groundwater harvesting is a rather new term and employed to cover traditional as well as unconventional ways of ground water extraction. Qanat systems, underground dams and special types of wells are a few examples of the groundwater harvesting techniques. Groundwater dams like 'Subsurface Dams' and 'Sand Storage Dams' are other fine examples of groundwater harvesting. They obstruct the flow of ephemeral streams in a river bed; the water is stored in the sediment below ground surface and can be used for aquifer recharge.

12.3 Water Harvesting Technique

This includes runoff harvesting, flood water harvesting and groundwater harvesting.

12.3.1 Runoff Harvesting

Runoff harvesting for short and long term is done by constructing structures as given below.

12.3.1.1 Short Term Runoff Harvesting Techniques

Contour Bunds: This method involves the construction of bunds on the contour of the catchment area (Fig. 28.1). These bunds hold the flowing surface runoff in the area located between two adjacent bunds. The height of contour bund generally ranges from 0.30 to 1.0 m and length from 10 to a few 100 meters. The side slope of the bund should be as per the requirement. The height of the bund determines the storage capacity of its upstream area.

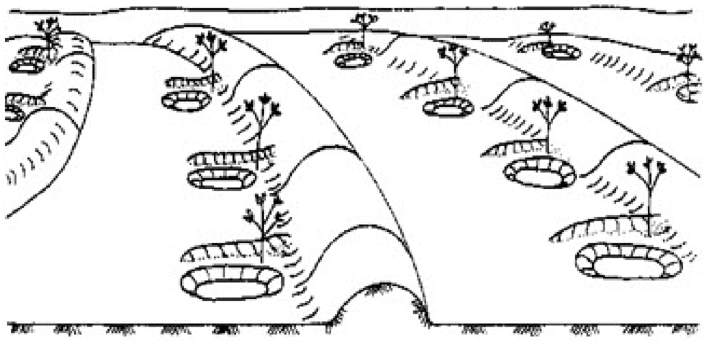


Fig. 12.1. Contour Bunds. (Source: Barron and Salas, 2009)

Semicircular Hoop: This type of structure consists of an earthen impartment constructed in the shape of a semicircle (Fig. 28.2). The tips of the semicircular hoop are furnished on the contour. The water contributed from the area is collected within the hoop to a maximum depth equal to the height of the embankment. Excess water is discharged from the point around the tips to the next lower hoop. The rows of semicircular hoops are arranged in a staggered form so that the over flowing water from the upper row can be easily interrupted by the lower row. The height of hoop is kept from 0.1 to 0.5 m and radius varies from 5 to 30 m. Such type of structure is mostly used for irrigation of grasses, fodder, shrubs, trees etc.

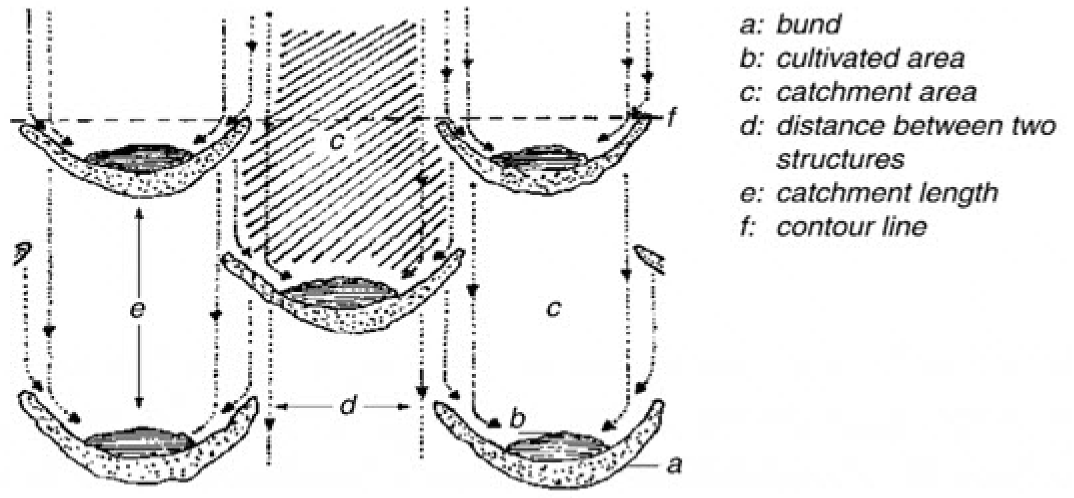


Fig. 12.2. Layout of Semi-Circular Hoop. (Source: Barron and Salas 2009)

Trapezoidal Bunds: Such bunds also consist of an earthen embankment, constructed in the shape of trapezoids. The tips of the bund wings are placed on the contour. The runoff water yielded from the watershed is collected into the covered area. The excess water overflows around the tips. In this system of water harvesting the rows of bunds are also arranged in staggered form to intercept the overflow of water from the adjacent upstream areas. The layout of the trapezoidal bunds is the same as the semicircular hoops, but they unusually cover a larger area (Fig. 28.3). Trapezoidal bund technique is suitable for the areas where the rainfall intensity is too high and causes large surface flow to damage the contour bunds. This technique of water harvesting is widely used for irrigating crops, grasses, shrubs, trees etc.

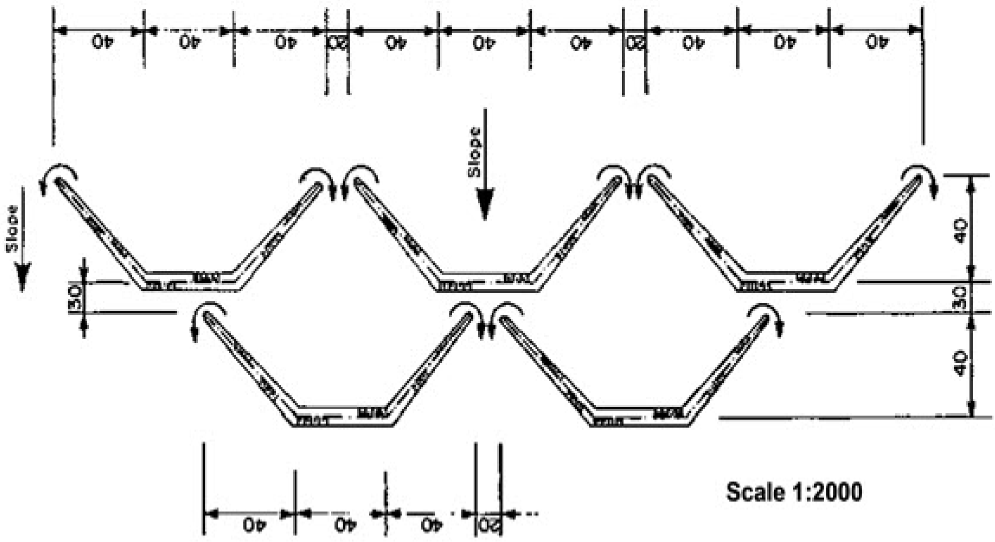


Fig. 12.3. Layout of Trapezoidal Bund. (Source: Barron and Salas, 2009)

Graded Bunds: Graded bunds also referred as off contour bunds. They consist of earthen or stone embankments and are constructed on a land with a slope range of 0.5 to 2%. The design and construction of graded bunds are different from the contour bunds. They are used as an option where rainfall intensity and soils are such that the runoff water discharged from the field can be easily intercepted. The excess intercepted or harvested water is diverted to the next field though a channel ranges. The height of the graded bund ranges from 0.3 to 0.6 m. The downstream bunds consist of wings to intercept the overflowing water from the upstream bunds. Due to this, the configuration of the graded bund looks like an open ended trapezoidal bund. That is why sometimes it is also known as modified trapezoidal bund. This type of bunds for water harvesting is generally used for irrigating the crops.

Rock Catchment: The rock catchments are the exposed rock surfaces, used for collecting the runoff water in a part as depressed area. The water harvesting under this method can be explained as: when rainfall occurs on the exposed rock surface, runoff takes place very rapidly because there is very little loss. The runoff so formed is drained towards the lowest point called storage tank and the harvested water is stored there. The area of rock catchment may vary from a 100 m^2 to few 1000 m^2; accordingly the dimensions of the storage tank should also be designed. The water collected in the tank can be used for domestic use or irrigation purposes.

Ground Catchment: In this method, a large area of ground is used as catchment for runoff yield. The runoff is diverted into a storage tank where it is stored. The ground is cleared from vegetation and compacted very well. The channels are as well compacted to reduce the seepage or percolation loss and sometimes they are also covered with gravel. Ground catchments are also called roaded catchments. This process is also called runoff inducement. Ground catchments have also been traditionally used since last 4000 years in the Negev (a desert in southern Israel) where annul crops and some drought tolerant species like pistachio dependent on such harvested water are grown.

12.3.1.2 Long Term Runoff Harvesting Techniques

The long term runoff harvesting is done for building a large water storage for the purpose of irrigation, fish farming, electricity generation etc. It is done by constructing reservoirs and big ponds in the area. The design criteria of these constructions are given below.

- Watershed should contribute a sufficient amount of runoff.
- There should be suitable collection site, where water can be safely stored.
- Appropriate techniques should be used for minimizing various types of water losses such as seepage and evaporation during storage and its subsequent use in the watershed.
- There should also be some suitable methods for efficient utilization of the harvested water for maximizing crop yield per unit volume of available water.

The most common long term runoff harvesting structures are:

- Dugout Ponds
- Embankment Type Reservoirs

Dugout Ponds: The dugout ponds are constructed by excavating the soil from the ground surface. These ponds may be fed by ground water or surface runoff or by both. Construction of these ponds is limited to those areas which have land slope less than 4% and where water table lies within 1.5-2 meters depth from the ground surface (Fig. 28.4). Dugout ponds involve more construction cost, therefore these are generally recommended when embankment type ponds are not economically feasible. The dugout ponds can also be recommended where maximum utilization of the harvested runoff water is possible for increasing the production of some important crops. This type of ponds require brick lining with cement plastering to ensure maximum storage by reducing the seepage loss.

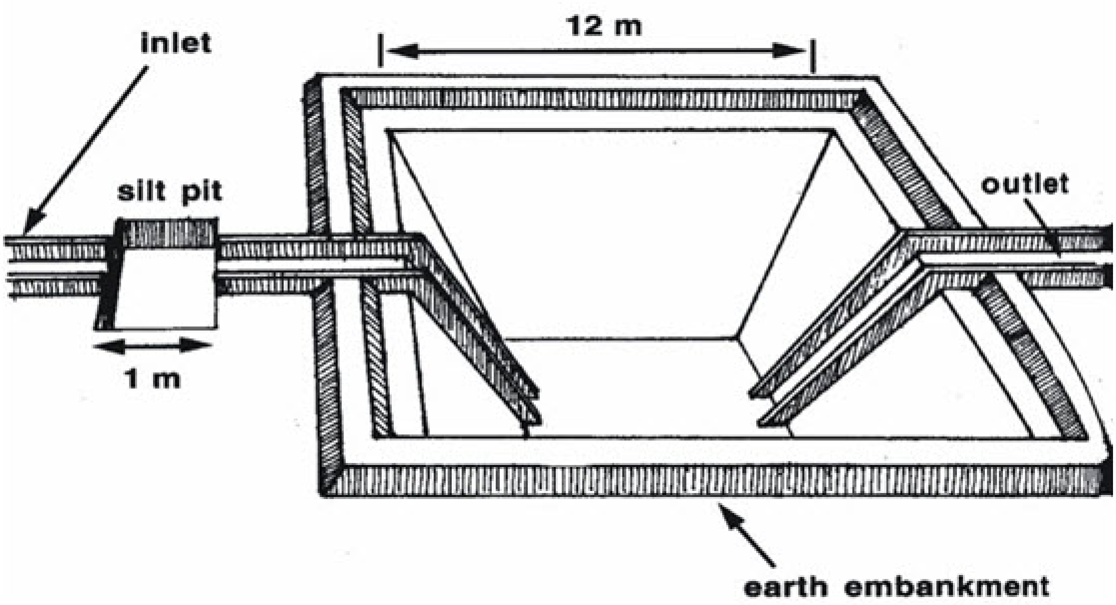


Fig. 12.4. Illustration of Dugout Pond. (Source: Barron and Salas, 2009)

Embankment Type Reservoir: These types of reservoirs are constructed by forming a dam or embankment on the valley or depression of the catchment area. The runoff water is collected into this reservoir and is used as per requirement. The storage capacity of the reservoir is determined on the basis of water requirement for various demands and available surface runoff from the catchment. In a situation when heavy uses of water are expected, then the storage capacity of the reservoir must be kept sufficient so that it can fulfill the demand for more than one year.

Embankment type reservoirs are again classified as given below according to the purpose for which they are meant.

Irrigation Dam: The irrigation dams are mainly meant to store the surface water for irrigating the crops. The capacity is decided based on the amount of input water available and output water desired. These dams have the provisions of gated pipe spillway for taking out the water from the reservoir. Spillway is located at the bottom of the dam leaving some minimum dead storage below it.

Silt Detention Dam: The basic purpose of silt detention dam is to detain the silt load coming along with the runoff water from the catchment area and simultaneously to harvest water. The silt laden water is stored in the depressed part of the catchment where the silt deposition takes place and comparatively silt free water is diverted for use. Such dams are located at the lower reaches of the catchment where water enters the valley and finally released into the streams. In this type of dam, provision of outlet is made for taking out the water for irrigation purposes. For better result a series of such dams can be constructed along the slope of the catchment.

High Level Pond: Such dams are located at the head of the valley to form the shape of a water tank or pond. The stored water in the pond is used to irrigate the area lying downstream. Usually, for better result a series of ponds can be constructed in such a way that the command area of the tank located upstream forms the catchment area for the downstream tank. Thus all but the uppermost tanks are facilitated with the collection of runoff and excess irrigation water from the adjacent higher catchment area.

Farm Pond: Farm ponds are constructed for multi-purpose objectives, such as for irrigation, live-stock, water supply to the cattle feed, fish production etc. The pond should have adequate capacity to meet all the requirements. The location of farm pond should be such that all requirements are easily and conveniently met.

Water Harvesting Pond: The farm ponds can be considered as water harvesting ponds. They may be dugout or embankment type. Their capacity depends upon the size of catchment area. Runoff yield from the catchment is diverted into these ponds, where it is properly stored. Measures against seepage and evaporation losses from these ponds should also be.

Percolation Dam: These dams are generally constructed at the valley head, without the provision of checking the percolation loss. Thus, a large portion of the runoff is stored in the soil. The growing crops on downstream side of the dam, receive the percolated water for their growth.

12.3.2 Flood Water Harvesting

To harvest flood water, wide valleys are reshaped and formed into a series of broad level terraces and the flood water is allowed to enter into them. The flood water is spread on these terraces where some amount of it is absorbed by the soil which is used later on by the crops grown in the area. Therefore, it is often referred to as "Water Spreading" and sometimes "Spate Irrigation". The main characteristics of water spreading are:

- Turbulent channel flow is harvested either (a) by diversion or (b) by spreading within the channel bed/valley floor.
- Runoff is stored in soil profile.
- It has usually a long catchment (may be several km)
- The ratio between catchment to cultivated area lies above 10:1.
- It has provision for overflow of excess water.

The typical examples of flood water harvesting through water spreading are given below.

Permeable Rock Dams (for Crops)

These are long low rock dams across valleys slowing and spreading floodwater as well as healing gullies (Fig. 28.5). These are suitable for a situation where gently sloping valleys are likely to transform into gullies and better water spreading is required.

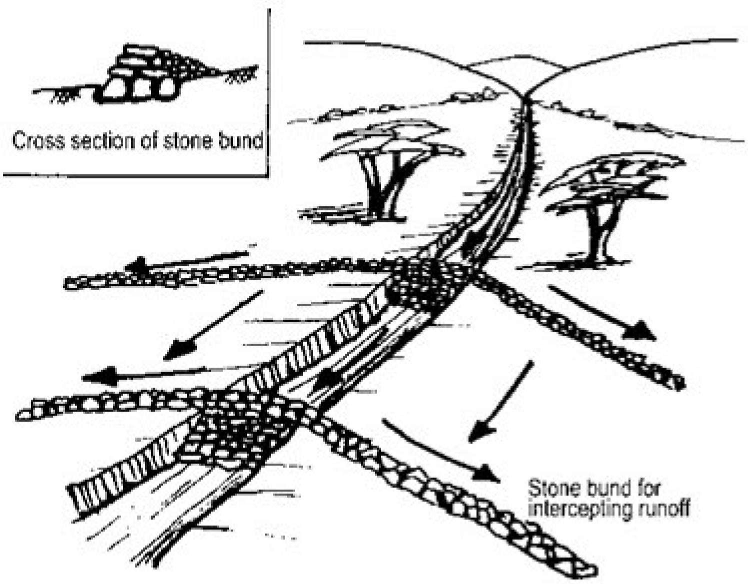


Fig. 12.5. Permeable Rock Dams. (Source: Barron and Salas, 2009)

Water Spreading Bunds (for Crops and Rangeland): In this method, runoff water is diverted to the area covered by graded bund by constructing diversion structures such as diversion drains. They lead to the basin through channels, where crops are irrigated by flooding. Earthen bunds are set at a gradient, with a "dogleg" shape and helps in spreading diverted floodwater (Fig. 28.6). These are constructed in arid areas where water is diverted from watercourse onto crop or fodder block.

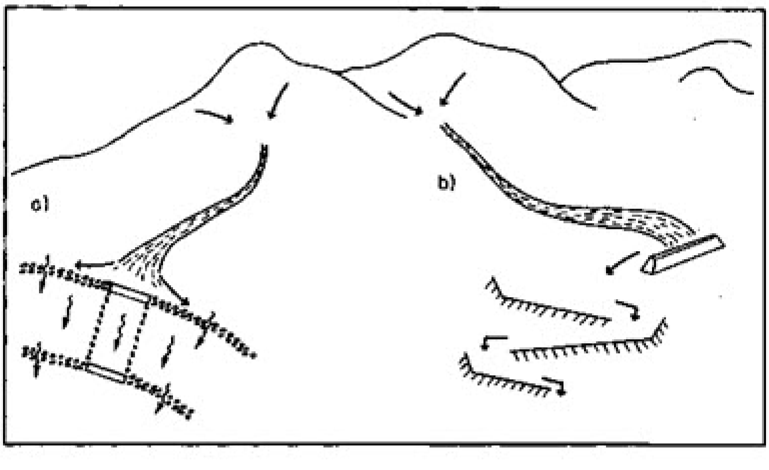


Fig. 12.6. Floodwater farming systems: (a) spreading within channel bed; (b) diversion system. (Source: Barron and Salas, 2009)

Flood Control Reservoir: The reservoirs constructed at suitable sites for controlling the flood are known as flood control reservoirs. They are well equipped with self-operating mechanical outlets for letting out the harvested water into the stream or canal below the reservoir as per requirement.

12.3.3 Groundwater Harvesting

Qanat System: A qanat consists of a long tunnel or conduit leading from a well dug at a reliable source of groundwater (the mother well). Often, the mother well is dug at the base of a hill or in the foothills of a mountain range. The tunnel leading from the mother well slopes gradually downward to communities in the valley below. Access shafts are dug intermittently along the horizontal conduit to allow for construction and maintenance of the qanat (Fig. 12.7). The Qanat system was used widely across Persia and the Middle East for many reasons. First, the system requires no energy, relies on the force of gravity alone. Second, the system can carry water across long distances through subterranean chambers avoiding leakage, evaporation, or pollution. And lastly, the discharge is fixed by nature, producing only the amount of water that is distributed naturally from a spring or mountain, ensuring that the water table is not depleted. More importantly, it allows access to a reliable and plentiful source of water to those living in otherwise marginal landscapes (Fig. 12.8).

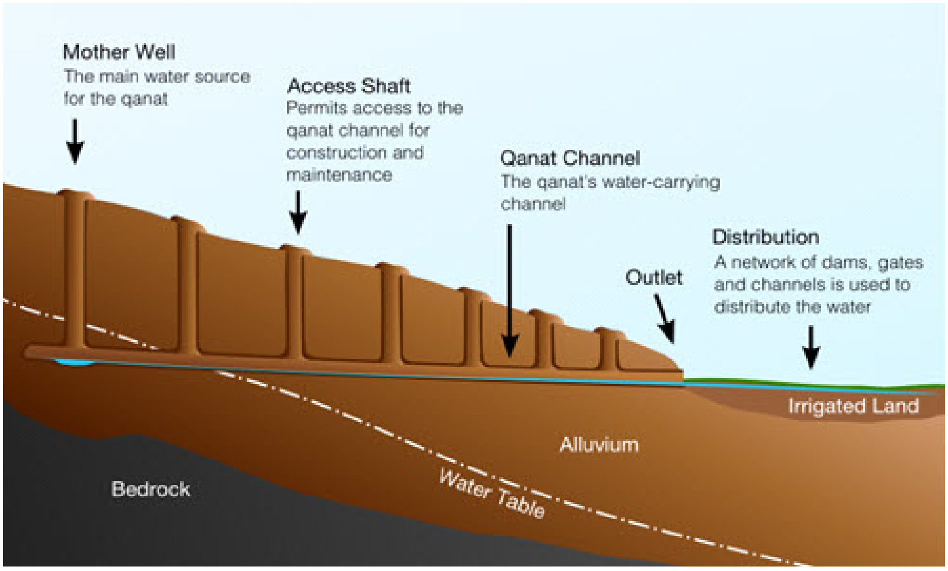


Fig. 12.7. Cross Section Showing Qanats. (Source: Barron and Salas, 2009)

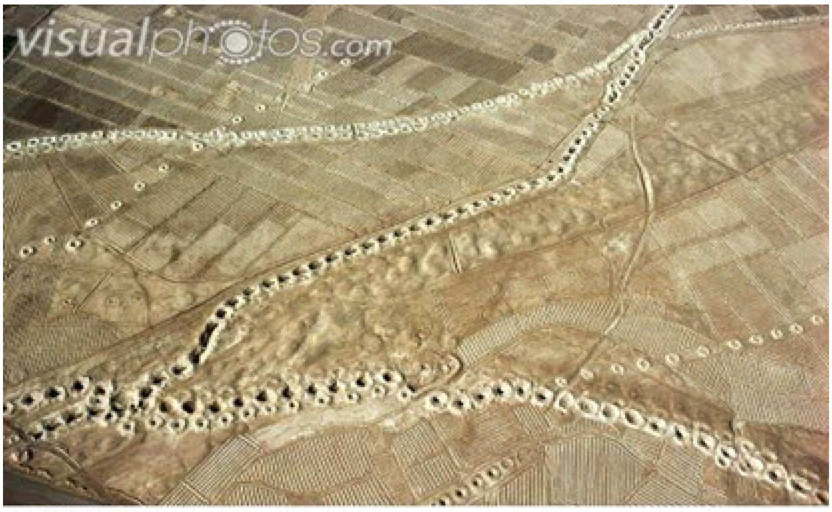


Fig. 12.8. Ariel view of Qanats. (Source: www.visualphotos.com)

12.4 Runoff vs. Flood Water Harvesting

- Water harvesting techniques which harvest runoff from roofs or ground surfaces fall under the term rainwater harvesting while all systems which collect discharges from watercourses are grouped under the term flood water harvesting.
- Runoff harvesting increases water availability for on-site vegetation while flood waters harvesting provide a valuable source of water to local and downstream water users and play an important role in replenishing floodplains, rivers, wetlands and groundwater.
- Runoff harvesting reduces water flow velocity, as well as erosion rate and controls siltation problem while in flood water harvesting,floodwater enters into the fields through the inundation canals, carrying not only rich silt but also fish which can swim through the canals into the lakes and tanks to feed on the larva of mosquitoes.

Lecture 13: Surveying and Field Area Calculation

The purpose of topographic survey is to get the necessary data to produce a topographic map of the earth's surface. This map will include contour lines, location of natural features, such as streams, gullies, and ditches and man-made features like bridges, culverts, roads, fences, etc. which are essential for detailed planning. The best practical method of presenting topography is by means of land surveys and contour maps.

13.1 Survey of Land

Land surveying is the science and art of making all essential measurements to determine the relative position of points or physical and cultural details above, on, or beneath the surface of the earth and to depict them in a usable form, or to establish the position of points or details. These points are usually on the surface of the earth and they are often used to establish land maps and boundaries for ownership or governmental purposes. Furthermore, it is the detailed study or inspection by gathering information through observations, measurements in the field, questionnaires, or research of legal instruments and data analysis for the purpose of planning, designing, and establishing property boundaries. It involves the re-establishment of cadastral surveys and land boundaries based on documents of record and historical evidence, as well as certifying surveys (as required by statute or local ordinance) of subdivision plans/maps, registered land surveys, judicial surveys and space delineation.

Land surveying can include associated services such as mapping, related data accumulation, construction layout surveys, precision measurements of length, angle, elevation, area, volume, as well as horizontal and vertical control surveys. It also includes the analysis and utilization of land survey data. Surveying has been an essential element in the development of the human environment since the beginning of recorded history (about 5,000 years ago). It is required in the planning and execution of nearly every form of construction. It's most familiar modern uses are in the fields of transport, building and construction, communications, mapping and the definition of legal boundaries for land ownership.

The earliest surveys were performed only for the purpose of recording the boundaries of plots of land. Due to advancements in technology, the science of surveying has also attained its due importance. In the absence of accurate maps, it is impossible to lay out the alignment of roads, railways, canals, tunnels, transmission, power lines, and microwave or television relaying towers. Detailed maps of the sites of engineering projects are necessary for the precise installation of sophisticated plants and machineries. Surveying is the first step for the execution of any such project.

13.2 Types of Maps and Mapping Units

The following types of maps are used in land surveying.

- **Plan:** A plan is a graphical representation of the features on the earth surface or below the earth surface as projected on a horizontal plane. This may not necessarily show its graphical position on the globe. On a plan, horizontal distances and directions are generally shown.
- **Map:** The representation of the earth surface on a small scale is called a map. The map must show its geographical position on the globe with the help of latitude and longitude. On a map the topography of the terrain, is depicted generally by contours, hachures and spot levels.
- **Topographical Map:** The maps which are on sufficiently large scale to enable the individual features shown on the map to be identified on the ground by their shapes and positions, are called *topographical maps*.
- **Geographical Maps:** The maps which are on such a small scale that the features shown on the map are suitably generalised and give a picture of the country as a whole and not a strict representation of its individual features, are called *Geographical maps*.

Two kinds of measurements are used in plane surveying;

- Linear Measurement, i.e. Horizontal or Vertical Distance
- Angular Measurement, i.e. Horizontal or Vertical Angles.

i) Linear Measures: According to the standards of Weight and Measure Act (India) 1956, the metric system has been introduced in India. Before 1956, F.P.S (Foot, pound, second) system was used for the measurements. For measurements of distances, metre and centimetre have been recommended as standard units.

Basic units of length in metric system:	10 millimetres = 1 centimetre 10 centimetres = 1 decimetre 10 decimetre = 1 metre 10 metres = 1 decametre 10 decametres = 1 hectametre 10 hectametres = 1 kilometres 1.852 kilometres = 1 nautical mile
Basic units of area in metric system	100 sq. metres = 1 are 10 ares = 1 deka-are 10 deca ares = 1 hecta-are

Basic units of volume in metric system	1000 cub. millimetres = 1 cub. centimetre 1000 cub. centimetres = 1 cub. decimetre 1000 cub. decimetres = 1 cub. metre
Basic units of length in FPS system	12 inches = 1 foot 3 feet = 1 yard 5.5 yards = 1 rod, pole, or 1 sq. perch 4 poles = 1 chain (66 feet) 10 chains = 1 furlong 8 furlong = 1 mile 6 feet = 1 fathom 120 fathoms = 1 cable length 6080 feet = 1 nautical mile
Basic units of volume in FPS system	1728 cu. inches = 1 cu. Foot 27 cu. Feet = 1 cu. Yard

Conversion Factor for Lengths

Metres	Yards	Feet	Inches
1	1.0936	3.2808	39.37
0.9144	1	3	36
0.3048	0.3333	1	12
0.0254	0.0278	0.0833	1

Conversion Factor for Areas

Sq. metres	Sq. yards	Sq. feet	Sq. inches
1	1.196	10.7639	1550
0.8361	1	9	1296
0.0929	0.1111	1	144
0.00065	0.00077	0.0069	1

Conversion Factor for Areas

Ares	Acres	Sq. metres	Sq. yards
1	0.0247	100	119.6
40.496	1	4046.9	4840
0.01	0.000247	1	1.196
0.0084	0.00021	0.8361	1

Conversion Factor for Volumes

Cub. metres	Cub. yards	Gallons (Imps)
1	1.308	219.969
0.7645	1	168.178
0.00455	0.00595	1

ii) **Angular Measures:** Angles may be defined as the difference in the direction of two intersecting lines; it is the inclination of two straight lines. The unit of a plane angle is 'radian'. Angle is defined as the measure between two radii of a circle which contain an arc equal to the radius of the circle. The popular system of angular measurements, are:

Sexagesimal System of Angular Measurements:

In this system the circumference of a circle, is divided into 360 equal parts, each part is known as one degree. $1/60^{th}$ part of a degree is called a*minute* and $1/60^{th}$ part of a minute, is called a second. i.e.

1 circumference = 360 degree of arc

1° = 60 minutes of arc

1 minute = 60 seconds of arc

Centesimal System of Angular Measurements:

In this system circumference of a circle is divided into 400 equal parts, each part is known as grad. One hundredth part of a grad is known as*centigrad* and one hundredth part of a centigrad is known *centi-centigrad.* i.e.

1 circumference = 400 grads

1 grad = 100 centigrads

1 centigrad = 100 centi-centigrads

From the ancient times, sexagesimal system is being widely used in different countries of the world. Most complete mathematical tables are available in this system and most surveying instruments i.e. theodolites, sextants etc. are graduated according to this system. Due to increased facility in computation and interpolation, the centesimal system for angular measurements is gaining popularity in the western countries these days.

13.3 Contour Maps Preparation

An imaginary line on the ground, joining the points of equal elevation above the assumed datum is called a contour line. It is a plan projection of the plane passing through the points of equal elevation on the surface of the earth. Concept of a contour can be made clear by surveying the boundary of still water in a pond. If the level of the water surface is 100 m, then the periphery of water represents a contour line of 100 m. If the water level is reduced by 5 metres, the new periphery of water will then represent a contour of 95 m. The following characteristics of contours are kept in view while preparing or reading a contour map.

- Two contours of equal elevation do not cross each other except in the case of an over-hanging cliff.
- Contours of different elevations do not unite to form one contour except in the case of a vertical cliff.
- Contours lines located close to each other indicate a steep slope and those located far apart represent a gentle slope.
- Contours equally spaced depict a uniform slope. Parallel, equidistant and straight contours lines represent an inclined plane surface.
- Contours at any point are perpendicular to the line of the steepest slope at the point.
- A contour line must close itself but need to be necessarily within the limits of the map itself.
- Ring contours with higher values inside depict a hill whereas a set of ring contours with lower values inside represent a pond or a depression without an outlet.
- When contours cross a ridge or V-shaped valley, they form sharp V-shapes across them. Contours represent a ridge line, if the concavity of higher value contours lies towards the next lower value contour and a valley if the concavity of the lower value contours lies towards the higher value contour.
- The same contour must appear on both the sides of a ridge or a valley.
- Contours do not have sharp turnings.

Field work for locating contours may be in various ways according to the instruments used. The various methods of locating contours may be divided into two main classes:

- Direct Method
- Indirect Method

i) Direct Method: In the direct method, the contour to be plotted is actually traced on the ground. Points which happen to fall on a desired contour are only surveyed, plotted and finally joined to obtain the particular contour. This method is slow and tedious and thus used for large scale maps, small contour interval and high degree of precision. A temporary benchmark is established near the area to be surveyed with reference to a permanent bench mark. The level is then set up in such a position so that the maximum number of points can be commanded from the instrument station. The height of instrument is determined by taking a back sight on the benchmark and adding it to the reference level of bench mark. The staff reading required to fix points on the various contours is determined by subtracting the Reduced Level (R.L.) of each of the contours from the height of instrument.

ii) Indirect Method: In practice, generally indirect method is used. In this method sufficient numbers of points are given spot levels. The location of such points can be conveniently plotted on a plane table section as these generally form the corners of the well, shaped geometrical figures i.e. squares, rectangles, triangles, etc. It is seldom possible to have exact spot level of any point on exact value of the contour. The spot level of the important features which represent hill tops, ridge lines, bed of streams and lowest points of the depression are also taken, to depict their correct features while drawing contour lines. The contours in between spot levels are interpolated and drawn. This method of contouring is sometimes known as contouring by spot levels. Indirect method of contouring is commonly employed in small scale surveys of extensive areas. This method is cheaper, quicker and less tedious as compared to the direct method of contouring.

13.4 Uses of Contour Maps in SWCE

Keeping in view, the characteristics of contours enumerated above, different natural features may be shown by contours. Followings are some of the important uses:

- To study the general character of the tract of the country without visiting the ground. With the knowledge of the characteristic of the contours, it is easier to visualise whether the country is flat, undulating or mountainous.
- To decide the most economical and suitable sites of re-engineering for engineering works such as canals, sewers, reservoirs, roads, railways etc.
- To determine the catchment area of the drainage basin and hence the capacity of the proposed reservoir.
- To compute the earth work required for filling or cutting along the linear alignment of projects such as canals, roads, etc.
- Site selection and dimensioning of soil and water conservation measures like contour bunds, contour trenches etc.

13.5 Use of surveying and leveling instruments

Surveying is defines as the art of determining the relative positions of various points above, on or below the surface of the earth. The ultimate object of survey is to prepare a map or plant using the data obtained through the survey. The collection of data by linear and angular measurements and elevation difference is called the field work. The processing of data plotting and computation of area and volume are called office work.

Use of agricultural survey

Surveying is primarily divided into two types.

(1) Plane surveying

(2) Geodetic surveying

Agricultural surveying is the simplest form of plane surveying. With the use of survey, the boundaries of fields can be correctly located and area can be accurately computed. Land leveling and grading may be perfectly done if the differences in elevations are known. Alignments of canals for irrigation and drainage can be effectively done by proper surveying. Surveying plays a vital role in soil conservation measures like contour bunding, graded bunding, bench terracing construction of farm ponds and percolation ponds etc. In addition to this, surveying plays a key role in laying underground pipe line system, alignment of irrigation channels, drainage systems, farm roads and farm stead construction etc. For linear and angular measurements in the plains, chain, compass and plane table surveys are used with necessary instruments. To determine the difference in elevation a dumpy level is used.

The details of instruments used in each survey are given below:

1. Chain survey

1. Chain and Tape
2. Cross Staff
3. Ranging rods
4. Offset Rods
5. Arrows

2. Compass Survey

1. Prismatic Compass
2. Chain
3. Ranging Rods
4. Offset Rods

3. Plane Table Survey

1. Plane Table with Tripod Stand
2. Alidade
3. Trough Compass
4. ‘U’ frame with plumb bob

5. Spirit Level
6. Chain
7. Ranging Rods

4. Leveling

1. Dumpy Level
2. Tripod Stand
3. Telescopic Metric Staff

13.6 Field area calculation

Aim: To locate the boundaries of a given field and also to determine the area.

Instruments required: Chain, Cross staff, Arrows, Ranging rods and Offset rods

Procedure:

In order to calculate the area of any irregular shaped field, it is necessary to divide that area into number of right angled triangles and trapezoids. Corners along the boundary of the field should be first identified and named as A, B, C, D, E, F, G *etc.* in clockwise direction. Any two stations located in opposite sides should be selected in such a way that distance between them is the longest of other stations and almost equal numbers of corners/ stations are located on both sides. Chaining should be started along the base line and offset distance to the corners on both sides to be measured simultaneously after ranging, as already explained. All the details should be entered in the field book.

Care should be taken that no offset is overlooked before the chain is moved forward. To check the accuracy of the field work boundary line between any two corners should be measured directly and compared. After the field work is over the survey data may be plotted to a suitable scale on a drawing paper.

The area enclosed by the boundary lines is divided into a number of triangles and trapezoids.

Measurement by a chain and cross staff is based upon two formulas

- The area of a right angled triangle is equal to the base multiplied by half the perpendicular, and
- The area of a trapezoid is equal to the base multiplied by half the sum of the perpendiculars

Example 1) Plot the following cross-staff survey of a field ABCDEFGA and calculate its area in hectares. All distances are in meters.

		B		C			
		40		90			
A 0	80	100	125	140	160	200	D
	10		70		35		
			G		F		E

Practical 7: Water Lifting Pump Capacity and Power Requirements for Pumping

7.1 Types and Selection of Pumps

The mechanical device or arrangement by which water is caused to flow at increased pressure is known as a *pump* and the process of using a pump for this purpose is known as *pumping*. Irrigation pumps, in general, are driven either by engines or electric motors. Basically, the following four principles are involved in pumping water. Atmospheric pressure, centrifugal force, positive displacement and movement of columns of fluid caused by differences in specific gravity. Pumps are classified on the basis of mechanical principles of operation as

Positive Displacement Pumps

(a) Reciprocating Pump

(b) Rotary Pump

Variable Displacement Pumps

(a) Centrifugal Pump

(b) Turbine Pump

    a. Deep well turbine

    b. Submersible pump

(c) Propeller Pump

(d) Jet Pump

(e) Air Lift Pump

7.2 Positive Displacement Pump

In a positive displacement pump, the fluid is physically displaced by mechanical devices such as the plunger, piston, gears, cams, screws etc. In this type of pump, a vacuum is created in a chamber by some mechanical means and then water is drawn in this chamber. The volume of water thus drawn in the chamber is then shifted or displaced mechanically out of chamber,

(a) Reciprocating Pumps: In this type of pump, a piston or a plunger moves inside a closed cylinder. On the intake stroke, the suction valve remains open and allows water to come into the cylinder. The delivery valve remains closed during intake stroke. On the discharge stroke, the suction valve is closed and water is forced in delivery pipe through delivery pipe through delivery valve which opens during discharge stroke.

The reciprocating pumps may be single acting or double acting. In the former type water is discharged only on the forward stroke of the piston and in the latter type, water is discharged on forward and return strokes of the piston. This type of pump is quite suitable for greater discharge under high head of water. Force required to work a reciprocating pump is P = w*a*1 where, 'P' is the force required to lift the piston in kg, 'a' is area of cylinder in m2, 'l' is the length of stroke in m and 'w' is the specific weight of water is 1000 kg m-3. Work done in one upstroke is w*a*1*h, where 'h' is the total height through which the water is raised, m.

(b) Rotary Pumps: In this type of pump, the reciprocating motion is substituted by the rotary motion. The rotary motion is achieved by cams or by gears. There are two cams or gears which fit with each other. They rotate in opposite directions. The water enters through the suction pipe and it is trapped between cams or teeth of gears and casing. It is then thrown with force into the discharge pipe. This type of pump is useful for moderate heads and small discharges not greater than 40 litres per second.

7.3 Variable Displacement Pump

The distinguishing feature of variable displacement pumps is the inverse relationship between the discharge rate and the pressure head. As the pumping head increases, the rate of pumping decreases. They are also termed as Roto Dynamic Pumps.

(a) Centrifugal Pump: A centrifugal pump may be defined as one in which an impeller rotating inside a close – fitting case draws in the liquid at the centre and, by virtue of centrifugal force, throws out through an opening at the side of the casing. In operation, the pump is filled with water and the impeller rotated. The blades cause the liquid to rotate with the impeller and, in turn, import a high velocity to the water particles. The centrifugal force causes the water particles to be thrown from the impeller reduces pressure at the inlet, allowing more water to be drawn in through the suction pipe by atmospheric pressure. The liquid passes into the casing, where its high velocity is reduced and converted into pressure and the water is pumped out through the discharge pipe. The conversion of velocity energy into pressure energy is accomplished either in a Volute casing or in a Diffuser.

(b) Turbine Pumps: Turbine pumps consist of impellers placed below the water level and are driven by a vertical shaft rotated by an engine or motor placed at the ground level or under the water.

1. ***Vertical Turbine Pump (or) Deep well Turbine Pump:*** is a vertical axis centrifugal or mixed flow type pump comprising of stages which accommodate rotating impellers and stationary bowls possessing guide vanes with the motor fixed on the ground level. The pump bowl is surrounded by a screen to keep coarse sand and gravel away from entering the pump.

These pumps are adopted to high lifts and high efficiencies under optimum operating conditions. The pressure head developed depends on the diameter of the impeller and the speed at which it is rotated. Since the pressure head developed by a single impeller is not great, additional head is obtained by adding more bowl assemblies or stages. Turbine pumps could be water lubricated or oil lubricated. It is preferable to use oil lubricated pumps for wells giving fine sand along with water.

2. *Submersible Pump* is a turbine pump coupled to a submersible electric motor. A cable passing through the water supplies power to the motor. Both the pump and the motor are suspended and operate under the water, pumping water through the discharge column. The pump eliminates the long shaft and bearings that are necessary for a vertical turbine pump. Submersible pumps are cheaper than the vertical turbine pumps. Suitable for deep settings and also for crooked wells which are not perfectly vertical. The installation of the pup is easy and the initial cost of installation low. The repair of the submersible pumps, when they go out of order is not easy and require technical skill. Submersible pump requires little maintenance, after 6000 hours of operation or two years of service life, it may be necessary to with draw the pump from the bore hole and overhaul it. Selection of the submersible pump is mainly depending upon the bore well size, type, well discharge etc.

3. *Propeller Pumps:* The principal parts of the propeller pumps and method of operation are similar to the turbine pumps. The main difference is in design of the impellers, which give high discharges at low heads. Two types of impellers *i.e.* axial flow type and mixed flow type are used in this pump. In single stage pumps only one impeller is used and in multistage pumps more than one impeller is used. The selection of a propeller pump is done based on the characteristic curves compared with the well discharge and head.

4. *Jet Pumps:* Consist of a combination of a centrifugal pump and a jet mechanism or ejector. Jet pump is used when the suction lift of the centrifugal pump exceeds the permissible limits. A portion of the water from the centrifugal pump is passed through the drop pipe to the nozzle of the jet assembly. This water is forced through the throat opening of the diffuser, creating a vacuum which causes water to be drawn from the well. The water mixed with the boost water is carried up through the diffuser where the high velocity energy is converted into useful pressure energy, forcing the water up through the delivery pipe to the centrifugal pump.

5. *Air-lift Pump* operates by the injection of compressed air directly into the water inside a discharge or eductor pipe at a point below the water level in the well. The injection of the air results in a mixture of air bubbles and water. This composite fluid is lighter in weight than water so that the heavier column of water around the pipe displaces the lighter mixture facing it upward and out of the discharge pipe. The piping assembly consists of a vertical discharge pipe called the eductor pipe – and a smaller air pipe. Airlift pumping is extensively used in the development and preliminary testing and cleaning of tube wells. The advantages of air-lift pumps are simplicity, tube well need not be perfectly straight or vertical, and impure water will not damage the pump. The main disadvantage is its low efficiency about 30 per cent.

7.4 Power Requirements for Pumping

1. ***Water Horse Power (WHP)*** is the theoretical horse power required for pumping.

$$\text{WHP} = \frac{\text{Discharge (litres sec}^{-1}) * \text{Total head (m)}}{75}$$

2. ***Shaft Horse Power*** is the power required at the pump shaft.

$$\text{Shaft Horse Power} = \frac{\text{Water Horse Power}}{\text{Pump Efficiency}}$$

3. ***Pump Efficiency*** $= \dfrac{\text{Water Horse Power}}{\text{Shaft Horse Power}} * 100$

4. ***Brake Horse Power (BHP)*** is the actual horse power required to be supplied by the engine or electric motor for driving the pump.

(i) For direct driven pump, BHP = Shaft Horse Power

(ii) With belt or indirect drives, BHP $= \dfrac{\text{Water Horse Power}}{\text{Pump Efficiency} * \text{Drive Efficiency}}$

5. ***Horse Power Input to electric motor*** =

$$\frac{\text{Water Horse Power}}{\text{Pump Efficiency} * \text{Drive Efficiency} * \text{Motor Efficiency}}$$

---

6. ***Kilowatt Input to electric motor (or) Energy Consumption in Kilowatt Hours***

$$\text{Energy in Kilowatts} = \frac{\text{Brake Horse Power} * 0.746}{\text{Motor Efficiency}}$$

7. Cost of operation for electric motor

= Energy in Kilowatts*Hours of pumping*Cost per Kilowatt Hour

The pump efficiency of most of the pumps generally ranges from 60 to 70 per cent and the drive efficiency of motor is about 80 per cent. The overall efficiency of the system may be approximately 50 to 55 per cent.

Example 1) Compute the cost of pumping 2 x 10^6 liter water from a well with a centrifugal pump from the following data: (a) suction head = 3 meters (b) Delivery head = 5.5 meters (c) Friction head = 1.5 m (d) Output of pump 15,000 lits./ hour (e) Pump efficiency = 70 % (f) Motor efficiency = 85 % cost of electricity = Rs.6/- per unit.

Problem 2: What are the power requirements for pumping 450 lt/min against a head of 50 m, assuming a pump efficiency of 65%. What size electrical motor is required to operate the pump.

Solution:

$$\text{WHP} = \frac{\text{Discharge in litres per second} \times \text{total head in m}}{76}$$

Discharge = 450 lt/min = $\frac{450}{60}$ **= 7.5 lt/s**

Total head = 50 m

$$\textbf{WHP} = \frac{7.5 \times 50}{76} = \mathbf{4.93}$$

$$\text{Shaft horsepower} = \frac{\text{Water horsepower}}{\text{Pump efficiency}} = \frac{4.93}{\frac{65}{100}} = 7.59 \cong 7.6$$

7.5 HP size electrical motor is required to operate the pump.

Example 3: A pump lifts 45,000 lts/hr against total head of 18 m. Compute the Water horsepower. If the pump has an efficiency of 65%, what size of prime mower is required to operate the pump? If a direct driven electrical motor, having an efficiency of 80%, is used to operate the pump, compute the cost of electrical energy in a month of 30 days. The pump is operated for 8 hours daily for 30 days. The cost of electrical energy is Rs. 2.50 per unit.

Solution:

Discharge = 45000 lts/hr = $\frac{45000}{3600}$ = 12.5 lts/s

Total head = 18 m

$$\text{WHP} = \frac{12.5 \times 18}{76} = 2.96$$

Output power of motor = Input power of pump

$$\text{SHP} = \frac{2.96}{\frac{65}{100}} = 4.55$$

Since the pump is direct driven, the shaft horsepower is the same as the brake horsepower of the prime mower. An electric motor of 5 HP is suitable.

$$\text{Kilowatt input to motor} = \frac{BHP \times 0.746}{Motor efficiency} = \frac{5 \times 0.746}{0.8} = 4.66 \text{ kW}$$

Total energy consumption per month = 4.66 × 8 × 30

=1118.4 Kilowatt-hours

(Electrical units)

Cost of electrical energy per month = 1118.4 × 2.50 = Rs. 2796=00

Lecture - 8

Levelling may be defined as the art of determining the relative heights or elevations of points or objects on the surface of the earth. Therefore, it deals with measurements in vertical plane. Levelling has wide applications in the field of agriculture. Construction of irrigation and drainage channels, terraces, bunds, reservoirs, outlet structures, etc. require the knowledge of surveying. For any soil conservation and land levelling work, levelling is the first job to be taken up.

8.0 Levelling instruments

Two instruments are required to determine the reduced levels of points. They are: (i) a level and (ii) a levelling staff. The level is used to provide a horizontal line of sight and the levelling staff which is a graduated rod is used to read the vertical height of the line of sight above the selected station.

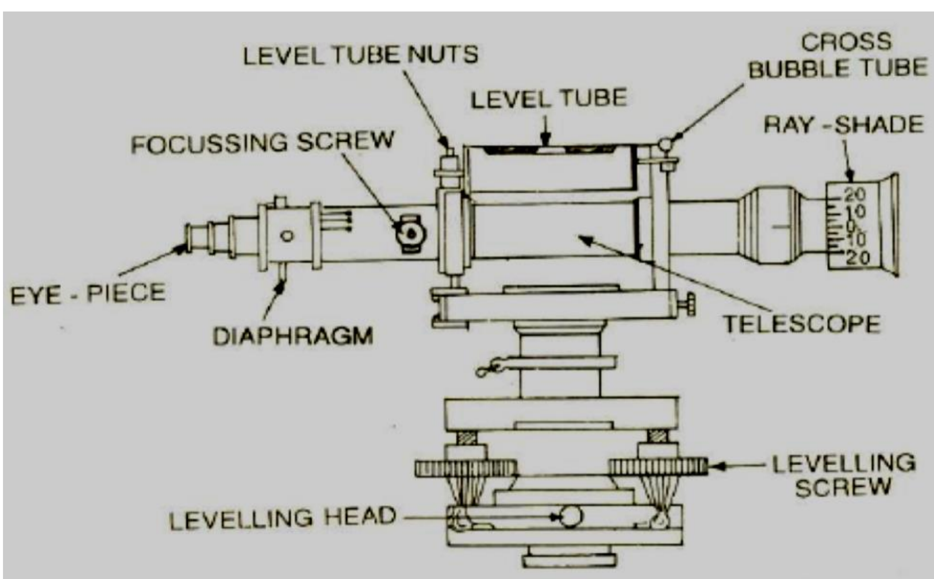
8.1 The level

Various types of levels are used for surveying viz. (i) Hand level, (ii) Farm level, (iii) Wey level, (iv) Tilting level and (v) Dumpy level etc. The dumpy level is widely used for levelling works. For small and rough levelling works, the hand levels and farm levels are used. The dumpy level is very sturdy, compact and stable equipment. The telescope is rigidly fixed to the frame. Therefore, the telescope cannot be rotated about the longitudinal axis and also cannot be removed from the support. Because of its simple features and versatile usefulness, it is widely used.

8.1.1 Dumpy level

The dumpy level is simple, compact and stable. Main parts of a dumpy level are shown in fig.20. A levelling instrument essentially consists of tripod or three-legged stand, levelling head mounted on the tripod, the limb, telescope and the bubble rube. The most important part is the telescope which may be either internal focusing or external focusing type.

A levelling head is mounted on the tripod stand having two parallel plates and three or four foot screws. The limb, consists of the vertical axis and a horizontal plate, connects the levelling head with the above telescope.



The telescope has an object glass at the forward end and eye piece at the rear end. The eye piece magnifies the image of the object formed by the object glass. All the parts above the levelling head are capable of rotating round the vertical axis. One or two bubble tubes are provided for leveling the instrument. The bubbles can be brought to the centre of the bubble tubes by adjusting the foot screws, which support the upper parallel plate.

The diaphragm is fixed a little beyond the eye-piece inside the main tube. The diaphragm houses a brass ring which is fitted with cross hairs. There are three sets of horizontal hairs. The central cross hair gives the line of sight. The line joining the intersection of the central cross hair to the optical centre of the object glass and its continuation is the line of sight. When sighted through the eye piece, continuation of the above line meets the leveling staff at a point denotes the staff reading.

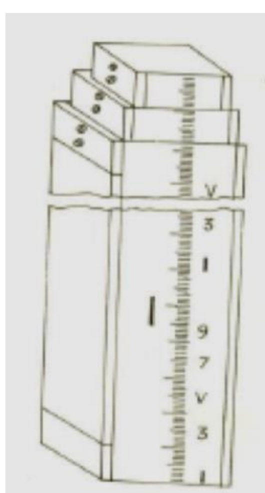
8.2 The levelling staff

There are various types of graduated staves. Out of all the “sop with telescopic staff” is commonly used. The purpose of a levelling staff is to determine the amount by which the station (foot of the staff) is above or below the line of sight.

8.2.1 Sop with telescopic staff

It is a straight rectangular, graduated rod with the foot of the staff representing the zero reading. The width and the thickness of the staff are 75 mm and 18 mm respectively. It is made of well seasoned wood such as cypress, blue pine or deodar free from any defect.

It is arranged in three telescopic lengths. It is usually 5 m long when fully extended (Fig.21). The solid top length of 1.5m slides into the central box of 1.5 m, which in turn slides into lower or bottom box of 2.0 m length. Each length when pulled out to its full length is held in position by means of a brass spring catch. Each metre is subdivided into 200 divisions, the thickness of graduation being 5mm. Spaces indicating the decimetre readings are marked in red while all other spaces are marked in black against a white background. Each decimetre length is figured with the corresponding numerals, the metre numeral is in red and marked to the right and the decimetre numeral in black and marked to the left. When viewed through the telescope, the staff appears inverted and therefore, readings are taken from top to downwards.



8.3 Terminology connected with leveling

Datum: It is also called datum plane or only datum. A datum surface is usually an imaginary level surface or arbitrarily assumed level surface, from which vertical distances are measured. Its elevation is zero. In India, the datum adopted for the Great Trignometrical survey (GTS) bench mark is the mean sea level at Karachi, now in Pakistan. At present, the mean sea level at Madras is used.

Elevation: It is the vertical distance above or below the datum. It is also known as reduced level (R.L.) The elevation of a point is plus or minus according as the point is above or below the datum.

Bench Mark (B.M.): It is a fixed point of reference of known or assumed elevation with respect to which other elevations are calculated. It is a starting point for leveling. Temporary bench marks are selected at the end of a day's work.
There are four kinds of Bench marks.

(a) **G.T.S (Great Trigonometrical Survey) Bench Mark:** These bench marks are established with very high precision at intervals all over the country by Survey of India department. Their position and elevation above the standard datum are given in the catalogue published by the department.

(b) **Permanent Bench Mark:** These are the fixed points of reference established between the GTS bench marks by Government agencies such as PWD. On clearly defined and permanent points such as top of the parapet wall of a bridge or culvert, corner of a plinth of a building, gate pillars etc.,

(c) **Arbitrary bench Marks:** These are the reference points whose elevations are arbitrarily assumed. They are used in small levelling operations.

(d) **Temporary Bench Marks**: These are the reference points established at the end of day's work or when there is a break in the work. The work, when resumed, is continued with reference to these bench marks.

(e) **Line of collimation:** It is the line joining the intersection of the cross hairs to the optical centre of the object glass and its continuation. It is called the line of sight.

(f) **Axis of telescope:** It is a line joining the optical centre of the object glass to the center of the eye piece.

(g) **Axis of the level tube or bubble tube:** It is an imaginary line tangential to the longitudinal curve of the tube at its middle point. It is also known as bubble line. It is horizontal, when the bubble is centered.

(h) **Height of the instrument:** It is the reduced level (RL.) of the plane of sight when the leveling instrument is correctly leveled. It is also called the "height of the plane of the collimation" or the collimation. The line of collimation will revolve in a horizontal plane known as plane of collimation or the plane of sight.

(i) **Back sight:** It is a staff reading taken on a point of known elevation, as on a bench mark or a change point. It is also called a plus sight. It is the first staff reading taken after the level is set up and levelled.

(j) **Foresight:** It is the last staff reading denoting the shifting of the level. It is the staff reading taken on a point whose elevation is to be determined. It is also termed as a minus sight. It is the last staff reading, denoting the shifting of the instrument.

(k) **Change point:** It is the point on which reading is taken just before and after shifting the instrument. That means both back sight and fore sight readings are taken on this point It is also called a turning point. It should be taken on a firm, well-defined object.

(l) **Station:** A station is a point whose elevation is to be determined or a point which is to be established at a given elevation.

Lecture - 10

10.0 Determination of reduced level

Whenever any leveling is to be carried out, the first reading is taken on a point of known elevation. This is called back sight (B.S.) reading. Before shifting the instrument one reading is taken on a firm object whose elevation is to be determined. This is known as fore sight (F.S.) reading. Between the B.S. and F.S. numbers of readings known as intermediate sights (I.S.) are taken. All these readings are required to be tabulated and converted to reduced levels (R.L.) for practical use. There are two systems of working out the reduced levels of points from the staff readings in the field: (1) the collimation or the height of instrument (H.I.) and (2) the rise and fall system.

10.1 The collimation system: At first, the R.L. of the plane of collimation i.e., height of instrument (H.I.) is calculated for every setting of the instrument and then R.L. of different stations re calculated with reference to the height of the instrument. In the first setting, the H.I. is calculated by adding the B.S. reading with the R.L. of the bench mark. By subtracting all the readings of all the intermediate sights and that of the first change point from the H.I., then their reduced levels are calculated. The new H.I is calculated by adding the B.S. reading with the R.L. of the first change point. The process is repeated till the entire area is covered.

Arithmetical check: The difference between the sum of back sights (B.S.) and the sum of fore sights (F.S.) should be equal to the difference of first and last R.L.

10.2. Rise and fall system: The level readings taken on different stations are compared with the readings taken from the intermediate proceeding stations. The difference in the readings indicates rise or fall depending upon whether the staff reading is smaller or greater than that of the preceding reading. The rise is added and fall is subtracted from the R.L. of a station to obtain the R.L. of the next station.

Arithmetical check: The difference between the sum of back sights (B.S.) and the sum of fore sights (F.S.) is equal to the difference between the sum of the rise and fall and should be equal to the difference of first and last R.L.

If the R.L. of A is known, the RL. of B may be found by the following relation:
R.L. of B = R.L. of A + Σ B.S. – Σ F.S.

The R.L.'s of the intermediate points maybe found by the following relation:
R.L. of a point = R.L. of B.M. + B.S. I.S.

The difference of level between A and B is equal to the algebraic sum of these differences or equals the difference between the sum of back sights (B.S.) and the sum of the foresights (F.S.) [Σ B.S. – Σ F.S.]. If the difference is positive, it indicates that the point B is higher than the point A, while if the negative, the point B is lower than the point A.

Example 1:
The following consecutive readings were taken with a dumpy level:

0.565, 0.854, 0.940, 1.005, 0.640, 0.660, 0.785, 0.800, 0.635, 1.135 and 1.420

The level was shifted after the fourth and the seventh readings. The first reading was taken on the bench mark of R.L. is 100.565. Calculate the reduced levels of the change points, and the difference of level between the first and last points.

Solution:
The level was shifted after the fourth and the seventh readings. Hence, the fourth (1.005) and seventh readings (0.785) are fore sight readings. Where as the fifth (0.640) and eight reading (0.800) are back sight readings. The starting reading is back sight reading. The last reading is fore sight reading.

B.S. F.S. B.S. F.S. B.S. F.S.
0.565, 0.854, 0.940, 1.005, 0.640, 0.660, 0.785, 0.800, 0.635, 1.135, and 1.420.

(i) Collimation or Height of instrument (H.I.) method

Station	Readings, m			R.L. of plane of collimation (H.I.), m	Reduced level (R.L.), m	Remarks
	B.S.	I.S.	F.S.			
	0.565			**100.565**	**100.000**	**B.M**
		0.854			**99.711**	
		0.940			**99.625**	
	0.640		**1.005**	**100.200**	**99.560**	**C.P. 1**
		0.660			**99.540**	
	0.800		**0.785**	**100.2.15**	**99.415**	**C.P. 2**
		0.635			**99.580**	
		1.135			**99.080**	
			1.420		**98.795**	**Last point**
	Σ B.S. =2.005		**Σ F.S. =3.210**			

Arithmetical check: The difference between the sum of back sights (B.S.) and the sum of fore sights (F.S.) should be equal to the difference of first and last R.L.

Σ B.S. = 2.005 ; Σ F.S. = 3.210 ; I R.L. = 100.000; Last R.L. = 98.795

2.005-3.210 = 98.795-100.000

-1.205 = -1.205 (Checked)

(i) Rise and fall method

Station	Readings, in			Rise, m	Fall, m	Reduced level (R.L.), m	Remarks
	B.S.	L.S.	F.S.				
	0.565					100.000	B.M.
		0.854			0.289	99.711	
		0.940			0.086	99.625	
	0.640		1.005		0.065	99.560	C.P. 1
		0.660			0.020	99.540	
	0.800		0.785		0.125	99.415	C.P. 2
		0.635		0.165		99.580	
		1.135			0.500	99.080	
			1.42.0		0.285	98.795	Last Poin
	Σ B.S. =2.005		Σ F.S. =3.210	Σ rise =0.165	Σ fall =1.370		

Arithmetical check: The difference between the sum of back sights (B.S.) and the sum of fore sights (F.S.) is equal to the difference between the sum of the rise and fall and should be equal to the difference of first and last R.L.

Σ B.S. = 1.365 ; Σ = 3.210 ; I R.L. = 100.000 ; Last R.L. = 98.795 ;

Σ rise = 0.165 ; Σ fall = 1.370

2.005 – 3.210 = 0.165 – 1.370 = 98.798 – 100.000

-1.205 -1.205 -1.205 (Checked)

2 (1+1)

Farm Machinery and Power

Lecture Outlines

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3	Terminology related to engine power: IHP, BHP, FHP, DBHP, compression ratio, stroke bore ratio, piston displacement, and mechanical efficiency. Numerical problems on calculation of IHP, BHP, C.R., stroke bore ratio, piston displacement volume.	16 – 20
4	Fuel supply and cooling system of I.C. engine – types, components and their functions, working principle of forced circulation cooling system.	21 – 31
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8	Disc plough – functions, constructional details, operational adjustments and maintenance.	57 - 61
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10	Harrows – types, functions, operation of disc harrows. Cultivators – rigid and spring loaded tynes. Puddlers, cage wheel, rotovators. Intercultural implements – hoes and weeders for dry and wetland cultivation.	65 - 77
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Lecture No.1

Farm power - sources of different farm power, advantages and disadvantages.

1.0 Farm power

Various types of agricultural operations performed on a farm can be broadly classified as:

1. Tractive work – such as seed bed preparation, cultivation, harvesting and transportation.

2. Stationary work- such as silage cutting, feed grinding, threshing, winnowing and lifting of irrigation water.

These operations are done by different sources of power, namely human, animal, mechanical power (oil engines and tractors), electrical power and renewable energy (solar energy, biogas, biomass and wind energy).

1.1 Human power

Human beings are the main sources of power for operating small tools and implements at the farm. They are also employed for doing stationary work like threshing, winnowing, chaff cutting and lifting irrigation water. Of the total rural population in India, only 30% is available for doing farm work. The indications are that the decline in number of labourers employed for agriculture. On an average, a man develops nearly 0.1 horse power (hp).

Advantages: Easily available and used for all types of work.

Disadvantages: Costliest power compared to all other farms of power, very low efficiency, requires full maintenance when not in use and affected by weather condition and seasons.

1.2 Animal power

The most important source of power on the farm all over the world and particularly in India is animal. It is estimated that, nearly 80% of the total draft power used in agriculture throughout the World is still provided by animals. India is having 22.68 crore cattle, which is the highest in the World. Mainly, bullocks and buffaloes happen to be the principle sources of animal power on Indian farms. However, camels, horses, donkeys and elephants are also used for the farm work. The average force a bullock can exert is nearly equal to one tenth of its body weight. Power developed by an average pair of bullocks is about 1 hp for usual farm work.

Advantages:

1. Easily available.
2. Used for all types of work.
3. Low initial investment.
4. Supplies manure to the field and fuels to farmers.
5. Live on farm produce.

Disadvantages:

1. Not very efficient.
2. Seasons and weather affect the efficiency.
3. Cannot work at a stretch.
4. Require full maintenance when there is no farm work.
5. Creates unhealthy and dirty atmosphere near the residence.
6. Very slow in doing work.

1.3 Mechanical power

It is available through tractors, power tillers and oil engines. The oil engine is a highly efficient device for converting fuel into useful work. The efficiency of diesel engine varies between 32 and 38%, whereas that of the carburetor engine (Petrol engine) is in the range of 25 and 32%. In recent years, diesel engines, tractors and power tillers have gained considerable popularity in agricultural operations. It is estimated that, about one million tractors of 25 hp range are in use for various agricultural operations in India. Similarly, total number of oil engines of 5 hp for stationery work is 60 lakhs. Normally, stationery diesel engines are used for pumping water, flour mills, oil ghanis, cotton gins, chaff cutter, sugarcane crusher, threshers and winnowers etc.,

Advantages: Efficiency is high; not affected by weather; cannot run at a stretch; requires less space and cheaper form of power.

Disadvantages: Initial capital investment is high; fuel is costly and repairs and maintenance needs technical knowledge.

1.4 Electrical power

Now-a- day‟s electricity has become a very important source of power on farms in various states of the country. Electrical power is used mostly for running electrical motors for pumping water, dairy industry, cold storage, farm product processing, and cattle feed grinding. It is clean source of power and smooth running. The operating cost remains almost constant throughout its life. Its maintenance and operation need less attention and care. On an average, about 1/10th of the total electrical power generated in India, is consumed for the farm work, approximately it is 4600 megawatt.

Advantages: Very cheap form of power; high efficiency; can work at a stretch; maintenance and operating cost is very low and not affected by weather conditions.

Disadvantages: Initial capital investment is high; require good amount of technical knowledge and it causes great danger, if handled without care,

1.5 Renewable energy

It is the energy mainly obtained from biomass; biogas, solar and wind are mainly used in agriculture for power generation and various agricultural processing operations. It can b used for lighting, power generation, water heating, drying, greenhouse heating, water distillation, refrigeration and diesel engine operation. This type of energy is inexhaustible in nature. The availability of wind energy for farm work is quite limited. Where the wind velocity is more than 32 kmph, wind mills can be used for lifting water. Main limitation for this source is uncertainty. Average capacity of a wind mill would be about 0.5 hp. There are about 2540 windmills in India. It is the cheapest sources of farm power available in India.

Lecture No.2

Internal combustion engine - different components and their functions, working principle of four stroke and two stroke cycle engine, comparison between diesel and petrol engine, difference between four and two stroke engine.

Heat engine is a machine for converting heat, developed by burning fuel into useful work (or) it is equipment which generates thermal energy and transforms it into mechanical energy. Heat engine is of two types: (i) External combustion engine, and (ii) Internal combustion engine.

2.1 External combustion engine: It is the engine designed to derive its power from the fuel, burnt outside the engine cylinder. Here combustion process uses heat in the form of steam, which is generated in a boiler, placed entirely separate from the working cylinder.

2.2 Internal combustion engine (I. C. Engine): It is the engine designed to derive its power from the fuel, burnt within the engine cylinder. Here combustion of fuel and generation of heat takes place within the cylinder of the engine.

2.3 Principle of I.C. Engine

A mixture of fuel with correct amount of air is exploded in an engine cylinder which is closed at one end. As a result of explosion, heat is released and this causes the pressure of the burning gases to increase. This pressure increase, forces a close fitting piston to move down the cylinder. This movement of piston is transmitted to a crankshaft by a connecting rod so that the crankshaft turns a flywheel. To obtain continuous rotation of the crankshaft this explosion has to be repeated. Before this, the burnt gases have to be expelled from the cylinder. At the same time the fresh charge of fuel and air must be admitted and the piston must be returns back to its starting position. This sequence of events is known as working cycle.

2.4 Working of I.C. Engine

I.C. engine converts the reciprocating motion of piston into rotary motion of the crankshaft by means of connecting rod. The piston which reciprocates in the cylinder is very close fit in the cylinder. Rings are inserted in the circumferential grooves of the piston to prevent leakage of gases from sides of the piston. Usually a cylinder is bored in a cylinder block. A gasket, made of copper sheet or asbestos is inserted between the cylinder and the cylinder head. The combustion space is provided at the top of the cylinder head where combustion takes place. There is a rod called connecting rod for connecting the piston and the crankshaft. A pin called gudgeon pin or wristpin is provided for connecting the piston and the connecting rod of the engine. The end of the connecting rod which fits over the gudgeon pin is called small end of the connecting rod. The other end which fits over the crank pin is called big end of the connecting rod. The crankshaft rotates in main bearings which are fitted in the crankcase. A flywheel is provided at one end of the crankshaft for smoothening the uneven torque, produced by the engine. There is an oil sump at the bottom of the engine which contains lubricating oil for lubricating different parts of the engine (Fig.1).

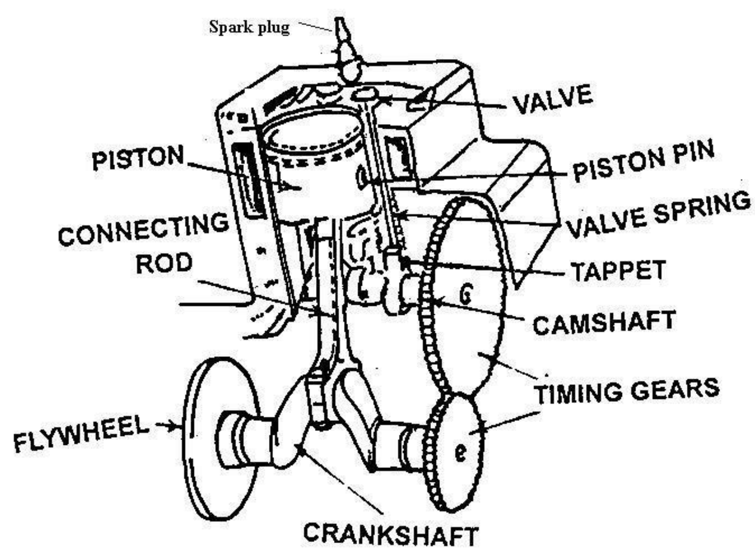


Fig. 1. Working components of I.C.Engine

2.5 Engine components

Internal combustion engine consists of the following parts (Fig.2):

Cylinder: It is a part of the engine which confines the expanding gases and forms the combustion space. It is the basic part of the engine. It provides space in which piston operates to suck the air or air-fuel mixture. The piston compresses the charge and the gas is allowed to expand in the cylinder, transmitting power for useful work. Cylinders are usually made of high grade cast iron.

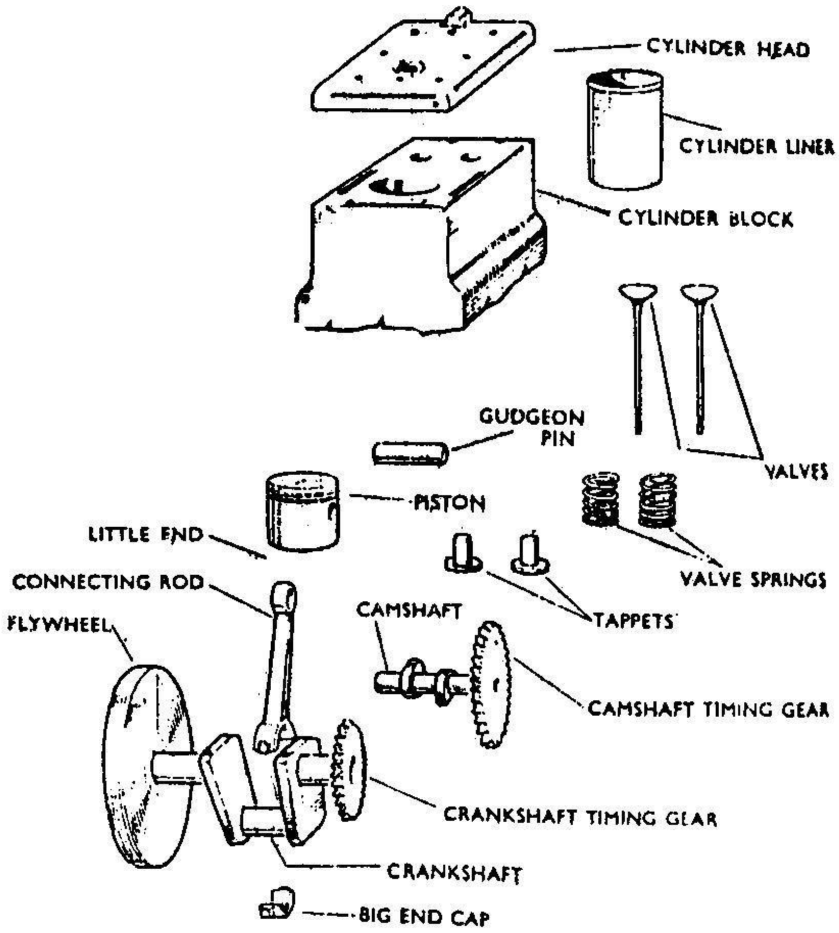


Fig. 2.Components of I.C.Engine

Cylinder block: It is the solid casting which includes the cylinder and water jackets (cooling fins in the air cooled engines).

Cylinder head: It is detachable portion of an engine which covers the cylinder and includes the combustion chamber, spark plugs and valves.

Cylinder liner or sleeve: It is a cylindrical lining either wet or dry which is inserted in the cylinder block in which the piston slides. Cylinder liners are fitted in the cylinder bore and they are easily replaceable. The overhauling and repairing of the engines, fitted with liners is easy and economical. Liners are classified as: dry liner, and wet liner. *Dry liner* makes metal to metal contact with the cylinder block casting. *Wet liners* come in contact with the cooling water, whereas dry liners do not come in contact with cooling water.

Piston: It is a cylindrical part closed at one end which maintains a close sliding fit in the engine cylinder. It is connected to the connecting rod by a piston pin. The force of the expanding gases against the closed end of the piston, forces the piston down in the cylinder. This causes the connecting rod to rotate the crankshaft. Cast iron is chosen due to its high compressive strength, low coefficient of expansion, resistance to high temperature, ease of casting and low cost. Aluminum and its alloys are preferred mainly due to its lightness.

Head (crown) of piston: It is top of the piston.

Skirt: It is that portion of the piston below the piston pin which is designed to absorb the side movements of the piston.

Piston ring: It is a split expansion ring, placed in the groove of the piston. Piston rings are fitted in the grooves, made in the piston. They are usually made of cast iron or pressed steel alloy. The functions of the ring are as follows:

(a) It forms a gas tight combustion chamber for all positions of piston.

(b) It reduces contact area between cylinder wall and piston wall for preventing friction losses and excessive wear.

(c) It controls the cylinder lubrication.

(d) It transmits the heat away from the piston to the cylinder walls.

Piston rings are of two types: (a) Compression ring and (b) Oil ring.

(a) **Compression ring**. Compression rings are usually plain, single piece and are always placed in the grooves, nearest to the piston head.

(b) **Oil ring**. Oil rings are grooved or slotted and are located either in lowest groove above the piston pin or in a groove above the piston skirt. They control the distribution of lubrication oil in the cylinder and the piston. They prevent excessive oil consumption also. Oil ring is provided with small holes through which excess oil returns back to the crankcase chamber.

Piston pin: It is also called wrist pin or gudgeon pin. Piston pin is used to join the connecting rod to the piston. It provides a flexible or hinge like connection between the piston and the connecting rod. It is usually made of case hardened alloy steel.

Connecting rod: It is a special type of rod, one end of which is attached to the piston and the other end to the crankshaft. It transmits the power of combustion to the crankshaft and makes it rotate continuously. It is usually made of drop forged steel.

Crankshaft: It is the main shaft of an engine which converts the reciprocating motion of the piston into rotary motion of the flywheel. Usually the crankshaft is made of drop forged steel or cast steel. The space that supports the crankshaft in the cylinder block is called main journal, whereas the part to which connecting rod is attached is known as crank journal.

Fly wheel: Fly wheel is made of cast iron. Its main functions are as follows:

(a) It stores energy during power stroke and returns back the same energy during the idle strokes, providing a uniform rotary motion by virtue of its inertia.

(b) It also carries ring gear that meshes with the pinion of the starting motor.

(c) The rear surface of the flywheel serves as one of the pressure surfaces for the clutch plate.

(d) Engine timing marks are usually stamped on the flywheel, which helps in adjusting the timing of the engine.

(e) Some times the flywheel serves the purpose of a pulley for transmitting power.

Crankcase: The crankcase is that part of the engine which supports and encloses the crankshaft and camshaft. It provides a reservoir for the lubricating oil of the engine.

Cam shaft: It is a shaft which raises and lowers the inlet and exhaust valves at proper time. Camshaft is driven by crankshaft by means of gears, chains or sprockets. The speed of the camshaft is exactly half the speed of the crankshaft in four stroke engine. Camshaft operates the ignition timing mechanism, lubricating oil pump and fuel pump. It is mounted in the crankcase, parallel to the crankshaft.

Timing gear: Timing gear is a combination of gears, one gear of which is mounted at one end of the camshaft and other gear on the end of the end of the crankshaft. Camshaft gear is bigger in size than that of the crankshaft gear and it has twice as many teeth as that of the losing crankshaft gear. For this reason, this gear is commonly called Half time gear. Timing gear controls the timing of ignition, timing of opening and closing of valves as well as fuel injection timing.

Inlet manifold: It is that part of the engine through which air or air-fuel mixture enters into the engine cylinder. It is fitted by the side of the cylinder head.

Exhaust manifold: It is that part of the engine through which exhaust gases go out of the engine cylinder. It is capable of with-standing high temperature of burnt gases. It is fitted by the side of the cylinder head.

2.6 Internal engine classification

Internal combustion engines are classified in two types depending on the period required to complete a cycle of operation. They are four stroke and two stroke engines.

1. When the cycle is completed in two revolutions of the crankshaft, it is called *four stroke cycle engines*.
2. When the cycle is completed in one revolution of the crankshaft, it is called *two stroke cycle engines*.

I.C. engines are of two types: (i) Petrol engine (carburetor type, spark ignition engine), and (ii) diesel engine (compression ignition engine).

Petrol engine: It is the engine, in which liquid fuel is atomized, vaporized and mixed with air in correct proportion before entering onto the engine cylinder during suction stroke. The fuel is ignited in the cylinder by an electric spark.

Diesel engine: In this engine, during suction stroke, only air is entered into the cylinder and compressed. The fuel is injected through fuel injectors and ignited by heat of compression.

2.5.1 Working of four stroke cycle engine

In four stroke cycle engine, all the events taking place inside the engine cylinder are completed in four strokes of the piston i.e., suction, compression, power and exhaust stroke (Fig.3). This engine has got valves for controlling the inlet of charge and outlet of exhaust gases. In two stroke cycle engine, all the events take place in two strokes of the piston.

The four strokes of the piston are as follows:

1. Suction stroke: During this stroke, only air or mixture of air and fuel are drawn inside the cylinder. The charge enters the engine through inlet valve which remains open during admission of charge. The exhaust valve remains closed during this stroke. The pressure in the engine cylinder is less than atmospheric pressure during this stroke.

2. Compression strike: The charge taken in the cylinder is compressed by the piston during this stroke. The entire charge of the cylinder is compressed to a small volume contained in the clearance volume of the cylinder. If only air is compressed in the cylinder (as in the case of diesel engine), the fuel is injected at the end of the compression stroke. The ignition takes place due to high pressure and temperature. If the mixture of air and fuel is compressed in the cylinder (as in the case of spark ignition engine i.e., petrol engine), the mixture is ignited by spark plug. After ignition, tremendous amount of heat is generated, causing very high pressure in the cylinder which pushes the piston backward for useful work. Both valves are closed during this stroke.

3. Power stroke: During power stroke, the high pressure developed due to combustion of fuel causes the piston to be forced downwards. The connecting rod with the help of crankshaft transmits the power to the transmission system for useful work. Both valves are closed during this stroke.

4. Exhaust stroke: Exhaust gases go out through exhaust valves during this stroke. All the burnt gases go out of the engine and the cylinder becomes ready to receive the fresh charge. The inlet valve is closed and exhaust valve remains open during this stroke. The exhaust valve is closed just after the end of the exhaust stroke, and the inlet valve is opened just before the burning of the suction stroke to repeat the cycle of operation.

Thus it is found that out of four strokes, there is only one power stroke and three idle strokes. The power stroke supplies necessary momentum for useful work.

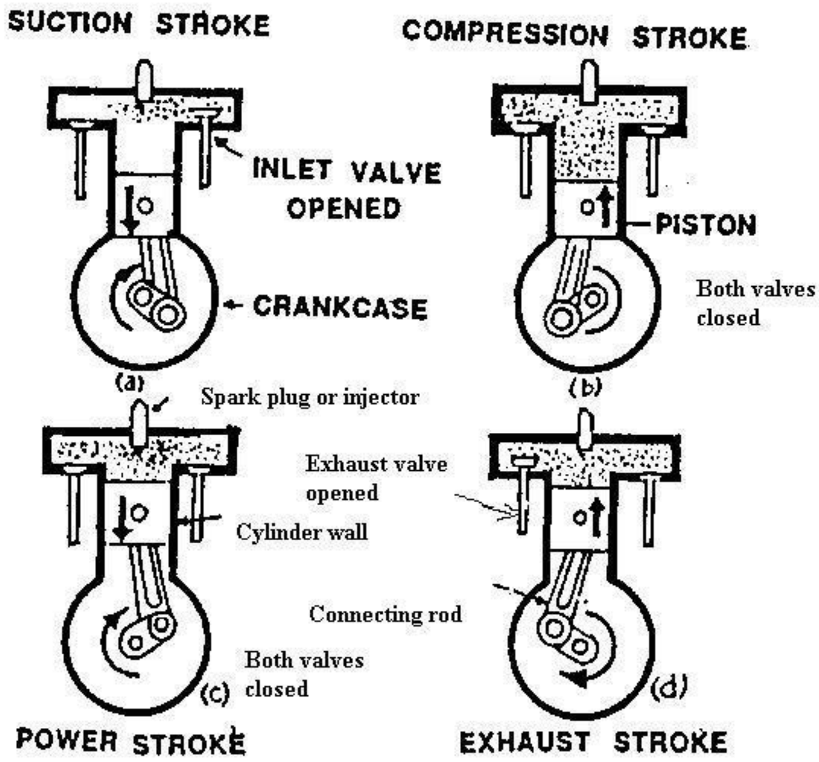


Fig. 3. Working of four stroke cycle engine

2.5.2 Two stroke cycle engine

In such engines, the whole sequence of events i.e. suction, compression, power and exhaust are completed in two strokes of the piston and in one complete revolution of the crankshaft (Fig.4). There is no valve in this type of engine. Gas movement takes place through holes called ports in the cylinder. The crankcase of the engine is gas tight in which the crankshaft rotates.

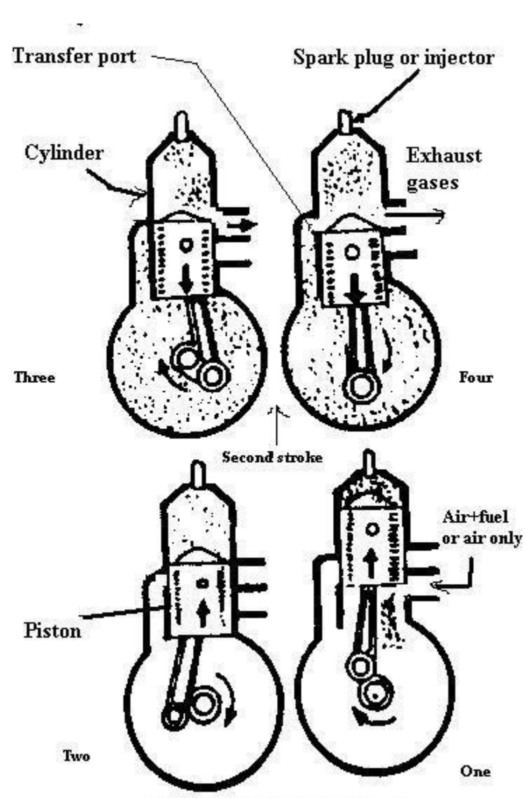


Fig. 4. Working of two stroke cycle engine

First stroke (suction + compression): When the piston moves up the cylinder, it covers two of the ports, the exhaust port and the transfer port, which are normally almost opposite to each other. This traps a charge of fresh mixture in the cylinder and further upward movement of the piston compresses this charge. Further movement of the piston also uncovers a third port in the cylinder suction port. More fresh mixture is drawn through this port into the crankcase. Just before the end of this stroke, the mixture in the cylinder is ignited as in the four stroke cycle.

Second stroke (Power + exhaust): The rise in pressure in the cylinder caused by the burning gases forces the piston to move down the cylinder. When the piston goes down, it covers and closes the suction port, trapping the mixture drawn into the crankcase during the previous stroke then compressing it. Further downward movements of the piston uncover first the exhaust port and then transfer port. This allows the burnt gases to flow out through exhaust port. Also the fresh mixture under pressure in the crankcase is transferred into the cylinder through transfer port during this stroke. Special shaped piston crown deflect the incoming mixture up around the cylinder so that it can help in driving out the exhaust gases.

When the piston is at the top of its stroke, it is said to be at the top dead centre (TDC). When the piston is at the bottom of its stroke, it is said to be at its bottom dead centre (BDC). In two stroke cycle engine, both the sides of the piston are effective, which is not the case in case of four stroke cycle engine.

Scavenging: The process of removal of burnt or exhaust gases from the engine cylinder is known as scavenging. Entire burnt gases do not go out in normal stroke, hence some type of blower or compressor is used to remove the exhaust gases in two stroke cycle engine.

2.6 Comparison between diesel and petrol (carburetor) engines

S.No.	**Diesel engine**	**Petrol engine**
1.	Diesel fuels are used.	Vapourizing fuels such as petrol, powerine or kerosene are used.
2.	Air alone is taken in during suction stroke.	Mixture of air and fuel is taken in.
3.	Fuel is injected into super heated air of the combustion space where burning takes place.	Air-fuel is compressed in the combustion chamber where it is ignited by an electric spark.
4.	Air-fuel ratio is not constant as the quantity of air drawn into the cylinder is always the same. To vary the load and speed the quantity of fuel injected is changed.	Air and fuel are almost always in the ratio of 15:1, but to vary the engine power, quantity of mixture is varied.
5.	Compression ratio of the engine varies from 14:1 to 20:1.	Compression ratio of the engine varies from 5:1 to 8:1.
6.	Specific fuel consumption is about 0.2 kg per BHP per hour.	Specific fuel consumption is about 0.29 kg per BHP per hour.
7.	4.5 litres of fuel is sufficient for nearly 20 hp hour.	4.5 litres of fuel will last about 12 hp hour.
8.	Diesel engine develops more torque, when it is heavily loaded.	This characteristic is not present in carburetor engines.
9.	Thermal efficiency varies between 32 and 38%.	Thermal efficiency varies between 25 and 32%.
10.	It runs at a lower temperature on part load.	Combustion gas temperature is slightly higher under part load.
11.	Engine weight per horse power is high.	Engine weight per horse power is comparatively low.
12.	Initial cost is high.	Initial cost is low.
13.	Operating cost is low.	Operating cost is comparatively high.

2.7 Comparison between two stroke and four stroke engines

S.No.	Particulars	Four stroke engine	Two stroke engine
1.	No. of power stroke	one power stroke for every two revolutions of the crankshaft	one power stroke for each revolutions of the crankshaft
2.	Power for the same cylinder volume	Small	Large (about 1.5 times of 4 stroke)
3.	Valve mechanism	Present	Ports instead of valves
4.	Construction and cost	Complicated and expensive	Simple, cheap
5.	Fuel consumption	Little	High (about 15% more)
6.	Removal of exhaust gases	Easy	Difficult
7.	Durability	Good	Poor
8.	Stability of operation	High	Low
9.	Lubrication	Equipped with an independent lubricating oil circuit	Using fuel, mixed with lubricating oil
10.	Oil consumption	Little	Much
11.	Carbon deposit inside cylinder	Not so much	Much because of mixed fuel
12.	Noise	Suction & exhaust is noiseless, but other working is noisy	Suction & exhaust is noiseless, but other working is noise less
13.	Air tight of crankcase	Un necessary	Must be sealed
14.	Cooling	Normal	Chances of overheating
15.	Self weight and size	Heavy & large	Light & small

Lecture No.3

Terminology related to engine power: IHP, BHP, FHP, DBHP, compression ratio, stroke bore ratio, piston displacement, and mechanical efficiency. Numerical problems on calculation of IHP, BHP, C.R., stroke bore ratio, piston displacement volume.

3.0 Engine Terminology

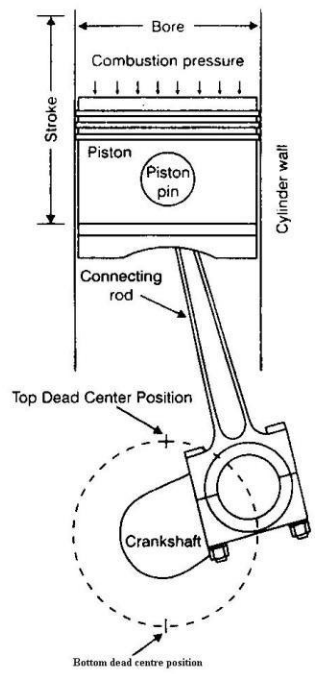


Fig.5. Diagram showing TDC and BDC positions

Bore : Bore is the diameter of the engine cylinder (Fig.5).

Stroke : It is the linear distance traveled by the piston from Top dead centre (TDC) to Bottom dead centre (BDC).

Stroke-bore ratio: The ratio of length of stroke (L) and diameter of bore (D) of the Cylinder is called Stroke-bore ratio (L/D). In general, this ratio varies between 1 to 1.45 and for tractor engines, this ratio is about 1.25.

Swept volume (Piston displacement): It is the volume (A x L) displaced by one stroke of the piston where **A** is the cross sectional area of piston and **L** is the length of stroke.

Compression ratio: It is the ratio of the volume of the charge at the beginning of the compression stroke to that at the end of compression stroke, i.e., ration of total cylinder volume to clearance volume. Compression ration of diesel engine varies from 14:1 to 20:1, carburetor engine varies from 4:1 to 8:1.

Power : It is the rate of doing work. Unit of power in SI units - Watt (Joule/sec).

Horse power: It is the rate of doing work. One HP is equivalent to 75 kg-m / sec.

Indicated Horse Power (IHP): it is the total horse power developed by all the cylinders and received by pistons, without friction and losses within the engine.

IHP = $\frac{PLAN}{4500} \times \frac{n}{2}$ (for four stroke engine)

IHP = $\frac{PLAN}{4500} \times n$ (for two stroke engine)

Where P - Mean effective pressure in Kg/cm^2

L- Length of the piston stroke in meters

A -Cross sectional area of piston in cm^2

N- rpm of the engine

n - Number of cylinders in the engine

Brake horse power (B.H.P): It is the horsepower delivered by the engine and is available at the end of the crankshaft and it is measured by suitable dynamometer.

Frictional horse power (F.H.P): It is the power required to run the engine at a given speed with out producing any useful work. It represents the friction and pumping losses of the engine.

F.H.P= I.H.P - B.H.P

I.H.P = B.H.P + F.H.P

Drawbar horse power (DBHP): It is the power of a tractor measured at the end of the drawbar. It is the power required to pull the loads.

Brake mean effective pressure (BMEP): It is the average pressure acting throughout the entire power strokes which are necessary to produce BHP of the engine.

BMEP = $\frac{BHP \times 75 \times 60}{L \times A \times N \times \frac{n}{2}}$ (for four stroke engine)

BMEP = $\frac{BHP \times 75 \times 60}{L \times A \times N \times n}$ (for two stroke engine)

Thermal efficiency: It is the ratio of the horse power output of the engine to the fuel horse power.

Mechanical efficiency: It is the ratio of the brake horse power to the indicated horse power.

Mechanical efficiency= $\frac{BHP}{IHP} \times 100$

Piston speed (Np) : It is the total length of travel of the piston in a cylinder in one minute. Piston speeds of the high speed tractor engine range between 300 to 500 m/m.

Displacement volume (Vd) : It is the total swept volume of all the pistons during power strokes occurring in a period of one minute.

$$Vd = ALn$$

A – piston area

L – piston stroke

N – number of power strokes per minute for all cylinders.

Example 1: Calculate the BHP of a 4 stroke, 4 cylinder I.C. Engine which has cylinder bore of 14 cm, stroke length of 16 cm, crankshaft speed of 1100 rpm, frictional horse power of 30, and mean effective pressure is 8 kg/cm^2.

Solution:

Data given: D = 14 cm ; L = 16 cm; N = 1100 rpm; FHP =30 and P=8 kg/cm^2

IHP = $\frac{PLAN}{4500} \times \frac{n}{2}$ (for four stroke engine)

IHP = $\frac{8 \times 0.16 \times \frac{\pi}{4} \times (14)^2 \times 1100}{4500} \times \frac{4}{2}$ = 96.4

I.H.P = B.H.P + F.H.P

$\therefore$ BHP = IHP – FHP = 96.4 – 30 = 66.4

Example 2: The horse power developed at the end of crankshaft of a 4 stroke, 4 cylinder I C engines was found to be 30 HP at a speed of 1500 RPM. The mean effective pressure is 6 kg/cm^2 .The stroke-bore ratio is 1.3. Find the length of stroke and diameter of bore if the mechanical efficiency is 80%.

Solution:

Data given: BHP =30; N = 1500; P=6 kg/cm^2; $\eta = 80\%$

Mechanical efficiency= $\frac{BHP}{IHP}\times 100$

IHP = $\frac{BHP}{\eta}$ = $\frac{30\times 100}{80}$ = 37.5

IHP = $\frac{PLAN}{4500}\times\frac{n}{2}$ (for four stroke engine)

Stroke-bore ratio = $\frac{L}{D}=$ 1.3 $\Rightarrow$ L = 1.3 D

$$\text{IHP} = \frac{6\times 1.3D\times\frac{\pi}{4}\times\ D^{\ 2}\times 1500}{4500}\times\frac{4}{2}$$

37.5 = 4.08 D^3 $\Rightarrow$ D = 2.1 cm

L = 1.3 × 2.1 = 2.7 cm

Example 3: A Four cylinder four stroke diesel engine has a cylinder diameter of 20 cm, stroke-bore ratio is 1.45, clearance volume 4508 cm^3, engine speed 250 rpm, mean effective pressure 6.8 kg/cm^2 and mechanical efficiency is 75%. Calculate (i) IHP, (II) BHP (iii) Compression ratio and (iv) Swept volume.

Solution:

Data given: D = 20 cm; N =250; P = 6.8 kg/cm^2; $\eta=$ 75%

clearance volume = 4508 cm^2

Stroke-bore ratio = $\frac{L}{D}=1.45$

Where D= 20 cm

$\therefore$ L = 1.45× 20 = 29 cm

(i) IHP = $\frac{PLAN}{4500}\times\frac{n}{2}$ (for four stroke engine)

$$\text{IHP} = \frac{6.8\times 0.29\times\frac{\pi}{4}\times\ (20)^2\times 250}{4500}\times\frac{4}{2} = 68.9$$

(ii) Mechanical efficiency= $\frac{BHP}{IHP}\times 100$

BHP = $\frac{IHP}{100}\times\eta$ = $\frac{68.9\times 75}{100}$ = 51.7

(iii) and (iv) Compression ratio: $\frac{\text{Swept volume + Clearence volume}}{\text{Clearence volume}}$

Swept volume = A x L

$$= \frac{\pi}{4} \times (20)^2 \times 29 = 9114.3 \text{ cm}^3$$

Compression ratio = $\frac{9114.3 + 4508}{4508}$ = 3.02

Example 4: Calculate (i) IHP (ii) BHP (iii) Stroke bore ratio (iv) Compression ratio (v) Swept volume of a four stroke four cylinder I.C. engine with the following data:

Cylinder size : 12.5 x 15 cm

Fly wheel speed : 1200 rpm

Mean effective pressure : 7 kg/cm^2

Mechanical efficiency : 70%

Clearance volume : 150 CC

Solution

Data given: L = 15 cm; D = 12.5 cm; N = 1200; P = 7 kg/cm^2; $\eta =$ 70%

(i) IHP = $\frac{PLAN}{4500} \times \frac{n}{2}$ (for four stroke engine)

$$\text{IHP} = \frac{7.0 \times 0.15 \times \frac{\pi}{4} \times (12.5)^2 \times 1200}{4500} \times \frac{4}{2} = 68.7$$

(ii) Mechanical efficiency= $\frac{BHP}{IHP} \times 100$

BHP = $\frac{IHP}{100} \times \eta = \frac{68.7 \times 70}{100}$ = 48.1

(iii) Stroke-bore ratio = $\frac{L}{D} = \frac{15}{12.5}$ = 1.2

(iv) nd (v) Compression ratio: $\frac{\text{Swept volume + Clearence volume}}{\text{Clearence volume}}$

Swept volume = A x L

$$= \frac{\pi}{4} \times (12.5)^2 \times 15 = 1841.5 \text{ cm}^3$$

Compression ratio = $\frac{1841.5 + 150}{150}$ = 13.3

Lecture No.4

Fuel supply and cooling system of I.C. engine – types, components and their functions, working principle of forced circulation cooling system.

4.1 Fuel and fuel supply system

Fuel is a substance consumed by the engine to produce energy. The common fuels for IC engines are: (i) petrol, (ii) power kerosene, (iii) high speed diesel oil (H.S.D oil) and (iv) light diesel oil (L.D.O)

4.2 Quality of fuel

The quality of fuel mainly depends upon the following properties: (i) volatility, (ii) calorific value and (iii) ignition quality of fuel. A good fuel contains a combination of qualities such as good volatility, high antiknock value, chemical purity, and freedom from gum.

4.2.1 Volatility

It is the vapourizing ability of a fuel at a given temperature. It indicates the operating characteristics of the fuel inside the engine. It is measured by means of distillation tests on the fuel.

In IC engine, all the liquid fuel must be converted into vapour fuel before burning. Petrol which shows lower initial and final boiling points, compared to other fuels, vapourizes at a lower temperature. HSD oil is most difficult to vapourize. Its vapourizing temperature is higher than that of the petrol, hence the petrol vapourizes quicker than diesel oil in the engine cylinder. This helps in easy starting of petrol engines. The oil that vapourizes quickly can be distributed well in different cylinders of the engine, hence distribution of fuel in different cylinders is better in petrol engine than that of diesel engine.

4.2.2 Calorific value

The heat liberated by combustion of a fuel is known as calorific value or heat value of the fuel. It is expressed in kcal/kg of the fuel. Calorific values (kcal/kg) of different fuels are as follows:

1) Petrol – 11,100 (highest)
2) Power kerosene – **10,850**
3) High speed diesel oil (HSD oil)- 10,550
4) Light diesel oil (LDO oil) – 10,300

4.2.3 Ignition quality

It refers to ease of burning the oil in the combustion chamber. Octane number and cetane number are the measures of ignition quality of the fuel. Octane number is standard yardstick for measuring knock characteristics of fuels.

Cetane number is the relative measure of the interval between the beginning of injection and auto-ignition of the fuel. The higher the cetane number, the shorter the delay interval and the greater its combustibility. Fuels with low cetane Numbers will result in difficult starting, noise and exhaust smoke.

4.2 Detonation

Detonation or engine knocking refers to violent noises heard in an engine during the process of combustion after the piston has passed over the TDC. It is an undesirable combustion and results in sudden rise in pressure, a loss of power and overheating of the engine. This may cause damage to pistons, valves, gasket and other parts.

Detonation is caused by improper combustion chamber, high compression pressure, early ignition timing, improper fuel and inadequate cooling arrangement.

4.3 Pre-ignition

Burning of air-fuel mixture in the combustion chamber before the piston has reached the TDC is called pre-ignition. This may be due to excessive heat in the cylinder.

4.4 Fuel supply system in compression ignition engine or diesel engine

The main components of the fuel supply system in diesel engine are: (i) fuel tank, (ii) primary fuel filter, (iii) fuel transfer pump or fuel lift pump, (iv) secondary fuel filter, (v) fuel injection pump, (vi) high pressure pipes, (vii) fuel injection nozzles or fuel injectors and over flow pipe (Fig.6).

During engine operation, the fuel is supplied by gravity from fuel tank to the primary filter where coarse impurities are removed. From the primary filter, the fuel is drawn by fuel transfer pump. This pump is also known as fuel lift pump, is activated by a cam on the engine camshaft. The fuel lift pump forces fuel under low pressure (2.5 kg/cm^2) through the secondary fuel filter to the injection pump, which is generally driven by the camshaft. The purpose of fuel injection pump is to deliver a metered quantity of fuel at a predetermined time under pressure (120 to 175 kg/cm^2 or more$^)$ through the high pressure tubes to the injection nozzles or injectors. The fuel that leaks out from the injection nozzles passes out through leakage pipe and returns to the fuel tank through the over flow pipe. In some tractors and industrial engines, the fuel supply is by gravity and hence no fuel lift pump is provided.

Two conditions are essential for efficient operation of the system:

(a) The fuel should be clean, free from water, suspended dirt, sand or other foreign matter.

(b) The fuel injection pump should create proper pressure, so that diesel fuel may be perfectly atomized by injectors at proper time and quantity.

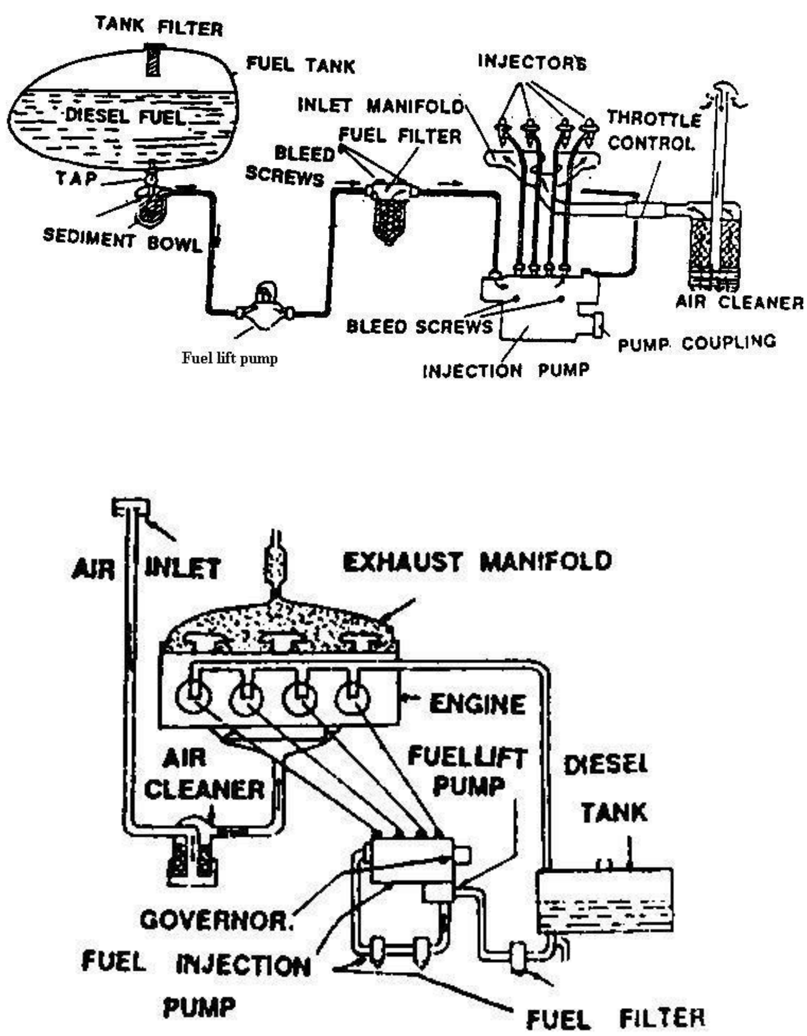


Fig. 6. Fuel supply system in diesel engine

4.4.1 Components of fuel supply system

Fuel tank

It is a storage tank of suitable size and shape, usually made of mild steel sheet. Atmospheric pressure is maintained in the tank with the help of a pin hole on the cap. Usually a wire gauge strainer is provided under the cap to prevent foreign particles. Usually a drain plug is provided at the bottom for flow of fuel.

Fuel lift pump

It transfers adequate amount of fuel from the fuel tank to the inlet gallery of the injection pump through fuel filter. The fuel pressure at the fuel lift pump in the range of 1.5 to 2.5 kg/cm^2. It is mounted on the body of fuel injection pump. Fuel lift pump may be (i) plunger type, (ii) diaphragm type.

Fuel filter

It is a device to remove dirt and solid particles from the fuel to ensure trouble free fuel supply (Fig.7). Solid particles and dust in diesel fuel are very harmful for giving a fine degree of filtration. Fuel injection equipment in diesel engines is extremely sensitive to dirt and solid particles present in fuel.

It consists of a hollow cylindrical element contained in a shell, an annular space being left between the shell and the element. The filtering element consists of metal gauge in conjunction with various media such as packed fibers, woven cloth, felt, paper etc. These filters are replaced at certain intervals, specified by the manufacturer.

Usually there are two filters in diesel engine: (1) Primary filter and (2) secondary filter. The primary filter removes water and coarse particle of dirt from the fuel. The secondary filter removes fine sediments from the fuel. Usually the primary filter is placed between the tank and the fuel lift pump.

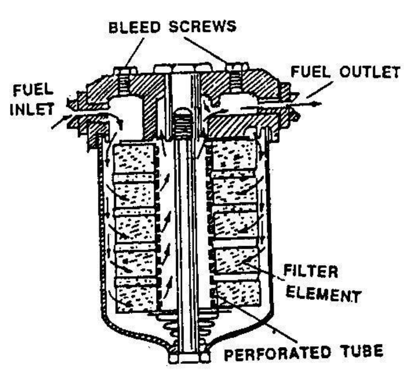


Fig. 7. Fuel filter

Fuel injection pump

It is a high pressure pump, which delivers metered quantity of fuel to each cylinder at appropriate time under pressure according to the firing order of the engine. It is used to create pressure varying from 120 to 175 kg/cm^2. Fuel injection pumps are mostly constant stroke type and in most of the tractors there is an individual pump for each cylinder.

The pumps used in tractor are of two types: (i) multi element pump and (ii) (ii) Distributor (Rotor) type pump.

Multi element injection pump

The plunger (Fig.8) reciprocates in close fitting barrel with the help of tappet and spring. The upper part of the plunger has got helix, which makes it possible to vary the delivery of the fuel. An annular groove in the central part of the plunger facilitates the distribution of fuel over the barrel. As the plunger moves down, the fuel enters the barrel from inlet side. As plunger moves up, it closes the inlet part of the barrel and pressurizes the fuel in the barrel. This causes delivery valve to lift off its seat and allows the fuel to enter into the injection line, leading to the fuel injector. As soon as the edge of the helix uncovers the split part of the barrel, the fuel pressure quickly drops. The cam shaft of the fuel injection pump is driven directly from the engine timing gear.

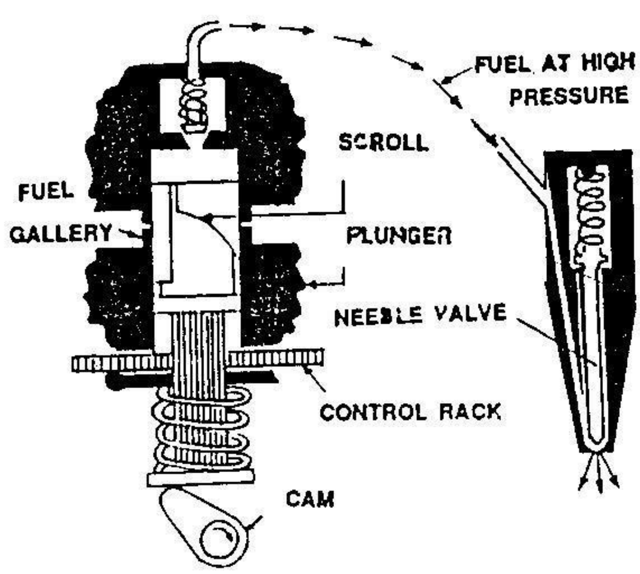


Fig. 8. Multi element fuel injection pump

Distributor (rotor) type pump:

In this type of pump, one plunger and one barrel assembly deliver fuel not to one cylinder but to several cylinders. The plunger not only reciprocates, but rotates in a close fitting barrel. This helps in distributing fuel to a number of cylinders at a time.

Fuel injector

It is the component which delivers finely atomized fuel under high pressure to the combustion chamber of the engine. Modern tractor engines use fuel injectors which have multiple holes.

Air cleaner

It is a device, which filters and removes dust, moisture and other foreign matter from the air before if reaches the engine cylinder. Air cleaner is usually of two types: (1) Dry type air cleaner and (2) Oil bath type air cleaner.

Dry type air cleaner

The filtering element in this case is a type of felt. The felt has got larger surface area, reduces the air speed while passing through and consequently particle or dirt in the air is deposited on or stopped by its surface.

Oil bath type air cleaner

In this type of air cleaner, the incoming air impinges upon the surface of the oil, kept in a container in the lower part of the casing. The foreign particles of the air are trapped in the oil and then the air passes through a wire element before reaching the inlet manifold of the engine. The wire element also arrests the remaining dirt particles of the air.

Governor

Governor is a mechanical device designed to control the speed of an engine within specified limit used on tractor or stationary engine for: (i) maintaining a nearly constant speed of engine under different load conditions (ii) protecting the engine and the attached equipments against high speeds, when the load is reduced or removed. Tractor engines are always fitted with governor. There is an important difference in principle between the controls of a tractor engine and that of a motor car. In case of motor car, the fuel supply is under direct control of the accelerator pedal, but in tractor engine, the fuel supply is controlled by the governor. The operator changes the engine speed by moving the governor control lever.

A governor is essential on a tractor engine for the reason that load on the tractor engine is subjected to rapid variation in the field and the operator can not control the rapid change of the engine speed without any automatic device. For example, if the load on the tractor is reduced, the engine would tend to race suddenly. If the load is increased, the engine would tend to slow down abruptly. Under these circumstances, it becomes difficult for the operator to regulate always the throttle lever to meet the temporary changes in the engine load. A governor automatically regulates the engine speed on varying load condition and thus the operator is relieved of the duty of constant regulating the throttle lever to suit different load conditions.

Principle of governor

Engine Governor is used for automatically controlling the speed of an engine regulating the intake of fuel or injection fuel, so that engine speed is maintained at the desired level under all conditions of loading.

Governor used on tractor engine is called *variable* speed governor and the one used on stationary engine is called constant speed governor. Governing system is classified as: (i) hit and miss system, (ii) throttle system

4.5 Cooling System

Fuel is burnt inside the cylinder of an internal combustion engine to produce power. The temperature produced on the power stroke of an engine can be as high as 1600ºC and this is greater than melting point of engine parts.

The cylinder and cylinder head are usually made of cast iron and pistons in most cases are made of aluminum alloy. It is estimated that about 40 % of total heat produced is passed to the atmosphere via the exhaust, 30 % is removed by cooling system and only about 30% is used to produce useful power.

4.5.1 Bad effect of high temperature in the engine

(i) Cylinder and piston may expand to such an extent that the piston would seize in the cylinder and stop the engine.

(ii) Lubricating quality of the oil inside the cylinder would be destroyed due to high temperature and there may not be sucking of air in the cylinder.

(iii) Pre-ignition of fuel mixture would take place and would cause engine knocking as well as loss of power.

For satisfactory performance of the engine, neither overheating nor over-cooling is desirable. Experiments have shown that best operating temperature of I.C engine lies between 140ºF to 200 ºF, depending upon types of engines and load conditions.

4.5.2 Purpose of cooling

(i) To maintain optimum temperature of engine for efficient operation under all conditions.

(ii) To dissipate surplus heat for protection of engine components like cylinder, cylinder head, piston, piston rings and valves.

(iii) To maintain the lubricating property of the oil inside the engine cylinder for normal functioning of the engine.

There are two different methods of cooling: (i) air cooling and (ii) water cooling.

4.5.3 Air cooling

Air cooled engines are those engines, in which heat is conducted from the working components of the engine to the atmosphere directly. In such engines, cylinders are generally not grouped in a block.

Principle of air cooling

The cylinder of an air cooled engine has fins to increase the area of contact of air for speedy cooling. The cylinder is normally enclosed in a sheet metal casing called *Cowling*. The flywheel has blades projecting from its face, so that it acts like a fan drawing air through a hole in the cowling and directing it around the finned cylinder. For maintenance of air cooling system, passage of air is kept clean by removing grasses etc. This is done by removing the cowling and cleaning out the dirt etc. by a stiff brush or compressed air. When separate fan is provided, the belt tension is to be checked and adjusted if necessary.

Advantages of air cooling

It is simpler in design and construction. Water jackets, radiators, water pump, thermostat, pipes, hoses etc. are not needed. It is more compact. It is comparatively lighter in weight.

Disadvantages

There is uneven cooling of the engine parts. Engine temperature is generally high during working period.

4.5.4 Water cooling

Engines, using water as cooling medium is called "water cooled engines". The liquid is circulated round the cylinders to absorb heat from the cylinder walls. In general, water is used as cooling liquid. The heated water is conducted through a radiator which helps in cooling the water.

There are three common methods of water cooling: (i) Open jacket or hopper method, (ii) Thermo siphon method, and (iii) Forced circulation method.

Forced circulation method

In this method, a water pump is used to force water from the radiator to the water jacket of the engine. After circulating the entire run of water jacket, hot water goes to the radiator, where it passes through tubes surrounded by air. A fan is driven with the help of a V-belt to suck air through tubes of the radiator unit, cooling radiator water. To maintain the correct engine temperature, a thermostat valve is placed at the outer end of cylinder head. Cooling liquid is by-passed through the water jacket of the engine until engine attains the desired temperature. Then thermostat valve opens and the by-pass is closed, allowing the water to go to the radiator. The system consists of water pump, radiator, fan, fan-belt, water jacket, thermostat valve, temperature gauge and hose pipe (Fig.9).

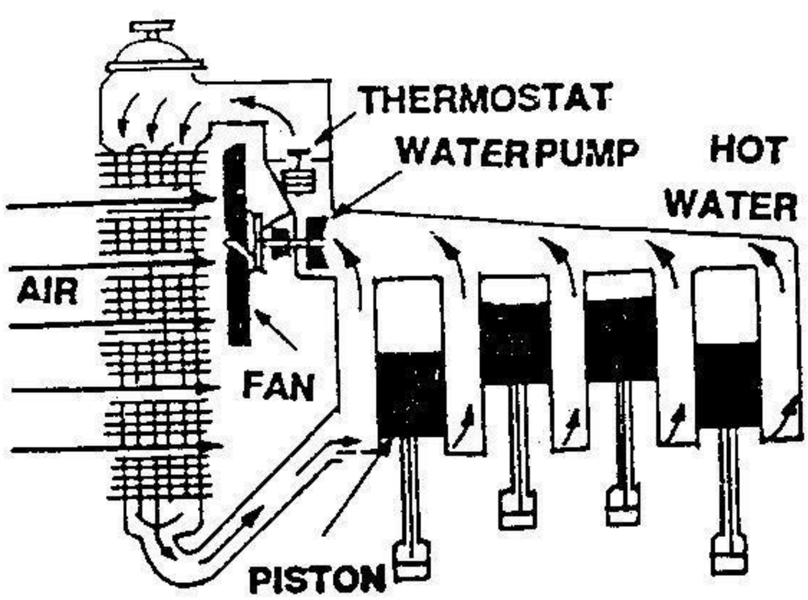


Fig. 9. Working of forced circulation cooling system

Water pump

It is a centrifugal type pump. It has a casing and an impeller, mounted on a shaft. The casing is usually made of cast iron. Pump shaft is made of some non-corrosive material. At the end of the shaft, a small pulley is fitted which is driven by a V-belt. Water pump is mounted at the front end of the cylinder block between the block and the radiator. When the impeller rotates, the water between the impeller blades is thrown outward by centrifugal force and thus water goes to the cylinder under pressure. The pump outlet is connected by a hose pipe to the bottom of the radiator. The impeller shaft is supported on one or more bearings. There is a seal which prevents leakage of water.

Radiator

Radiator is a device for cooling the circulating water in the engine. It holds a large volume of water in close contact with a large volume of air so that heat is transferred from the water to the air easily.

Hot water flows into thee radiator at the top and cold water flows out from the bottom. Tubes or passages carry the water from the top of the radiator to the bottom, passing it over a large metal surface. Air flows between the tubes or through the cells at right angles to the downward flowing water. This helps in transferring the heat from the water to the atmosphere. On the basis of fabrication, the radiator is of two types: tubular type and cellular type.

Tubular type radiator: It has round or flat water tubes, leading from the top to the bottom of the radiator. They may be soldered, brazed or welded in place or fastened by means of a stuffing box at each end. Fins or folded strips of light sheet metal, placed between the tubes, increase the radiating surface and improve the heat transfer.

Cellular type radiator: It has a core made of short air tubes which are laid horizontally and soldered together at the ends with space between them to allow water to flow. It is also called *Honey comb type* radiator.

Thermostat valve

It is a control valve, used in the cooling system to control the flow of water when activated by a temperature signal.

It is a special type of valve, which closes the inlet passage of the water connected to the radiator. The thermostat is placed in the water passage between the cylinder head and the top of radiator. Its purpose is to close this passage when the engine is cold, so that water circulation is restricted, causing the engine to reach operating temperature more quickly. Thermostats are designed to start opening at 70ºC to 75 ºC and then fully open at 82 ºC for petrol engine and 88-90 ºC for diesel engine.

The thermostat valves are of two types:

(a) Bellows and

(b) Bimetallic.

(a) Bellows type: Bellows type thermostats have got bellows, which contain a liquid like alcohol or ether. The liquid expands with the increase of temperature and raises the valve off its seat. This permits the water to circulate between the engine and the radiator.

(b) Bimetallic type: It consists of a bimetallic strip. Unequal expansion of two metallic strips causes the valve to open and allows the water to flow to the radiator.

Water jackets: Water jackets are cored out around the engine cylinder so that water can circulate freely around the cylinder as well as around the valve opening.

Fan: The fan is usually mounted on the water pump shaft. It is driven by the same belt that drives the pump and the dynamo. The purpose of the fan is to provide strong draft of air through the radiator to improve engine cooling.

Lecture No.5

Ignition and power transmission system of I.C engine – types, components and their functions, working principle of battery ignition system.

5.1 Ignition system

Fuel mixture of I. C engine must be ignited in the engine cylinder at proper time for useful work. Arrangement of different components for providing such ignition at proper time in the engine cylinder is called ignition system.

There are four different systems of igniting fuel: (i) i**gnition by electric spark i.e., spark ignition, (ii) ignition by heat of compression i.e. compression ignition, (iii) i**gnition by hot tube or hot bulb and (iv) ignition by open flame. Only the first two are important methods for modern engines.

5.2 Spark ignition

The purpose of spark ignition is to deliver a perfectly timed surge of electricity across an open spark plug gap in each cylinder at the exact moment, so that the charge may start burning with maximum efficiency. There are two methods in spark ignition: (a) Battery ignition and (b) Magneto ignition.

5.2.1 Battery ignition

Principle

Battery ignition system includes two circuits: low voltage (primary circuit) and high voltage (secondary circuit). The low-voltage circuit consists of : (i) battery (ii) ignition switch (iii) a series register (IV) primary winding and (v) contact breaker. All are connected in series. The high voltage circuit consists of: (i) secondary winding (ii) distributor rotor (iii) high voltage wiring and (iv) spark plugs. They are also connected in series. Battery ignition system on a modern tractor includes a storage battery, ignition switch, high tension coil, distributor, contact breaker mechanism, condenser, spark plugs, generator and cutout.

Working

Electric current is supplied by the battery to the ignition circuit. When the distributor breaker points are closed, low voltage current flows through the primary winding of the ignition coil to the distributor terminal and through the breaker points to the ground. During this time, a strong magnetic field built up in the coil. When the piston is at the end of compression stroke, the distributor points are opened, the magnetic field in the coil starts collapsing. Thus, a current is induced in the primary winding of the coil, which tends to prevent break down of the magnetic field. A very high voltage is produced in the secondary winding due to sudden collapse of the magnetic field. This sudden collapse of the magnetic field in the coil, produces a very high voltage across the secondary winding terminals to a value of 20 to 24 thousand volts. The high-voltage surge is delivered to the center terminal of the distributor cap, where it is picked up by the rotor and directed to the proper spark plug. The high voltage is capable of jumping the spark across the gap of the spark plug and ignites the compressed air-fuel mixture (Fig.10).

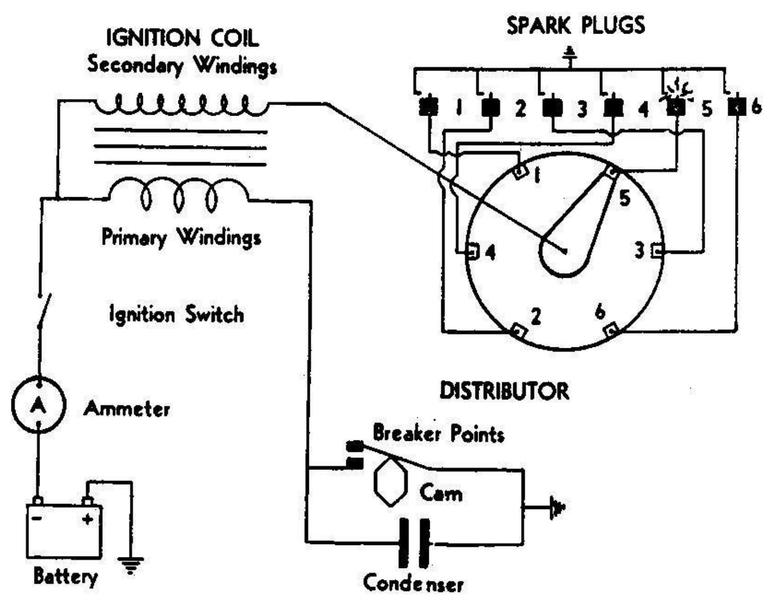


Fig. 10. Circuit diagram for battery ignition system

This system of a number of components such as: (i) Spark plug (ii) Distributor (iii)Ignition coil(iv)Condenser (v) Ignition switch (vi) Dynamo and (vii) Storage battery.

(1) Spark plug

Spark plug ignites the air –fuel mixture in combustion chamber. It is a device for the high voltage current to jump and ignite the charge. Each spark plug consists of a threaded outer shell with an outside electrode, insulator and a copper gasket. The width of the gap between the points of the two electrodes of a spark plug should conform to the manufacturers. If the clearance is too wide, it does not give satisfactory operation. Usually the spark plug gap settings are kept between 0.5 and 0.85 mm. The higher the compression pressure, the more difficult it is for the current to jump the gap. In this case, the gap setting should be closer. In adjusting the spark plug gap, it is always the outer electrode that is bent. The central electrode is never bent, otherwise the porcelain insulator may break. Sometimes, one or more cylinders of a tractor engine do not fire, or fire irregularly. This is generally due to dirty, cracked or ground plugs. A rich mixture causes carbon deposits on the plugs. Under all circumstances, the plugs should be taken out and cleaned properly.

The heat range of the spark plug is determined by the distance the heat must travel from the lower most tip of the central electrode to the engine block (via) the spark plug gasket. The farther the heat travels, the hotter the plug will run. Based on this, the spark plugs classified into two types: (a) cold plug and (b) hot plug. **Cold plug** has a short insulator, extending into the cylinder. It conducts the heat away from the point rapidly, allowing it to be cooled by the cylinder jacket. The short path dissipates heat quickly, so it is named as cold plug. Cold plugs are used on petrol engines. **Hot plug** has comparatively longer insulator, so the heat has to pass through a longer path to reach the cooling water and hence the heat is not dissipated quickly. Hot plugs are used for powerine engines.

Distributor

This is a rotary switch driven by the engine through gears at half the engine speed. This device used for interrupting the low voltage primary current and distributing the resulting high voltage current to the engine cylinder in proper sequence and in proper time.

The main functions of distributor are:

(i) it closes and opens the primary circuit.

(ii) it distributes the resulting high voltage current to the engine cylinder in proper sequence and in proper time.

Distributor cap is made of Bakelite or similar non-conducting material. High-tension cables connect the terminals in the distributor cap to the spark plug.

Ignition coil

It serves the purpose of a small transformer, which sets up low voltage (may be 6 volts) to very high voltage (may be 20,000 volts). It is necessary to jump the gap of the spark plug. The ignition coil is sealed to prevent entry of moisture which would cause short circuiting within the coil.

Condenser

A condenser consists of a pair of flat metal plates, separated by air. The most common type of condenser is of metal foil strips, separated by wax impregnated paper. The condenser in the distributor is connected across the contact breaker points. It is used to produce a quick collapse of the magnetic field in the coil to obtain extremely high voltage. In doing so, the condenser prevents sparking across the contact breaker points, thus preventing the points from burning.

Ignition switch

A switch is provided in the primary circuit for starting and stopping the engine is called ignition switch. It may be push pull type or key type.

Dynamo

The purpose of the dynamo is to keep the battery charged and to supply current for ignition, light and other electrical accessories. The dynamo supplies direct current to the battery and keeps it fully charged.

Storage battery

Storage battery is a device for converting chemical energy into electrical energy. There are several types of battery, but lead-acid battery is most common for IC engines, used for tractors and automobiles. A battery consists of plates, separators, electrolyte, container and terminal wire.

Plates are of two types: (i) positive and (ii) negative. All positive and negative plates are rectangular in shape. All positive plates are connected together to form a positive group and negative plates are connected together to form a negative group. Positive plates are made of lead and antimony and negative plates are made of spongy lead. Separators are used to act as insulators between the plates to prevent them from touching each other to avoid short-circuiting. Usually separators are made of wood, rubber and cellulose fibre. Electrolyte is the chemical solution used in battery for chemical reaction. It consists of 35% sulphuric acid and 65% distilled water by weight with a specific gravity of 1.280 in fully charged condition. The specific gravity is measured by hydrometer. The electrolyte level should be 12 to 14 mm above the top edge of the plates. Specific gravity of the electrolyte should be checked at suitable interval. If the specific gravity is below 1.225, it should be charged. Container is usually made of hard rubber. The tops are covered with rubber material and sealed with a water proof compound. Terminal wires are two in number, one connects the positive terminal and other connects the negative terminal with the electric circuit.

5.3 Power transmission system

Transmission is a speed reducing mechanism, equipped with several gears (Fig.11). It may be called a sequence of gears and shafts, through which the engine power is transmitted to the tractor wheels. The system consists of various devices that cause forward and backward movement of tractor to suit different field condition. The complete path of power from the engine to the wheels is called *power train.*

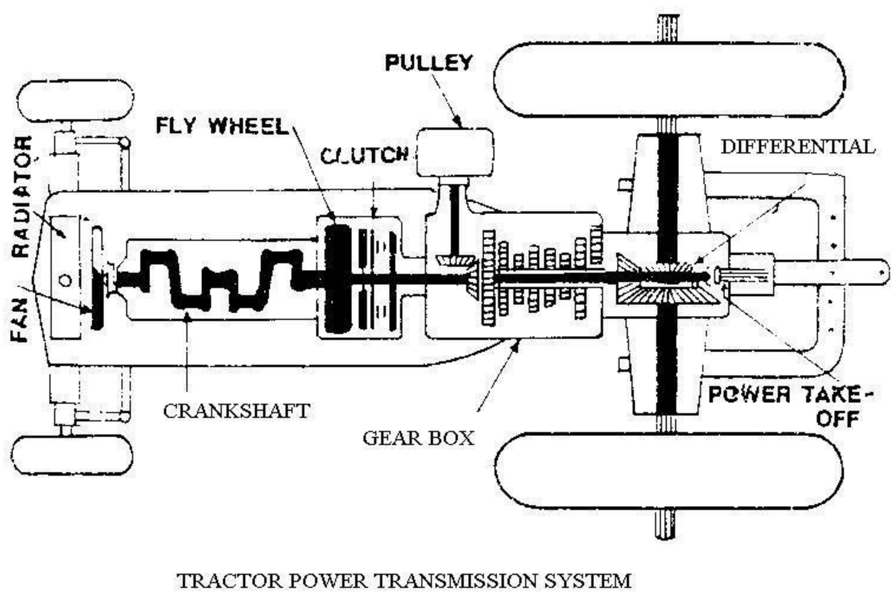


Fig. 11. Power transmission system of tractor

5.3.1 Function of power transmission system

(i) to transmit power from the engine to the rear wheels of the tractor.

(ii) to make reduced speed available, to rear wheels of the tractor.

(iii) to alter the ratio of wheel speed and engine speed in order to suit the field conditions.

(iv) to transmit power through right angle drive, because the crankshaft and rear axle are normally at right angles to each other.

The power transmission system consists of: (a) clutch, (b) transmission gears (c) differential, (d) final drive, (e) rear axle, (f) rear wheels. Combination of all these components is responsible for transmission of power.

5.3.2 Clutch

Clutch is a device, used to connect and disconnect the tractor engine from the transmission gears and drive wheels. Clutch transmits power by means of friction between driving members and driven members.

Necessity of clutch in a tractor

Clutch in a tractor is essential for the following reasons:

(i) Engine needs cranking by any suitable device. For easy cranking, the engine is disconnected from the rest of the transmission unit by a suitable clutch. After starting the engine, the clutch is engaged to transmit power from the engine to the gear box.

(ii) In order to change the gears, the gear box must be kept free from the engine power, otherwise the gear teeth will be damaged and engagement of gear will not be perfect. This work is done by a clutch.

(iii) When the belt pulley of the tractor works in the field it needs to be stopped without stopping the engine. This is done by a clutch.

Essential features of a good clutch

(i) It should have good ability of taking load without dragging and chattering.

(ii) It should have higher capacity to transmit maximum power without slipping.

(iii) Friction surface should be highly resistant to heat effect.

(iv) The control by hand lever or pedal lever should be easy.

Types of clutch

Clutches are mainly of three types:

(1) Friction clutch (2) Dog clutch (3) Fluid coupling.

Friction clutch (Fig.12) is most popular in four wheel tractors. Fluid clutch is also used in some tractors these days. Dog clutch is mostly used in power tillers. Friction clutch may be subdivided into three classes: (a) Single plate clutch or single disc clutch (b) Multiple plate clutch or multiple disc clutch (c) Cone clutch.

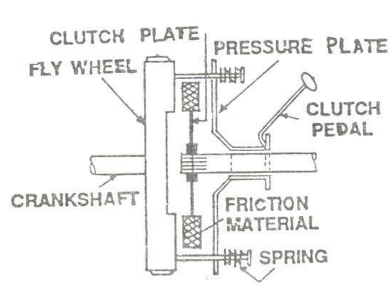


Fig. 12. Single plate clutch

5.3.3 Gears

Speed varies according to the field requirements and so a number of gear ratios are provided to suit the varying conditions. Gears are usually made of alloy steels. As the tractor has to transmit heavy torque all the time, best quality lubricants free from sediments, grit, alkali and moisture, is used for lubrication purpose. SAE 90 oil is generally recommended for gear box.

5.3.4 Differential

Differential unit (Fig.13) is a special arrangement of gears to permit one of the rear wheels of the tractor to rotate slower or faster than other. While turning the tractor on a curve path, the inner wheel has to travel lesser distance than the outer wheel. The inner wheel requires lesser power than the outer wheel, this condition is fulfilled by differential unit, which permits one of the rear wheels of the tractor to move faster than the other at the turning point.

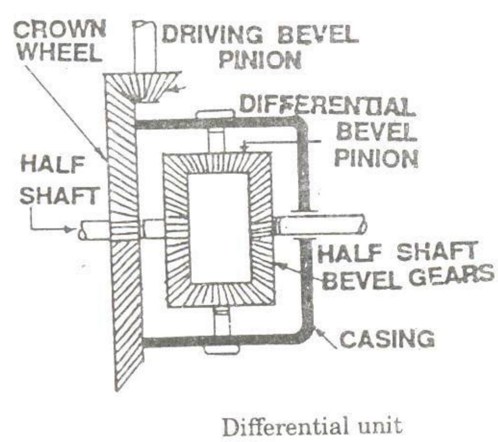


Fig.13. Tractor differential unit

5.3.5 Differential lock

Differential lock is a device to join both half axles of the tractor so that even if one wheel is under less resistance, the tractor comes out from the mud etc as both wheels move with the same speed and apply equal traction.

5.3.6 Final drive

Final drive is a rear reduction unit in the *power trains* between the *differential* and *drive wheels.*

Lecture No.6

Lubrication system of I.C. engine – types, purpose, components and their functions, working principle of forced feed system. Tractors classification, types, points to be considered in selection of tractors, estimating the cost of operation of tractor power.

6.1 Lubrication System

IC Engine is made of many moving parts. Due to continuous movement of two metallic surfaces over each other, there is wearing of moving parts, generation of heat and loss of power in the engine. Lubrication of moving parts is essential to prevent all these harmful effects.

6.2 Purpose of lubrication

Lubrication of the moving parts of an IC Engine performs the following functions:

(i) Reduces the wear and prevents seizure of rubbing surfaces (Reduce wear)

(ii) Reduces the power needed to overcome the frictional resistance (Reduce frictional effect).

(iii) moves the heat from the piston and other parts (Cooling effect)

(iv) rves as a seat between piston rings and cylinder (Sealing effect)

(v) emoves the foreign material between the engine working parts (Cleaning effect)

Reducing frictional effect

The primary purpose of the lubrication is to reduce friction and wear between two rubbing surfaces. The continuous friction produces heat which causes wearing of parts and loss of power. This can be avoided by proper lubrication, which forms an oil film between two moving surfaces.

Cooling effect

The heat generated by piston, cylinder and bearings is removed by lubrication to a great extent. Lubrication creates cooling effect on the engine parts.

Sealing effect

The lubricant enters into the gap between the cylinder liner, piston and piston rings. Thus, it prevents leakage of gases from the engine cylinder.

Cleaning effect

Lubrication keeps the engine clean by removing dirt or carbon from inside of the engine along with the oil.

6.3 Types of Lubricants

Lubricants are obtained from animal fat, vegetables and minerals. Lubricants made of animal fat, does not stand much heat. It becomes waxy and gummy which is not very suitable for machines. **Vegetable lubricants** are obtained from seeds, fruits and plants. Cotton seed oil, Olive oil, linseed oil and Castor oil are used as lubricant in small simple machines. **Mineral lubricants** are most popular for engines and machines. It is obtained from crude petroleum found in nature. Petroleum lubricants are less expensive and suitable for IC Engines.

6.4 Engine lubricating system

The lubricating system of an engine is an arrangement of mechanism and **devices** which maintains supply of lubricating oil to the rubbing surface of an engine at correct pressure and temperature. The parts which require lubrication are: (i) cylinder walls and piston, (ii) piston pin (iii) crankshaft and connecting rod bearings (iv) cam shaft bearings (v) valves and valve operating mechanism (vi) cooling fan (vii) water pump and (viii) ignition mechanism. There are three common systems of lubrication used on stationery engines, tractor engines and automobiles: (i) splash system, (ii) forced feed system, and (iii) combination of splash and forced feed system.

6.3.1 Forced feed system

In this system, the oil is pumped directly to all the moving parts (i.e., crankshaft, connecting rod, piston pin, timing gears and cam shaft) of the engine through suitable paths of oil (Fig.14). Lubricating oil pump is a positive displacement pump, usually **gear or vane type**, which is driven by the camshaft, forces oil from the crankcase to all crankshaft, and connecting rod bearings, cam shaft bearings and timing gears. Usually the oil first enters the main gallery, which may be a pipe or a channel in the crankcase casting. From this pipe, it passes to each of the main bearings through holes. From main bearings, it passes to big end bearings of connecting rod through drilled holes in the crankshaft. From there, it passes to lubricate the walls, pistons and rings. There is separate oil gallery to lubricate timing gears. The oil also passes to valve stem and rocker arm shaft under pressure through an oil gallery. The excess oil comes back from the cylinder head to the crankcase. The pump discharges oil into oil pipes, oil galleries or ducts, leading to different parts of the engine. The system is commonly used on high speed multi-cylinder engine in tractors, trucks and automobiles.

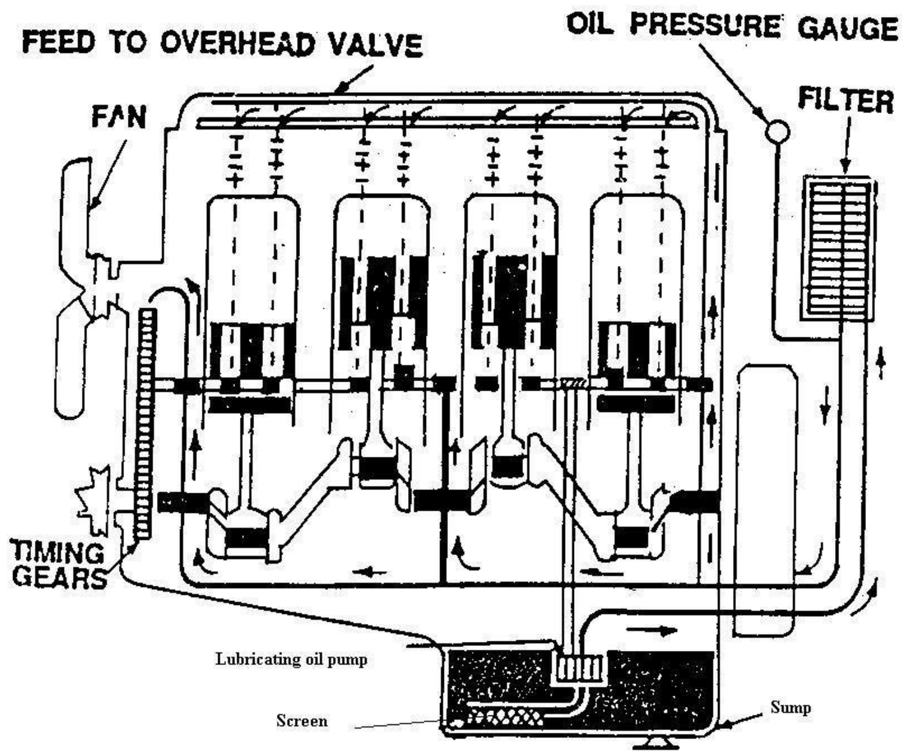


Fig. 14. Working of forced circulation lubrication system

Components

Oil Pump

It is usually a gear type pump, used to force oil into the oil pipe. The pump is driven by the camshaft of the engine. The lower end of the pump extends down into the crankcase, which is covered with a screen to check foreign particles. A portion of the oil is forced to the oil filter and the remaining oil goes to lubricate various parts of the engine. An oil pressure gauge fitted in the line, indicates the oil pressure in the lubricating system. About 3 kg/cm^2 pressure is developed in the lubrication system of a tractor engine.

Oil filters

Lubricating oil in an engine becomes contaminated with various materials such as dirt, metal particles and carbon. An oil filter removes all the dirty elements of the oil in an effective way. It is a type of strainer using cloth, paper, felt, wire screen or similar elements. Some oil filters can be cleaned by washing, but in general old filters are replaced by new filters at specified interval of time. It is normally changed after about 120 hours of engine operation. Oil filters are of two types: (i) full-flow filter, and (ii) by-pass filter

Full flow filter

In this filter, the entire quantity of oil is forced to circulate through it before it enters the engine. A spring loaded valve is usually fitted in the filter as a protection device against oil starvation in case of filter getting clogged.

By pass filter

By pass filters take a small portion of oil from the pump and return the filtered oil into the sump. Over a period of operation, all the oil in the crankcase passes through the filter. Through the filter, the balance oil reaches directly to the engine parts.

Crankcase breather

The engine crankcase is always fitted with some kind of breather, connecting the space above the oil level with the outside atmosphere. During the operation of engine, the crankcase oil reaches a temperature of 160-170°F or even more and simultaneously the air above it gets heated up. Consequently the air is likely to expand and cause pressure rise if it were unable to escape. The purpose of breather is to prevent building up pressure in the crankcase. It serves as ventilating passage of air.

Relief valve

It is provided to control the quantity of oil circulation and to maintain correct pressure in the lubricating system.

6.4 Farm tractor

Tractor is a self propelled power unit having wheels or tracks for operating agricultural implements and machines including trailers. Tractor engine is used as a prime mover for active tools and stationary farm machinery through power take-off shaft (PTO) or belt pulley.

6.4.1 Tractor development

The present tractor is the result of gradual development of machine in different stages. History of tractor development is given below in chronological order.

1890: The word *tractor* appeared first on record in a patent issued on a *tractor* or *tractor engine* invented by George H.Harris of Chicago.

1906: Successful gasoline tractor was introduced by Charles W. Hart and Charles H. Parr of Charles city, Iowa (48A).

1920-1924: All purpose tractor was developed.

1936-1937: Diesel engine was used in tractor and pneumatic tires were introduced.

1960-61: Tractor manufacturing was started in India by first manufacturer M/s Eicher Good Earth.

1971: Escorts tractor Ltd started producing *ford* tractor.

1982 Universal tractors were established.

6.4.2 Classification and selection of tractors

Classification

Tractors can be classified into three classes on the basis of structural design:

(i) Wheel tractor (ii) Crawler tractor (track type or chain type) and (iii) Walking tractor (power tiller).

(i) **Wheel tractor:** Tractors, having three of four pneumatic wheels are called *wheel tractors*. Four wheel tractors are most popular every where.

(ii) Crawler tractor: This is also called *track type tractor or chain type tractor*. In such tractors, there is endless chain or track in place of pneumatic wheels.

(iii) Power tiller: Power tiller is a walking type tractor. This tractor is usually fitted with two wheels only. The direction of travel and its control for field operation is performed by the operator, walking behind the tractor.

On the basis of purpose, wheeled tractor is classified into three groups: General purpose (b) Row crop and (c) Special purpose.

(a) General purpose tractor: It is used for major farm operations such as ploughing, harrowing, sowing, harvesting and transporting work. Such tractors have (i) low ground clearance (ii) increased engine power (iii) good adhesion and (iv) wide tyres.

(b) Row crop tractors: It is mainly designed to work in rows like planting, interculture etc. Such tractor is provided with replaceable driving wheels of different thread widths. It has high ground clearance to save damage of crops. Wide wheel track can be adjusted to suit inter row distance.

(c) Orchard tractors: These are special type of tractors, are mainly used in orchards. Such tractors have (i) less weight (ii) less width and (iii) no projected parts.

(d) Special purpose tractor: It is used for definite jobs like cotton fields, marshy land, hill sides, garden etc. Special designs are there for special purpose tractor.

6.4.3 Tractor components

A tractor is made of following main components: (1) I.C. engine (2) Clutch (3) Transmission gears (4) Differential units (5) Final drive (6) Rear or wheels (7) Front wheels (8) Steering mechanism (9) Hydraulic control and hitch system (10) Brakes (11) Power take-off unit (12) Tractor pulley and (13) Control panel.

6.4.4 lection of tractor

(i) Land holding: Under a single cropping pattern, it is normally recommended to consider 1hp for every 2 hectares of land. In other words, one tractor of 20-25 hp is suitable for 40 hectares farm.

(ii) Cropping pattern: Generally 1.5 hectare/hp has been recommended where adequate irrigation facilities are available and more than one crop is taken. So a 30-35 hp tractor is suitable for 40 hectares farm.

(iii) Soil condition: A tractor with less wheel base, higher ground clearance and low overall weight may work successfully in lighter soil but it will not be able to give sufficient depth in black cotton soil.

(iv) Climatic conditions: For very hot zone and desert area, air cooled engines are preferred over water cooled engines. Similarly for higher altitude, air cooled engines are preferred because water is liable to be frozen at higher altitude.

(v) Repairing facilities: It should be ensured that the tractor to be purchased has a dealer at nearby place with all the technical skills for repair and maintenance of machine.

(vi) Running cost: Tractors with less specific fuel consumption should be preferred over others so that running cost may be less.

(vii) Initial cost and resale value: While keeping the resale value in mind, the initial cost should not be very high, otherwise higher amount of interest will have to be paid.

(viii) Test report: Test report of tractors released from farm machinery testing stations should be consulted for guidance.

6.4.5 Estimating the cost of tractor power

The cost of operation of tractor is divided under two heads known as *Fixed cost* and *Operating cost*.

Fixed cost includes: (i) Depreciation, (ii) Interest on the capital, (iii) Housing, (iv) Insurance and (v) Taxes.

Operating cost includes: (i) Fuel, (ii) Lubricants, (iii) Repairs and maintenance, and (iv) Wages.

Fixed cost

Depreciation: It is the loss of value of a machine with the passing of time.

$$D = \frac{C - S}{L \times H}$$

Where

D is the depreciation per year

C is the capital investment

S is the salvage value, 10% of capital

H is the number of working hours per year and

L is the life of machine in years

Interest: Interest is calculated on the average investment of the tractor taking into consideration the value of the tractor in first and last year.

$$I = \frac{C + S}{2} \times \frac{i}{H}$$

Where

I is the interest per hour

I is the % rate of interest per year

Housing: Housing cost is calculated on the basis of the prevailing rates in the locality. In general, it may be taken as 1% of the initial cost of the tractor per year.

Insurance: Insurance charge is calculated on the basis of the actual payment to the insurance company. In general, it may be taken as 1% of the initial cost of the tractor per year.

Taxes: Taxes is calculated on the basis of the actual taxes paid per year. In general, it may be taken as 1% of the initial cost of the tractor per year.

Operating cost

Fuel cost: It is calculated on the basis of actual fuel consumption in the tractor.

Lubricants: Charges for lubricants should be calculated on the actual consumption. In general, it may be takes 30 to 35% of the fuel cost.

Repairs and maintenance: It varies between 5 to 10% of the initial cost of the tractor per year.

Wages: It is calculated on the basis of actual wages of the driver.

Problem 1:

Calculate the cost of operation of a 35 HP tractor per hour and hp hour. Initial cost is Rs. 5,50,000-00, life of the tractor is 12 years, number of working hours are 1200 per year, interest on the capital is 10%, cost of the diesel is Rs. 40/- per litre, fuel consumption is 5 litres per hour, wages of the driver is Rs. 36,000/-, lubricants cost is 35% of the fuel cost, repairs and replacements is 10% of initial cost; housing, taxes and insurance is 1.5% each of the initial cost.

Solution

Data given: C = Rs. 5,50,000/-

L = 12 years

H = 1200 hours er year

i = 10%

Cost of diesel = Rs.40/- per litre

Fuel consumption = 5 litres/hour

Wages of the driver = Rs. 36,000/- per annum

Lubricants cost = 35% of fuel cost.

Repairs and replacements cost = 10% of initial cost

Housing, taxes and insurance = 1.5% each of the initial cost

Fixed cost

Depreciation

$D = \frac{C - S}{L \times H} = \frac{550000 - 0}{12 \times 1200}$ = Rs. 38.19 per hour

(Since salvage value is not given, hence it is taken as “0”)

Interest

$$I = \frac{C+S}{2} \times \frac{i}{H}$$

I = $\frac{550000+0}{2} \times \frac{10}{100} \times \frac{1}{1200}$ = Rs. 22.92 per hour

Housing cost

H = $\frac{1.5}{100} \times 550000 \times \frac{1}{1200}$ = 6.87 per hour

Similarly, Insurance is Rs. 6.87 and Taxes are Rs. 6.87 per hour

Total fixed cost per hour = 38.19+22.92+6.87+6.87+6.87 = Rs. 81.72

Operating cost

Fuel cost = 40 ×5 = Rs. 200.00 per hour

Lubricants cost = $\frac{35}{100} \times 200$ = Rs. 70.00 per hour

Repairs and replacements cost = $\frac{10}{100} \times 550000 \times \frac{1}{1200}$ = Rs. 45.83

Wages = $\frac{36000}{1200}$ = Rs. 30.00

Total operating cost per hour = 200+70+45.83+30 = Rs. 345.83

Total cost of operation per hour = Total fixed cost + Total operating cost

= 81.72 + 345.83 = Rs. 427.55

Total cost of operation per hp per hour = $\frac{427.55}{35}$ = Rs. 12.22

Lecture No.7

Tillage - primary and secondary tillage. M.B. plough – functions, constructional features, operational adjustments and maintenance.

7.1 Tillage

It is a mechanical manipulation of soil to provide favourable condition for crop production. Soil tillage consists of breaking the compact surface of earth to a certain depth and to loosen the soil mass, so as to enable the roots of the crops to penetrate and spread into the soil. Tillage may be called the practice of modifying the state of soil to provide favourable conditions for plant growth. Tillage operation is most labour consuming and difficult operation, compared to all subsequent operation in the field.

7.2 Objective of tillage

1. to obtain deep seed bed, suitable for different type of crops.
2. to add more humus and fertility to soil by covering the vegetation.
3. to destroy and prevent weeds.
4. to aerate the soil for proper growth of crops.
5. to increase water absorbing capacity of the soil.
6. to destroy the insects, pests and their breeding places and
7. to reduce the soil erosion.

7.3 Classification and types of tillage

Tillage is divided into two classes: 1. Primary tillage, 2. Secondary tillage

7.3.1 Primary tillage: It constitutes the initial major soil working operation. It is normally designed to reduce soil strength, cover plant materials, and rearrange aggregates. The operations performed to open up any cultivable land with a view to prepare a seed bed for growing crops in known as Primary tillage. Implements may be tractor drawn or animal drawn implements. Animal drawn implements mostly include indigenous plough and mould-board plough. Tractor drawn implements include mould-board plough, disc plough, subsoil plough, chisel plough and other similar implements.

7.3.2 Secondary tillage: Tillage operations following primary tillage which are performed to crease proper soil tilth for seeding and planting are Secondary tillage. These are lighter and finer operations, performed on the soil after primary tillage operations. Secondary tillage consists of conditioning the soil to meet the different tillage objectives of the farm. The implements used for secondary tillage operations are called Secondary tillage implements. They include different types of harrow, cultivators, levelers, cited crushers and similar implements. These operations are generally done on the surface soil of the farm. Seconday tillage operations do not cause much soil inversion and shifting of soil from one place to other. These operations consume less power per unit area compared to primary tillage operations. Secondary tillage implements may be tractor drawn or bullock drawn implements. Bullock drawn implements include harrows, cultivators, hoes etc.

7.4 Indigenous plough

Indigenous plough is one of the most common implements used by Indian farmers. There are about 40 or more different types of indigenous ploughs in this country which are basically the same, but with variations in their shape, size and weight. These variations are due to soil types and tillage requirements of various crops.

In addition to ploughing, the plough is used for sowing crops like wheat, barley, gram etc., for interculture and for harvesting the underground part of crops.

The main parts of the plough are i) body ii) shoe iii) share iv) beam and v) handle. The body is the main part of the plough to which the shoe, beam and handle are generally attached. The share is the working part of the plough, and is attached to the shoe, which penetrates into the soil and breaks it open. The shoe also helps in stabilizing and balancing the plough while in operation. The beam is generally a long wooden piece which connects the main body of the plough to the yoke. A wooden piece which is attached vertically to the body to enable the operator to control the plough is called the handle.

7.4.1 Ploughing by indigenous plough

When the plough is pulled forward, the shoe and share enter the soil and separate the furrow slice from the main body of the soil. A portion of the soil rides over the shoe, but the larger portion is pushed aside to both sides. After the plough has moved ahead leaving the furrow behind, some of the cut soil falls back into the furrow. It has been observed that an indigenous plough cuts a trapezoidal furrow cross section and leaves some unploughed land between the two adjacent furrows. To plough almost every bit of soil in the field, an indigenous plough has to be used three times. This is the main reason for the high energy and time requirements in using an indigenous plough as compared to other types. For complete and through ploughing of a field, the indigenous plough must be operated three times: first ploughing, then cross ploughing and finally ploughing along the corners.

7.4 Mould board plough

A mouldboard plough is very common implement used for primer tillage operations. This plough performs several functions at a time such as (1) Cutting the furrow slice (2) Lifting the furrow slice (3) turning the furrow slice (4) Pulverizing the soil.

7.4.1 Components

M.B. Plough consists of (a) Share, (b) Mould Board, (c) Landside and (d) Frog (Fig.15).

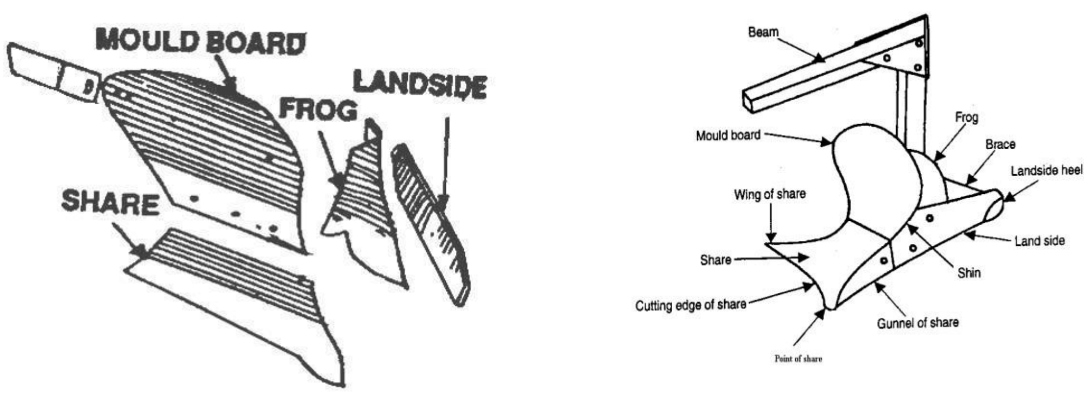


Fig. 15. Components of mould board plough

Share

It is the part of the plough bottom (Fig.16), that penetrates into the soil and cut the soil in horizontal direction below the soil surface is called share. It is a sharp, well polished and pointed component.

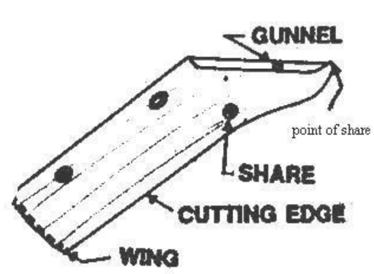


Fig.16. Parts of share

Different portions of the share are called by different names such as (I) share point, (ii) cutting edge, (iii) wing of the share (iv) gunnel (v) clevage edge.

The forward end of the cutting edge which actually penetrates into the soil is called share point.

The front edge of the share which makes horizontal cut in the soil is called cutting edge if the share.

The outer end of the cutting edge of the share is called wing of the share. It supports the plough bottom.

The vertical face of the share which slides along the furrow well is called gunnel. It takes the side thrust of the soil and supports the plough bottom against the furrow wall.

The edge of the share which forms joint between mould board and share on the frog. The shares are made of chilled cast iron or steel. The steel mainly contains about 0.7-0.8% carbon and about 0.5-0.8% manganese besides other minor elements.

Types of share

Share is of different such as (a) slip share (b) slip nose share (c) shin share (d) bar share and (e) bar point share (Fig.17).

a) Slip share: it is one piece with curved cutting edge having no additional part. It is a common type of share, mostly used by the farmers. It is simple in design, but it has got the disadvantage that the entire share has to be replaced if it is worn out due to constant use.

b) Slip nose share: it is a share in which the point of the share is provided by a small detachable piece. It has the advantage that the share point can be replaced as and when required . If the point is worn out, it can be changed without replacing the entire share, effecting considerable economy.

c) Shin share: it is a share, having a shin as an additional part. It is similar to the slip share with the difference that an extension is provided to fit by the side of the mould board. This prevents the mouldboard from wearing along its cutting edge.

d) Bar share : It is provided with an extension on its gunnel side which acts as the landside of the plough bottom. It does not offer any advantage over the other types.

e) Bar point share: it is a share, in which the point of the share is provided by an adjustable and replaceable bar. This bar serves the purpose of point of the share and landside of the plough. As the point wears out, it is pushed forward.

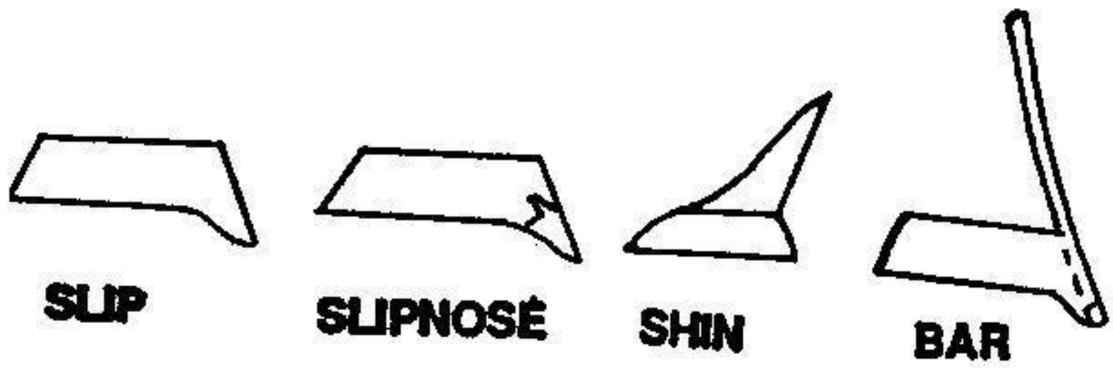


Fig.17. Types of share

Mould Board

Mould board is the part of the plough, which receives the furrow slice from the share, it lifted, turns and breaks the furrow slice. Different soil conditions require mould boards of varying shapes and sizes to carryout a good job of ploughing. The texture of the soil, amount of moisture and extent of vegetative cover on the surface determine the soil pulverization. The pulverization and inversion depend upon the curvature of the mouldboard. A long, gradual curved mouldboard turns the furrow gently and does not break the soil much. Short, abruptly curved mould boards twist and shear the soil and pulverize it. Mouldboards for general use fall between the two extremes of the conditions. Mould boards are made of cast iron.

The mould board is of following types (Fig.18): (i) General purpose (ii) stubble (iii) sod and breaker (iv) slat and (v) high speed.

(i) General purpose mould board

It is the best for all round general farm use to give through pulverization. It is a mould board having medium curvature lying between stubble and sod. The sloping of the surface is gradual. It turns the well-defined furrow slice and pulverizes the soil thoroughly. It has a fairly long mould board with a gradual twist, the surface being slightly convex.

(ii) Stubble mould board

It is adopted for ploughing an old ground where good pulverization is desired. Its curvature is not gradual, **but it is abrupt along the top edge**. This causes the furrow slice to be thrown off quickly, pulverization is much better than the other type of mould board. It is best suited in stubble soil i. e under cultivation for years together. Stubble soil is that, soil in which stubble of the plants from the previous crop is still left on the land at the time of ploughing. This type of mould board is not suitable for lands with full of grasses.

(iii) Sod and breaker type mould board

It is a long mould board with gentle curvature which lifts and inverts the furrow slice. It is used in tough soils of grasses. It turns over thickly covered soil. This is very useful where complete inversion of soil is required by the farmer. This type has been designed for use in sod soils.

(iv) lat type mould board

It is a mould board whose surface is made of slats placed along the length of the mould board, so that there are gaps between the slats. This type of mould board is often used, where the soil is sticky, because the solid mould board does not score well in sticky soils.

(v) High speed type mould board

Most of the high speed bottoms are used on tractor ploughs for general farm use.

Land side

Landside is the part of the plough bottom, which **slides** along the furrow wall, providing stability against tilting sideways, due to soil pressure acting on the mould board.

The width of the landside of animal drawn plough varies between 5 and 10 cm. It also helps in stabilizing the plough while in operation. Landside fastened to the frog with the help of plough bolts. The rear bottom of the landside is known as heal which rubs against the furrow sole.

Frog

Frog is the part of the plough bottom to which the share, mould board and land side are attached rigidly. It is an irregular piece of metal casting and heart of the plough bottom. It may be made of either cast iron or steel.

7.4.2 Plough accessories: there are few accessories are necessary for plough such as: (a) coulter, (ii) jointer and (iii) gauge wheel (Fig.19).

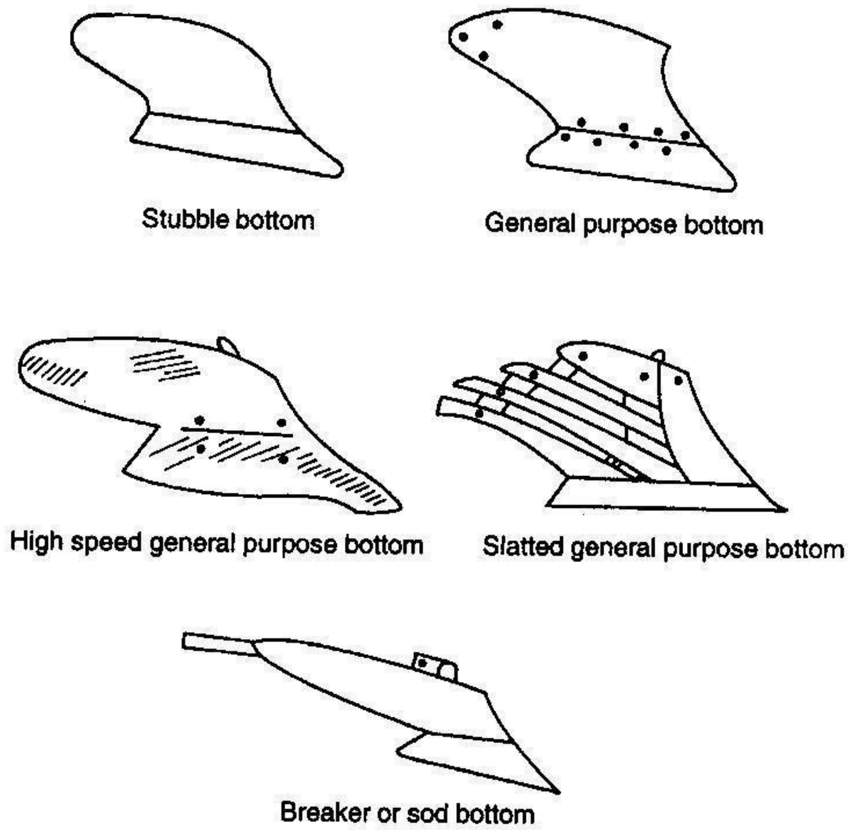


Fig.18. Types of mould board

Coulter

It is device used to cut the furrow slice vertically from the land ahead of the plough bottom. It cut the furrow slice from the land and leaves a clear wall. It also cuts trashes which are covered under the soil by the plough. The coulter may be a) rolling type b) sliding type.

(a) Rolling coulter

It is **round steel disc**, used on ploughs to cut trash and help to keep the plough from clogging. In general, the coulters should be set about 5cm shallower than the depth of ploughing. To obtain a neat furrow wall, the coulter is usually set 2 cm outside the landside of the plough. It is so fitted that it can be adjusted up and down and side ways.

(b) Sliding coulter

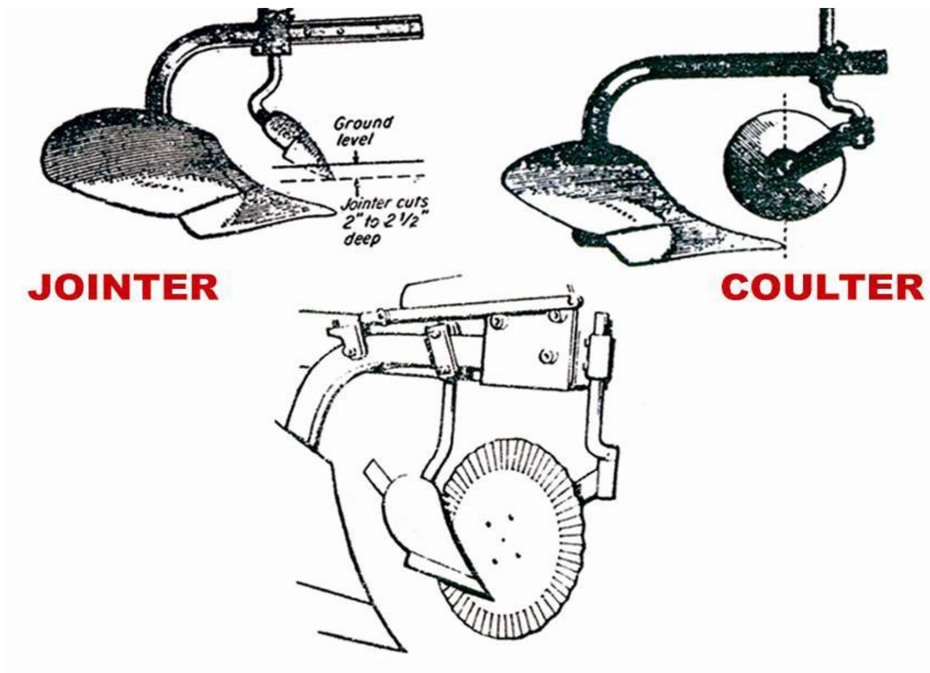
It is a **stationery knife** fixed downward in a vertical position on the ground. It includes knife, which does not roll over the ground but slides on the ground, the knife may be different shapes and sizes.

Jointer

It is a small irregular piece of metal having a shape similar to an ordinary plough bottom. **It looks like a miniature plough**. The jointer should be set to cut 4 to 5 cm deep. The purpose of the jointer is to cut a small furrow off the main furrow slice and throw it towards the furrow. The jointer should be set as near the coulter as possible.

Gauge wheel

It is an auxiliary wheel of an implement**,** helps to maintain uniformity in respect of depth of sloughing in different soil conditions it is usually placed in hanging position.



Throat clearance

Fig. 19. Plough accessories of M.B.Plough

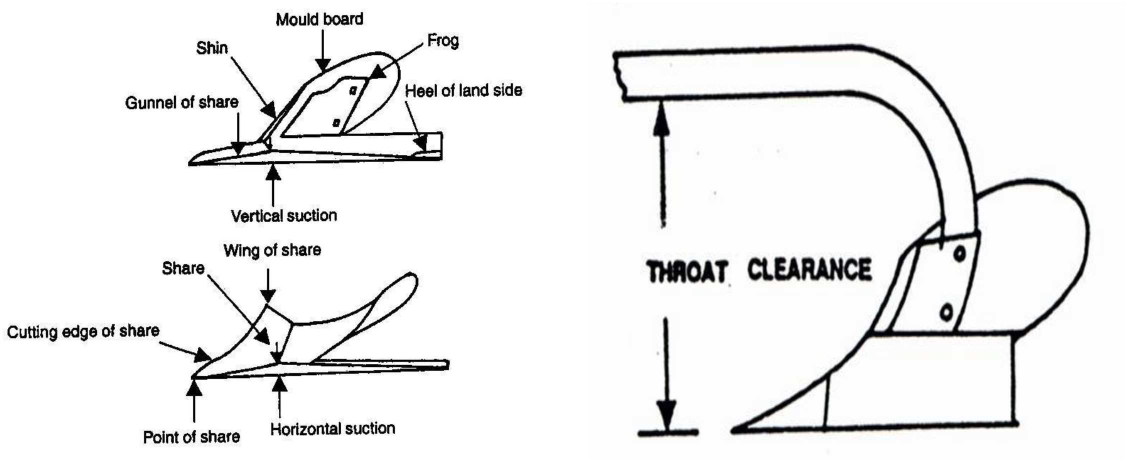
7.5 Adjustments of mould board plough

For proper penetration and efficient work, the mould board ploughs need some clearance where the share joins the landside. This clearance is called suction of the plough. Suction in mould board plough is of two types (Fig.20): (i) Vertical suction and (ii) Horizontal suction.

If a straight edge is placed under the point of the share and the landside, a clearance of 0.3 to 0.5 cm should be measured. It is known as the vertical suction of the plough. Similarly, there should be side clearance of about 0.5 cm in such ploughs. Side clearance is also known as horizontal suction of the plough. If the share worn out, these clearances are vary much reduced, with the result that, the plough does not penetrate properly into the soil.

Throat clearance

It is the perpendicular distance between point of share and lower position of the beam of the plough.



(a) (b)

Fig.20. (a) Vertical suction, horizontal suction and (b) throat clearance of M.B.Plough

Plough size

The size of mould board is expressed by the width of furrow that is designed to cut. It is the perpendicular distance from the wing of the share to the line joining the point of share and the heel of the landside. Animal drawn ploughs are usually available in the range between 15 and 20 cm. The size of the light plough is above 100 mm width but below 150 mm; medium plough is 150 to 200 mm and heavy plough is 200 mm and above.

Vertical clevis: it is a vertical plate with a no of holes at the end of the beam to control the depth of operation and to adjust the line of pull.

Horizontal clevis: it is a device to make the lateral adjustment of the plough relative to the line of pull.

The centre of pull or resistance: It is the point where all the forces on a plough are act. The centre lies at a distance equal to ¾th size of the plough from wing of the share.

Lecture No.8

Disc plough – functions, constructional details, operational adjustments and maintenance.

8.1 Disc ploughs

It is a plough (Fig.21) which cuts, turns and in some cases breaks furrow slices by means of separately mounted large steel discs. A disc plough is designed with a view to reduce friction by making a rolling plough bottom. A disc plough works well in the conditions where mould board plough does not work satisfactorily.

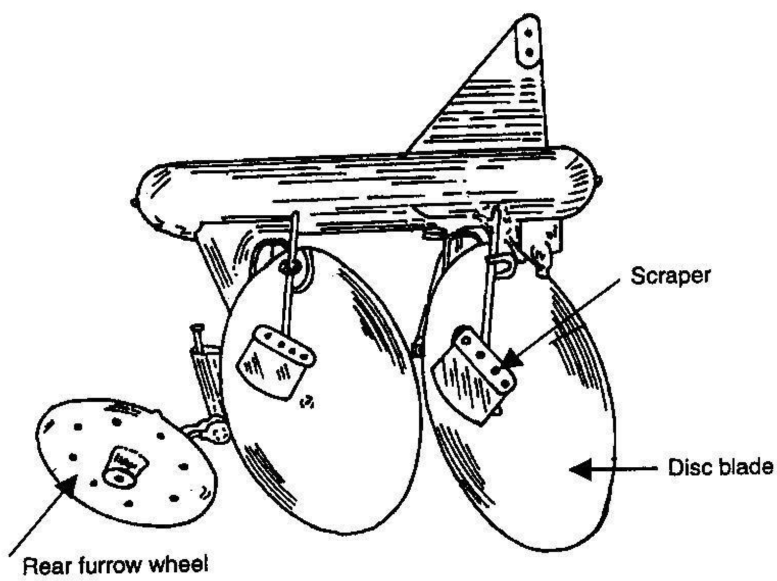


Fig. 21. Parts of disc plough

8.2 Advantages of disc plough

(i) A disc plough can be forced to penetrate into the soil which is too hard and dry.

(ii) It works well in sticky soil in which a mould board plough does not scour. It is more useful for deep ploughing.

(iii) It can be used safely in stony and stumpy soil without much danger of breakage.

(iv) A disc plough works well even after a considerable part of a disc is worn off in abrasive soil.

(v) It works in loose soil also (such as peat) without much clogging.

8.3 Disadvantages of disc plough

(i) It is not suitable for covering surface trash and weeds affectively as mould board plough does.

(ii) Comparatively, the disc plough leaves the soil in rough and cloddy condition than that of mould board plough.

(iii) Disc plough is much heavier than mould board plough for equal capacities because penetration of this plough is affected largely by its weight rather than suction. There is one significant difference between mould board plough and disc plough i.e., mould board plough forced into the ground by the suction of the plough, while the disc plough is forced into the ground by its own weight.

Disc: It is a circular, concave revolving steel plate used for cutting and inverting the soil. It is made of heat treated steel of 5 to 10 mm thickness. The edge of the disc is well sharpened to cut the soil.

Disc angle: It is the angle at which the plane of the cutting edge of the disc is inclined to the direction of travel. Usually, the disc angle of good plough varies between 42 and 45^0 (Fig.22).

Tilt angle: It is the angle at which the plane of the cutting edge of the disc is inclined to vertical plane. Usually, the tilt angle of good plough varies between 15 and 25^0(Fig.22).

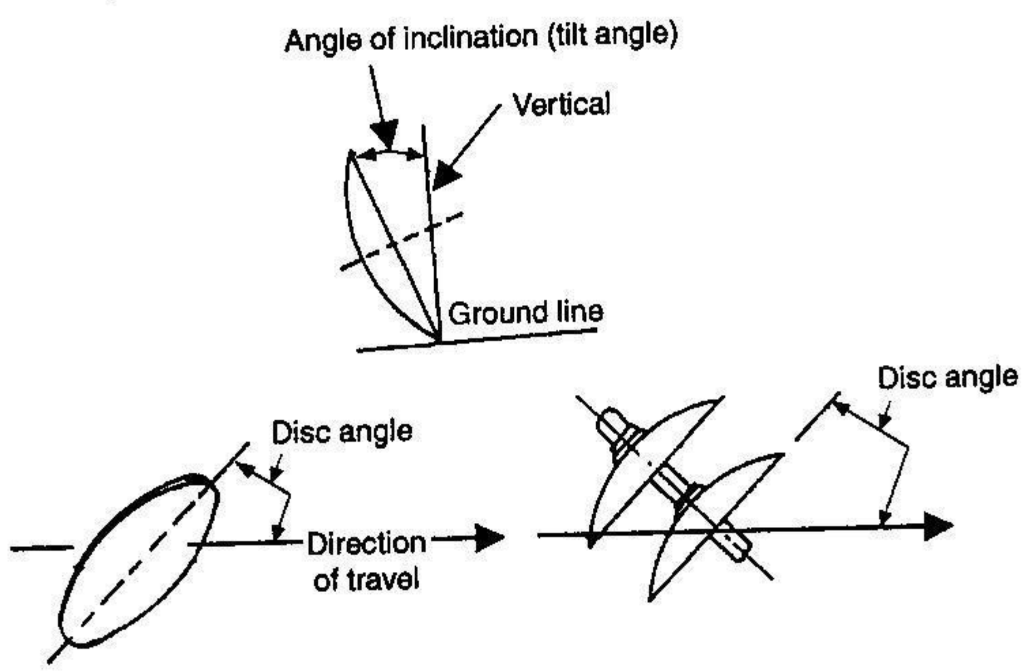


Fig. 22. Tilt angle and disc angle of disc plough

Scraper: It is a device to remove soil that tends to stick to the working surface of a disc.

Concavity: It is the depth measured at the center of the disc by placing its concave side on a flat surface.

Disc ploughs are favoured in areas where the climate is dry and where the soil is rough and stony. They also work well in heavy clay, hard pan and loose sandy soils. Such soil conditions do not permit the operation of mould board ploughs to good advantage. It is also preferred for land infested with heavy growth of vegetation and for land requiring deep ploughing for reclamation purposes. It leaves the trash on top of the ground to conserve soil moisture. Penetration of the disc plough depends mainly on the weight of the plough as a whole. Tractor drawn disk ploughs weigh between **180 and 540 kg** per disk. But the animal drawn plough weighs about 30 kg per disk.

Disc ploughs are broadly classified as:

1. Standard disc plough - animal drawn and tractor drawn
2. Vertical disc plough or harrow ploughs

8.4 Animal drawn standard disc plough

It is attached to a universal frame which is mounted on two wheels. The frame is pulled by a pair of bullocks and it is provided with a seat for the operator. There is only one disk blade on these ploughs and it can be tilted back ward from 15 to 25^0 (tilt angle) in the vertical plane. It also makes an angle of about 45^0 (disk angle) with the direction of motion. The diameter of the disk is 45 cm. A rear furrow wheel provided with the plough takes care of the side thrust of the plough.

8.3.1 Tractor drawn standard disc plough

It consists of **one to seven** disk blades which have the same tilt and disk angles as the animal drawn plough. The diameter of the disk blades varies between **60 and 90 cm.** The perfectly round concave steel disks sharpened on the edges are bolted to the cast iron supports which are individually suspended from the main frame. Taper roller bearings or thrust type ball bearings are used on the ploughs. These ploughs are provided with a front furrow wheel, a rear furrow wheel and a land wheel. There are also provided with depth adjusting levers, drag links and scrapers on the plough. When the plough is pulled forward, the individual disk rotates on its own axis. The furrow slice rides along the curvature and is pulverized to some extent. In order to cut a deeper furrow slice, the tilt angle of the disk is reduced. The other method of increasing the penetration is by adding weights to the plough frame. If the soil condition is favourable, the tilt angle should be increased to achieve better turning of the furrow slice. If the soil condition is not favourable, the disk angle should be increased to improve the penetration, but the width of cut should be reduced (Fig.23).

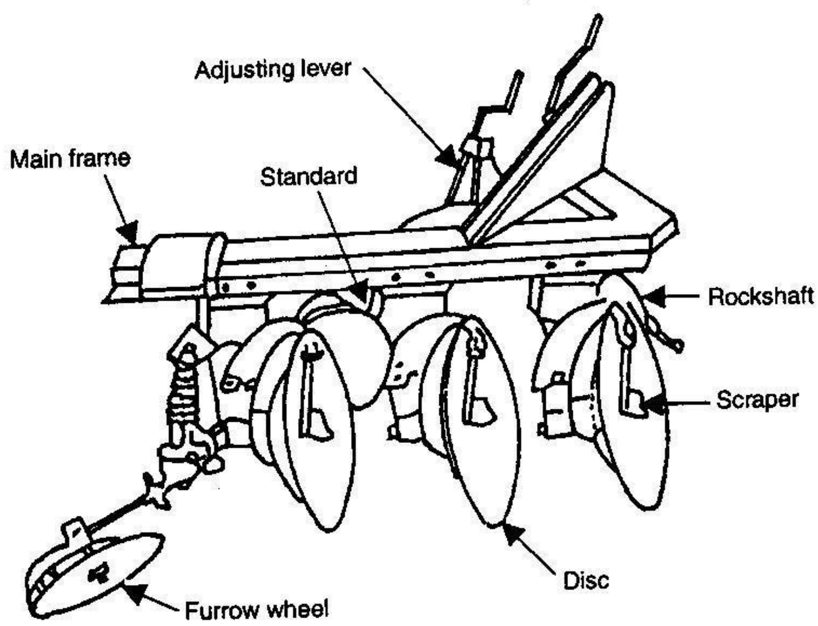


Fig. 23. Standard disc plough

8.4 Vertical disk plough

It is known as harrow plough or one way disc plough. Its action is intermediate between regular disc plough and disc harrow. It is similar to standard disk plough, major difference is that, all the disk blades are mounted on a common axle and they rotate as one unit. The diameter & curvature of the individual disk of the plough is slightly smaller. All the disks are fixed to throw the furrow slice is only one direction. It may have **2 to 32** disks, spaced about 20 to 25 cm apart on a gang. These are used for shallow ploughing and are preferred in wheat growing areas, where moisture conservation for winter crops is the main objective. Diameter of the disk varies between **50 and 65** cm and the disk angle ranges from 40 to 45^0. Disc angle of 40 to 45° gives the minimum draft for a given width of cut (Fig.24).

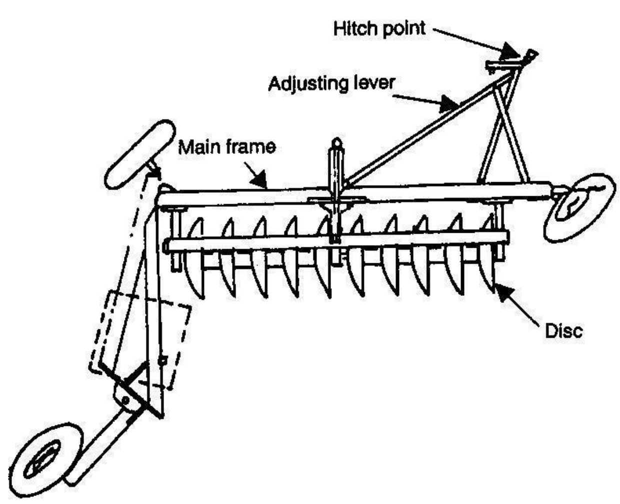


Fig. 24. Vertical disc plough

The following adjustments that are done on the disk ploughs to control the depth or width of ploughing or to increase the pulverization:

(i) by increasing the tilt angle, penetration is improved.

(ii) by increasing the disk angle, penetration is improved but the width of cut is reduced.

(iii) by adding weights to the plough, penetration can be increased.

(iv) the width of the cut by the plough may be adjusted by adjusting the angle between the frame and land wheel axle.

Lecture No.9

Numerical problems on M.B. plough and disc plough.

Draft: It is the horizontal component of the pull parallel to the line of motion.

Metric hp = $\frac{Draft \times speed}{75}$

Where draft in kg

Speed in m/s

Draft depends upon: (1) sharpness of cutting edge, (2) working speed, (3) working width, (4) working depth, (5) type of implement, (6) soil condition, and (7) attachments.

Unit draft: It is the draft per unit cross-sectional area of the furrow.

Theoretical field capacity: It is the rate of field coverage of the implement, based on 100 percent of time at the rated speed and covering 100 percent of its rated width.

Theoretical field capacity = $\frac{W \times S \times 36}{10000}$

Where, Theoretical field capacity in ha/hr

W is the width of cut of machine in cm

S is the speed of travel in m/s

Effective field capacity (C): It is the actual area covered by the implement based on its total time consumed and its width.

C = $\frac{S \times W}{10} \times \frac{E}{100}$

Where C is the effective field capacity, ha/hr

S is the speed of travel in kmph

W is the theoretical width of cut of the machine in m

E is the field efficiency in percent

Field efficiency: It is the ratio of effective field capacity and theoretical field capacity expressed in percent.

Problem 1: Determine the horse power required to pull a four bottom 32 cm plough, working to depth of 14 cm. The tractor is operating at a speed of 5.5 kmph. The soil resistance is 0.8 kg/cm^2.

Solution:

Total width of ploughing = 32×4 = 128 cm

Furrow cross section = 128 ×14 = 1792 cm^2

Total draft = soil resistance × furrow cross section

= 0.8 × 1792 = 1433.6 kg

HP = $\frac{Draft \times speed}{75} = \frac{1433.6 \times 5.5 \times 1000}{75 \times 3600} = 29.2$

Problem 2: Calculate the area covered per day of 8 hours by a tractor drawn four bottom 35cm plough if the speed of the ploughing is 5kmph, the time lost in turning is 10%.

Solution:

Area covered per hour = $\frac{4 \times 35}{100} \times 5 \times 1000$ = 7000 m^2

Area to be covered in 8 hrs = 7000×8 = 56,000 m^2 = $\frac{560000}{10,000}$ **= 5.6 ha**

Turning loss = $\frac{5.6 \times 10}{100}$ **= 0.56 ha**

Actual area covered in 8 hrs = 5.6 – 0.56 = 5.04 ha

Problem 3: Calculate the size of a tractor to pull a four bottom 35 cm MB plough through a depth of 8 cm. The soil resistance is 0.8 kg/cm^2. The speed of the tractor is 5.5 kmph, transmission and tractive efficiency of the tractor being 80% and 30% respectively.

Solution:

Furrow cross section = $4 \times 35 \times 8$ = 1120 cm^2

Total draft = 1120 ×0.8 = 896 kg

HP = $\frac{896 \times 5.5 \times 1000}{75 \times 3600} \times \frac{1}{0.8} \times \frac{1}{0.3} = 76$

Problem 4: Total draft of four bottom, 35 cm MB plough when ploughing 18 cm deep at 5 kmph speed is 1600 kg. (a) Calculate the unit draft in kg/cm^2 (b) What is actual power requirement? (c) If the field efficiency is 75% what is the rate of doing work in ha/hr.

Solution:

Unit draft = $\dfrac{1600}{4 \times 35 \times 18}$ = 0.635 kg/cm^2

HP requirement= $\dfrac{1600 \times 5 \times 1000}{75 \times 3600}$ = 29.6

C = $\dfrac{S \times W}{10} \times \dfrac{E}{100}$

Where C is the effective field capacity, ha/hr

S is the speed of travel in kmph

W is the theoretical width of cut of the machine in m

E is the field efficiency in percent

Area covered per hr i.e., C = $\left(\dfrac{5 \times 4 \times 35}{10 \times 100}\right) \times \dfrac{75}{100} = 0.525$ ha/hr

Lecture No.10

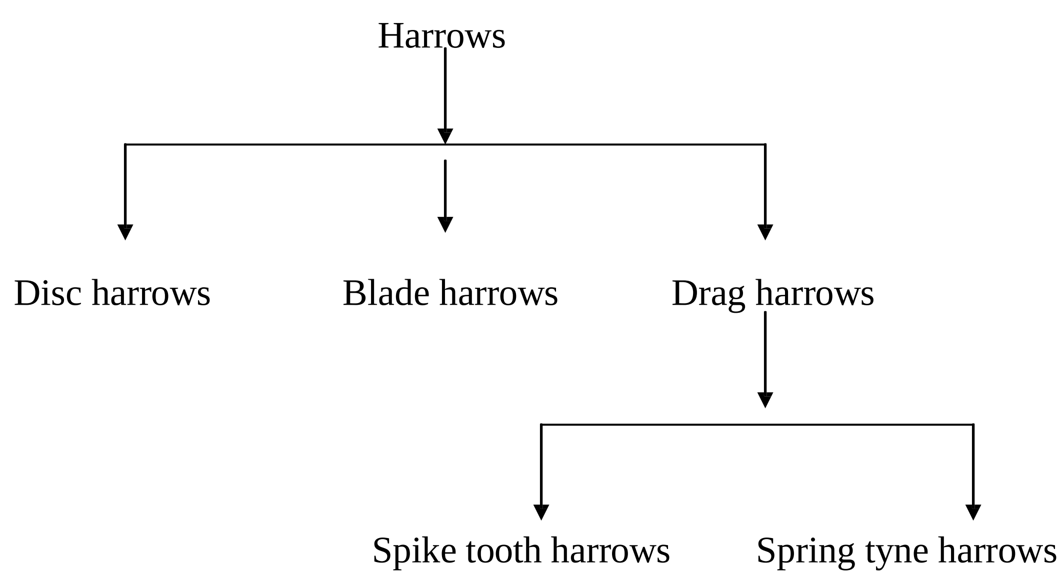
Harrows – types, functions, operation of disc harrows. Cultivators – rigid and spring loaded tynes. Puddlers, cage wheel, rotovators. Intercultural implements – hoes and weeders for dry and wetland cultivation.

10.1 Harrowing

It is secondary tillage operation which pulverizes, smoothens and packs the soil in seed bed preparation and/or to control weeds.

10.2 Harrow

A harrow is a implement that cuts the soil to a shallow depth for smoothening and pulverizing the soil as well as to cut the weeds and to mix materials with soil. It is an implement used to break the clods after ploughing, to collect trash from the ploughed land and to level the seed bed.There are several types of harrows used in India are mentioned below:



10.3 Disc harrow

It is harrow which performs the harrowing operations by means of a set (or a number of sets) of rotating steel discs, each set being mounted on a common shaft. Disc harrows are of two types depending upon the sources of power:

1. Tractor drawn
2. Animal drawn.

Tractor drawn disc harrow: Disc harrow is found very suitable for hard ground, full of stalks and grasses. It cuts the lumps of soil, clods and roots. Discs are mounted on one, two or more axles which may be set at a variable angle to the line of motion. As the harrow is pulled ahead, the discs rotate on the ground. Depending upon the disc arrangements, disc harrows are divided into two classes (Fig.25): (i) single action, and (ii) double action.

Single action disc harrow

It is a harrow with two gangs placed end to end, which throw the soil in opposite directions. The discs are arranged in such a way that right side gang throws the soil towards right, and left side gang throws the soil towards left.

Double action disc harrow

A disc harrow consisting of two or more gangs, in which a set of one or two gangs follow behind the set of the other one or two, arranged in such a way that the front and back gangs throw the soil in opposite directions. Thus the entire field is worked twice in each trip. It may be of two types:

(i) Tandem, and

(ii) Off-set.

Tandem disc harrow

It is a disc harrow comprising of four gangs in which each gang can be angled in opposite direction.

Off-set disc harrow

It is a disc harrow with two gangs in tandem, capable of being off-set to either side of the centre line of pull. Two gangs are fitted one behind the other. The soil is thrown in both directions because discs of both gangs face in opposite directions. It is very useful for orchards and gardens. It travels left or right of the tractor. The line of pull is not in the middle, that‟s why it is called off-set disc harrow (Fig.25).

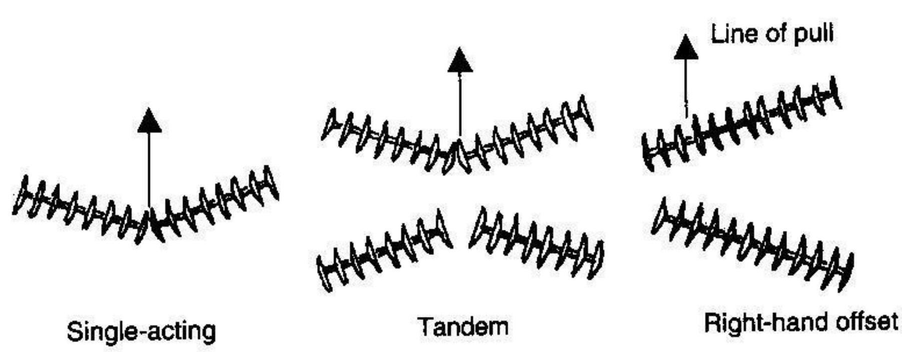


Fig. 25. Tractor drawn disc harrows

10.4 Components of disc harrow

A disc harrow mainly consists of: (i) disc, (ii) gang, (iii) gang bolt or arbor bolt, (iv) gang angle, (v) gang control lever, (vi) spools or spacer, (vii) bearings, (viii) transport wheels, (ix) scraper and (x) weight box.

1. Disc: It is a circular, concave revolving steel plate used for cutting and inverting the soil. Disc is made of high grade heat treated hardened steel. Tractor drawn disc harrows have concave discs of size varying from 35 to 70 cm diameter. Concavity of the disc affects penetration and pulverization of soil. Usually two types of disc are used in disc harrows: (a) Plain disc and (b) Cut-away disc.

Plain discs have plain edges and they are used for all normal works. Most of the harrows are fitted with plain discs only. Cut-away discs have serrated edges and they cut stalks, grasses and other vegetative matter better than plain discs. Cut-away discs are not very effective for pulverization of soil but it is very useful for pudding the field especially for paddy cultivation.

2.Gang: It is an assembly of concave discs mounted on a common shaft with spools in between.

3. Gang axle or arbor axle: It is a shaft on which a set of discs are mounted. The spacing between the discs on the gang bolt ranges from 15cm to 23cm for light duty harrows and 25 to 30 cm for heavy duty harrows.

4. Gang angle: The angle between the axis of the gang and the line perpendicular to the direction of travel is called *Gang angle.*

5. Gang control lever: A lever which operates the angling mechanism of disc harrow is called *Gang control lever.*

6. Spool or Spacer: The flanged tube, mounted on the gang axle between every two discs to retain them at fixed position laterally on the shaft is called spool or spacer. It is just a device for keeping the discs at equal spacing on the axle. It is usually cast in special shapes and sizes and is generally made of cast iron.

7. Bearing: Bearing is essential to counteract the end thrust of the gangs due to soil thrust. Disc harrow bearings are subjected to heavy radial and thrust loads. Chilled cast iron bearings, ball bearings or tapered roller bearings may be used on disc harrows. Oil soaked wooden bearings are very common for disc harrows, because they are cheaply available. Chilled cast iron bearings are also used due to their durability.

8. Transport wheel: In trailing type discs harrows, transport wheels are provided for transport work on roads and for preventing the damage of the roads. This also helps in protecting the edges of the discs. Mounted type disc harrows do not require wheels for transport purpose.

9. Scraper: Scraper prevents the discs from clogging. It removes the soil that may stick to the concave side of the disc.

10. Weight box: A box like frame is provided on the main frame of the harrow for putting additional weight on the implement. Additional weight helps in increasing the penetration of the discs in the soil.

Penetration of disc harrow

There are several factors which affect the penetration of disc harrow in the field. If the disc gangs are set perpendicular to the line of draft, the penetration is not adequate. Penetration can be increased by adding some additional weight on the frame of the harrow. For obtaining maximum penetration, the gangs should be set with the forward edges of the disc parallel to the direction of motion. If the hitch point is lowered, better penetration is achieved.

A sharp edged disc has more effective penetration compared to blunt edged disc. It is observed that penetration is better in low speed than in high speed. In short, the following are a few adjustments for obtaining higher penetration.

1. By increasing the disc angle.
2. By adding additional weight on the harrow.
3. By lowering the hitch point.
4. By using sharp edged discs of small diameter and lesser concavity and
5. By regulating the optimum speed.

10.5 Care and maintenance of disc harrow

Bearing must be thoroughly greased at regular intervals. All the nuts and bolts must be checked daily before taking the implement to the field. Blunt edges of the discs should be sharpened regularly. During slack season, the worn parts including bearings should be fully replaced. It is better to coat the outer and inner surfaces of the discs when the harrow is lying without use in slack season.

10.6 Animal drawn disc harrow: It consists of: (i) disc, (ii) gang frame, (iii) beam, (iv) gang angle mechanism, (v) scraper, (vi) spacer(spool), (vii) clevis, (viii) axle, (ix) middle tyne, and (x) bearings (Fig.26).

1. Disc: Disc is the main part of the harrow which cuts and pulverizes the soil. Discs are arranged in two gangs. The thickness of the material used for disc is at least 3.15 nm. The cutting edge is beveled for easy penetration. The disc has a square opening in the centre to allow the passage of the axle. The disc is usually made of steel with carbon content ranging from 0.80 to 0.90%.

2. Gang frame: All the gangs are mounted on a frame, called Gang frame. It is usually made of sturdy mild steel structure. The gang frame is bolted to the beam of the implement.

3. Beam: It is that part of the harrow which connects the implement with the yoke. The rear end of the beam has a clevis to fix its height of hitching to suit the size of animals. It is made of wood which is locally available in the area.

4. Gang angle mechanism: It is a mechanism by means of which the gang angles are adjusted. Arranged of adjusted the width and depth of cuts of the implement, is done by gang mechanism. The lever of the gang angle is usually made of mild steel flat with a wooden handle. The gang angle can be adjusted approximately in the range from 0^o to 27^o only.

5. Scraper: It is that part of the harrow which scrapes the soil from the concave side of the disc and keeps it clean for effective working of the harrow in the field.

6. Spacer (spool): Spacer is used to separate the two adjacent discs and to keep them in position. It is usually made of cast iron. The spacer has a suitable square opening in the middle to allow the passage of the axle.

7. Clevis: Clevis is the part fitted to the beam and the frame which permits vertical hitching of the harrow.

8. Axle: The axle is usually 20 × 20 mm square section. The length of axis depends upon the size of the harrow.

9. Middle tyne: The tyne which breaks the unbroken strip of soil left in between two gangs of the harrow during operation is called middle tyne. This tyne is suitable fixed to the rear end of the gang frame in such a way that it is replaced easily.

10. Bearing: There is one or two bearings, made of cast iron or wood fitted at each end of the gang.

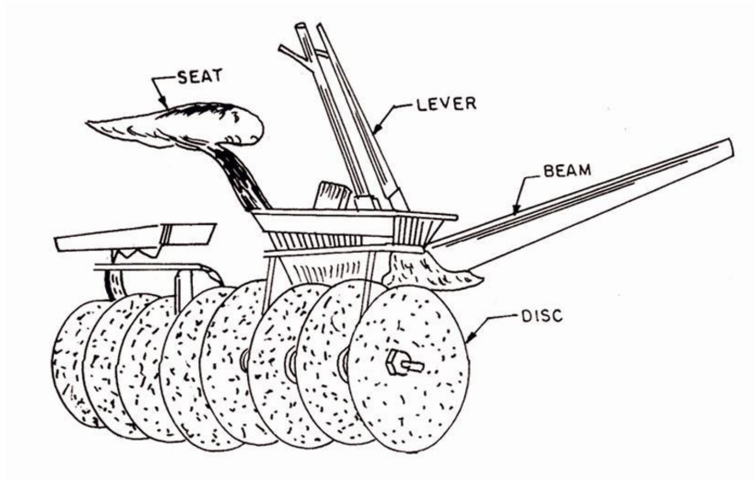


Fig.26. Animal drawn disc harrow

10.7 Drag harrows

Drag harrows have been used since ancient times; early farmers used to cut branches from the trees for use in leveling the soil. Even today in some places farmers drag long bamboo pieces with long nails to break the soil crust and stir the surface. These harrows are used to break the clods, to stir the soil, to uproot the early weeds, to level the ground, to break the soil crust and to cover the seeds. There are two principal kinds of drag harrows, namely, (1) spike tooth and (2) spring type harrow.

Spike tooth harrows are either rigid or flexible. The flexible type tractor drawn can be rolled up for transporting. But the animal drawn harrows are always of rigid frame type. There may or may not be provision for changing the angle of the spikes while operating the harrow. The basic frame of the harrow may be triangle (Fig.27). It has pointed steel pegs (teeth) about 23 cm long with their pointed ends towards ground. Each peg is rigidly clamped with the help of a U-bolt to the cross bars of the frame. In the case of harrows with a wooden frame, the pegs have threatened ends to be tightened from the top. Generally the wooden frame is triangular in shape, and the pegs are fixed along the three arms of the frame. Before operating the harrow in the field, adjustments should be made for efficient and effective operation. The peg point is tilted backward vertically so that soil is not accumulated in the front. The pegs of the rigid harrows are fixed slightly tilted so that no arrangement is needed to change the angle. The harrow is dragged over the surface by means of a chain or rope tied to the yoke. The animal drawn harrows cover almost 1 to 1.2 m width and are used to stir the soil to a depth of about 5 cm. The depth of penetration can be increased by adding weights to the frame.

Spring tyne tractor drawn harrows have looping, elliptical or spring like tynes. But the animal drawn unit is only provided with elliptical tynes. They are used extensively to prepare ploughed land before planting. They penetrate much deeper than spike tooth harrows and are generally used in the soil where obstructions like stones, roots and weeds are hidden a few centimeters below the surface. The basic frame of the harrow is mostly rectangular. The spring tynes are bolted staggered on to the frame to avoid clogging during operation.

Spike tooth and spring tyne harrows do not require lubrication. The harrow teeth, however, are adjustable and may be loosened and turned to present a new cutting edge when they wear out. Teeth may also be removed for sharpening. Spring tyne harrows can be sharpened by grinding. The spikes of the spike tooth harrow are either square or diamond shaped and are of the self sharpening type.

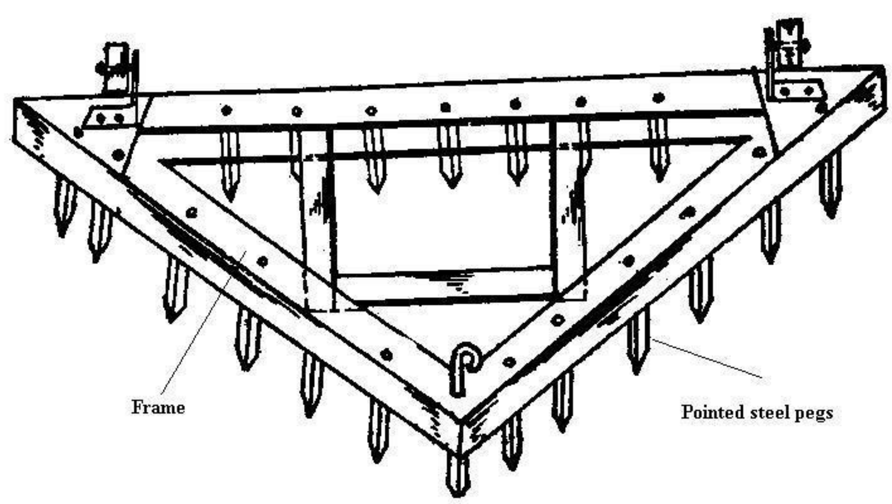


Fig. 27. Peg tooth or triangular harrow

10.6.1 Blade harrows

The blade harrows popularly known as *bakhar,* is the most common type of harrow used by Indian farmers. It is generally used in clay soils for preparing seedbeds of both *kharif* (rainy season) and *Rabi* (winter) crops. It is also used for covering the seed in *Kharif* sowing. The action of blade harrow is like that of sweep, moving into the top surface of the soil without inverting it. Sometimes, it is used to chisel out the uncut portion left after ploughing by an indigenous plough. Thus the primary function of the implement is to pulverize the soil and create soil mulch. The blade is made of steel. *Shisham* or *Babool* wood is used for making the body and the beam. The width cut by the harrow varies from 38 to 105 cm (Fig.28). *Guntaka* also is an improved type of this implement.

Frequent clogging with the roots and weeds which wrap along the edge of blade possess a serious problem and stoppage of work. However, the improved V-shaped blade if fitted on the implement can provide relief from clogging.. Besides, it offers the advantage of reduction in draft, easy penetration and smooth working in the field.

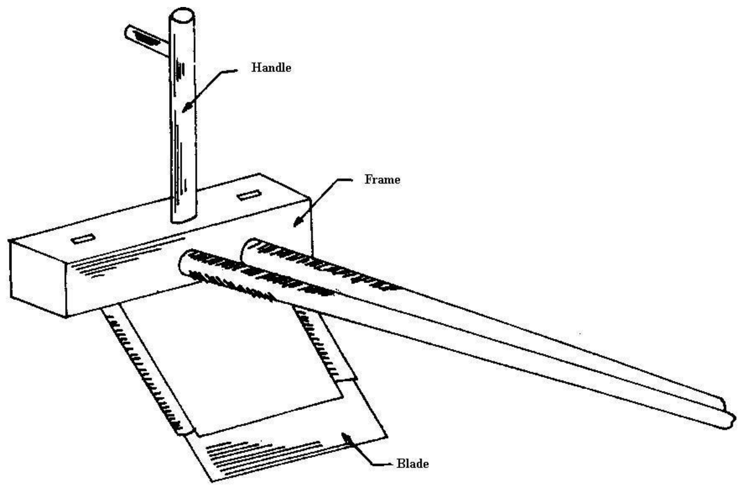


Fig. 28. Blade harrow

10.7 Cultivator

10.7.1 Cultivator with spring loaded tines

A tine hinged to the frame and loaded with a spring so that it swings back when an obstacle is encountered, is called spring loaded tine. Each tine of this cultivator is provided with two heavy coil springs, tensioned to ensure minimum movement except when an obstacle is encountered. The springs operate, when the points strike roots or large stones by allowing the tines to ride over the obstruction, thus preventing damage. On passing over the obstruction, the tines are automatically reset and work continues without interruption. The tines are made of high carbon steel and are held in proper alignment on the main frame members. This type of cultivator is particularly recommended for soils which are embedded with stones or stumps. A pair of gauge wheel is provided on the cultivator for controlling the depth of operation. The cultivator may be fitted with 7, 9, 11, 13 tines or more depending upon the requirement (Fig.29).

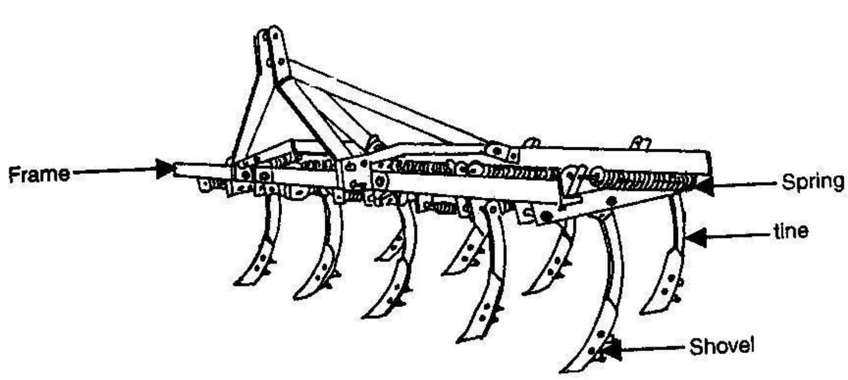


Fig. 29. Cultivator with spring loaded tines

10.7.2 Cultivator with rigid tines

Rigid tines of the cultivator are those tines which do not deflect during the work in the field. The tynes are bolted between angle braces, fastened to the main bars by sturdy clamps and bolts. Spacing of the tines are changed simply by slackening the bolts and sliding the braces to the desired position. Since rigid tines are mounted on the front and rear tool bars, the spacing between the tynes can be easily adjusted without getting the tines chocked with stubbles of the previous crop or weed growth. A pair of gauge wheel is used for controlling the depth of operation (Fig.30).

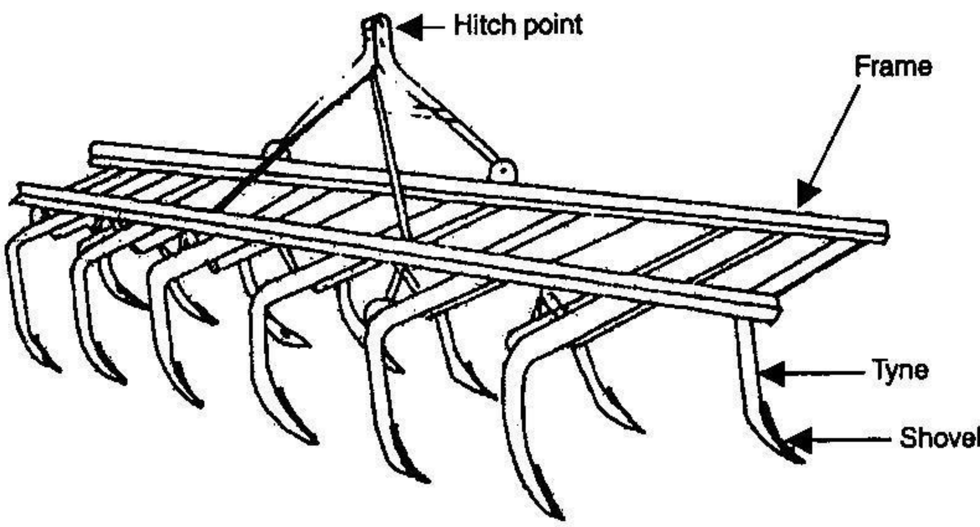


Fig.30. Cultivator with rigid tines

10.8 Puddlers

Puddling of soil is one of the most common farm operations in paddy growing areas. The most desirable soil conditions at the time of transplanting appears to be one having semi-pervious hard pan covered with approximately 10 to 15 cm dense mud and very little free water on the surface.It usually refers to the churning of soil in the presence of excess water by means of a puddler or any other implement for that purpose. Purpose of puddling is to reduce leaching of water, to kill weeds by decomposing and to facilitate the transplanting of paddy seedlings by making the soil softer. It is done in a standing water of 5 to 10 cm depth in the field, which has already received one ploughing by the mould board plough. In some areas, an indigeneous plough is used as a puddler by some farmers.

Puddlers are classified as: (i) hand operated puddlers, (ii) animal drawn puddlers, and (iii) tractor drawn puddlers. Among the various types, animal drawn puddlers are mostly used in the country. The indigenous plough and peg tooth harrow are used for puddling in paddy growing areas. None of these implements are as effective as the rotating blade type puddlers.

The open blade type implement is commonly used for puddling in south India. It consists of series of steel or cast iron blades fastened to a cast iron hub at an angle. The number of cast iron hubs may be two or more. These hubs revolve on a steel shaft to which the wooden beam and the operator‟s seat are attached. Sometimes, these hubs form an integral part of the shaft which revolves either in wooden or metallic bearings at the ends in the frame. This type of implement is generally a walking type. The effective width of the puddler varies between 0.9 and 1.2 m (Fig.31).

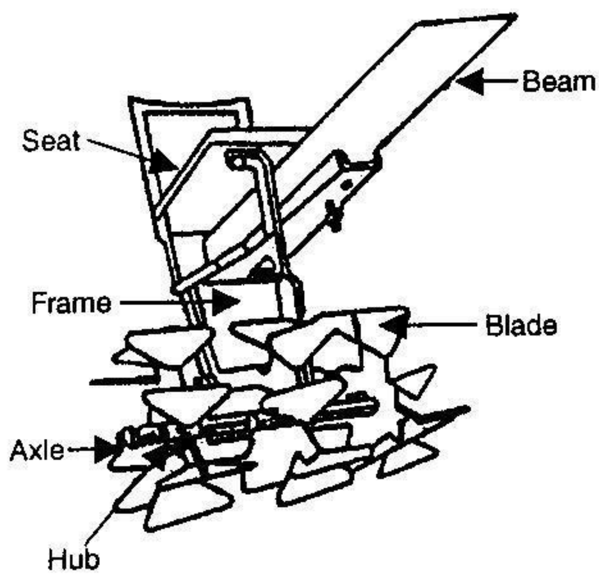


Fig.31. Open blade puddler

There are four classes of tractor drawn puddlers: (i) tine tiller, (ii) rotating blade puddler, (iii) disk harrow and (iv) power rotary tiller. Among these tractor drawn implements, disk harrow and power rotary tiller are in great use.

10.8.1 Cage wheel

It is a wheel or an attachment to a wheel with spaced cross bars for improving the traction of the tractor in a wet field. It is generally used in paddy fields.

10.8.2 Rotavator

It is an implement that cuts and pulverizes the soil by impact forces through a number of rotary times or knives mounted as a horizontal shaft. It is also called „rotary tiller‟. It is suitable for shallow cultivation and weed control. It consists of a power driven shaft on which knives or tines are mounted to cut the soil and trash. Rotor has got several types of tines fitted on the shaft having a speed of 200-300 rpm. Generally, sharp edged L-shaped blades are used on the rotor. According to power used, rotavators are classified as animal-drawn, engine operated and tractor-drawn rotavators. One or two operations of this implement are sufficient for good pulverization of soil depending upon soil and crop conditions. It is not meant for sandy soil. The power from the engine to rotor shaft is transmitted through chain. A clutch is provided in transmission system for engaging and disengaging power. The speed of rotor is kept at about 350 rpm for rated rpm of 1500 of prune mover. The depth of penetration can be adjusted up to 12.5 cm. The suitable protective cover is provided at the rear to prevent under scattering of soil. It can cover about 1.5-2.0 ha/day. Bullock-drawn engine operated rotary tiller is quite useful for timely preparation of seedbed particularly in rice-wheat rotation. Power tiller operated rotary tillers are also quite useful for hilly areas and small hand holdings.

10.8.3 ANGRAU puddler

It is used for preparation of paddy fields with standing water (5-10 cm depth) after initial ploughing. It breaks up the clods and churns the soil. The main purpose of puddling is to reduce leaching of water and to kill weeds. Puddling facilitates transplanting of paddy seedlings. Puddler consists of puddling units each having four paddles (or blades) mounted on an axle, frame, beam, metal-cross and handle (Fig.32). Paddles are made of mild steel sheet having thickness of 3.15 mm. The blades are welded to the metal cross, made of mild steel rounds. The blades with the metal cross are welded to the axle, at an angle of 10° for 30” (750 mm) puddler and 7½° for 40” (1000 mm) puddler. While moving, blades (paddles) churn the soil and mix it properly. The weeds are also chopped and mixed with soil for decomposition. Two to three operations are good enough to get desired puddle soil. The animal-drawn puddler can cover 0.4-0.5 ha/day. According to the power used, puddlers are classified as hand operated, animal-drawn and tractor-drawn puddlers. Animal-drawn puddlers are commonly used in India.

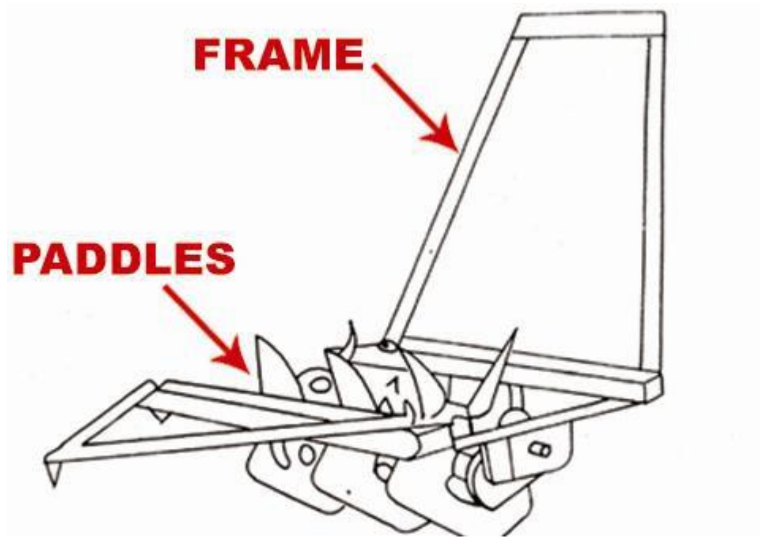


Fig. 32. ANGRAU Puddler

10.9 Intercultural implements

10.9.1 Hand hoe

Mechanical as well as chemical methods are being used to control the weeds during the cultivation of different crops. Number of mechanical tools is available but „khurpa‟ is the most popular weeding tool amongst the small farmers in spite of its low work rate and uncomfortable operating posture. Different types of hand hoes are used in different parts of country depending upon the nature of soil and crop grown. The shape and size of hoe vary-from place to place. A few important hand hoes are khurpa, spade or kudali.

10.9.2 Paddy weeder

It is important equipment for inter-culture used in paddy cultivation. It is used for uprooting weeds and burying them in puddle soil between rows of standing paddy crop. It improves aeration of soil. It consists of frame, weeding roll, the tines, float and handle (Fig. 33). The frame is made of mild steel to which float, front and rear weeding rolls and angle regulator are attached. Weeding roll with fingerlike projections does the weeding operation in water. There are two weeding rolls one to front and other at rear and both are made of mild steel. Float, made of mild steel, is placed in front of weeding roll that helps in maintaining easy sliding motion during operation.

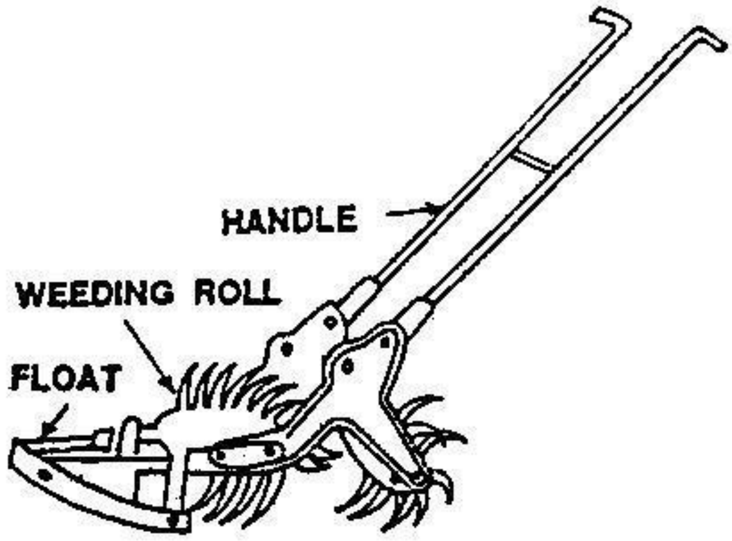


Fig. 33. Paddy weeder

10.9.3 Wheel hoe

It is a hoe with one or two wheels. Wheel hoe is used for intercultural operations in between the rows of crops. There is a wheel attached to the two handles, to which a working tool is attached. Wheel is helpful in guiding the tool and maintaining proper depth. It is useful for kitchen gardens.

Lecture No.11

Sowing equipment - seed cum fertilizer drills – types, functions, types of metering mechanisms, functional components, calibration. Paddy transplanters.

Seeding or sowing is an art of placing seeds in the soil to have good germination in the field.

Seed drill is a machine for placing the seeds in a continuous flow in furrows at uniform rate and at controlled depth with or without the arrangement of covering the seed with soil. Drills are used for sowing seeds in rows at 15-35 cm apart. The seed drill performs the following functions: (i) to carry the seeds, (ii) to open furrow to an uniform depth, (iii) to meter the seeds, (iv) to place the seed in furrows in an acceptable pattern, and (v) to cover the seeds and compact the soil around the seed.

Seed drills, fitted with fertilizer dropping attachment, distribute the fertilizer uniformly on the ground, is called seed cum fertilizer drills. It has a large seed box which is divided length wise into two compartments, one for seeds and another for fertilizers.

11.1 Components of seed drill

A seed drill with mechanical seed metering device mainly consists of: (i) frame, (ii) seed box, (iii) seed metering mechanism, (iv) furrow openers, (v) covering device, and (vi) transport wheels.

Frame. The frame is usually made angle iron with suitable braces and brackets. The frame is strong enough to withstand all types of loads inn working condition.

Seed box. It may be made of mild steel sheet or galvanized iron with a suitable cover. A small agitator is sometimes provided to prevent clogging of seeds.

Covering device. It is a device to refill a furrow after the seed has been placed in it. Covering the seeds are usually done by patta, chains, drags, packers, rollers and press wheels, designed in various sizes and shapes.

Transport wheel. There are two wheels fitted on the main axle. Some seed drills have got pneumatic wheels also. The wheels have suitable attachments to transmit power to operate seed dropping mechanism.

11.2 Seed metering mechanism

The mechanism of a seed drill or fertilizer distributor which deliver seeds or fertilizers from the hopper at selected rates is called Seed metering mechanism. Seed metering mechanism may be of several types: (i) fluted feed type, (ii) internal double run type, (iii) cup feed type, (iv) cell feed mechanism, (v) brush feed mechanism, (vi) auger feed mechanism, (vii) picker wheel mechanism, and (viii) star wheel mechanism.

Most common type of metering devices that delivers a more or less continuous flow of seeds is fluted roller type or internal double run type. These metering devices are driven by ground wheel. Some of above metering devices have not been commercially accepted and popularized.

11.2.1 Fluted feed type seed metering mechanism

The fluted wheel (also known as fluted roller) is driven by a square shaft. Fluted rollers are provided with longitudinal grooves along the outer periphery and can be shifted on the shaft sideways (Fig.34). The size of groove is different for different crops. The fluted rollers are mounted at the bottom of the seed box; receive the seeds into longitudinal grooves and pass on to the seed tube through the seed hole. By shifting the rollers sideways, the length of the groove exposed to the seed, can be increased or decreased and hence the amount of seed sown is changed. The number of rollers on a drill is the same as the number of furrow openers. There is also an adjustable gate on the discharge side of the fluted wheel. The gate opening can be changed to fit the size of the seed. Generally, the speed of the square shaft is constant, but on some drills, the speed of the shaft can also be changed, resulting in a change in the seed rate. The number of flutes on the roller ranges from 8 to 12. This method is favoured for sowing small or medium size seeds. For bold size seeds, this mechanism is not preferred as the seeds are likely to get crushed during metering operation.

Fluted roller is a simple, low cost, trouble free device suitable for bulk metering even for granulated fertilizers. An improved design of the fluted roller has spiral shaped flutes. This design offers a uniform distribution of seeds as compared to straight shaped flutes. However, most of the low cost animal drawn ferti- drills are fitted with straight shaped rollers. It is mostly used for drilling wheat. The fluted feed mechanism is more positive in its metering action than the *Internal double run* method.

11.2.2 Internal double run type seed metering mechanism

It has a double faced wheel; one face has a larger opening for the larger seeds and the other face or side has a smaller opening for use with smaller seeds. A gate is provided in the bottom of the box to cover the opening not in use. When one of the sides is being used, the seed is prevented from flowing through the other side by using a special cover. The discs mounted on a spindle and housing in a casing fitted below the seed box. The rate of seeding is varied by adjusting the speed of the spindle which carries the discs. This mechanism is used for metering bold and small seeds (Fig.35).

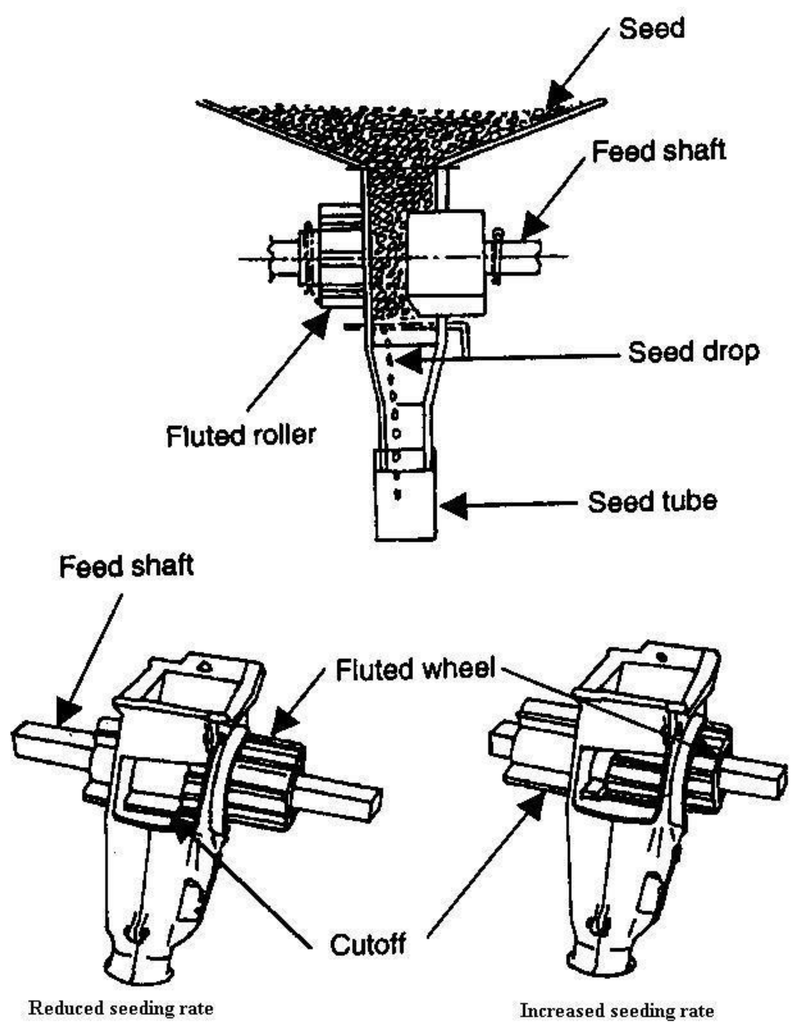
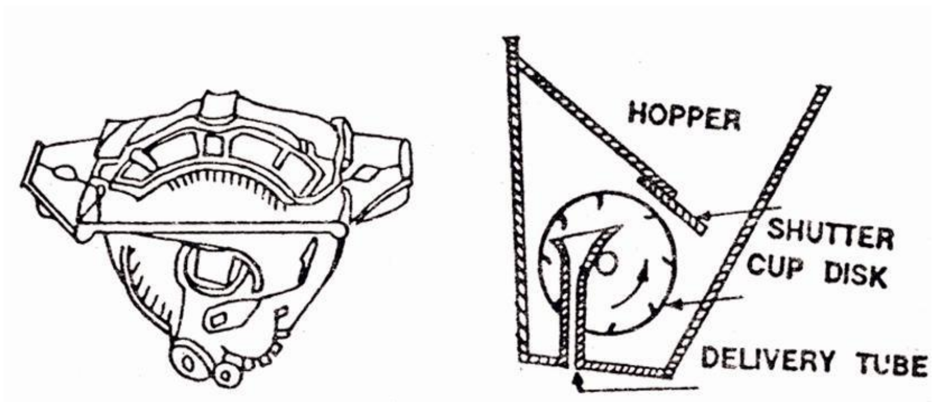


Fig. 34. Fluted roller seed metering mechanism

11.2.3 Cup feed seed metering mechanism

It is a mechanism consisting of cups of spoons on the periphery of a vertical rotating disc which picks up the seeds from the hopper and delivers them into the seed tubes. It consists of a seed hopper which has two parts. The upper one is called *Grain box* and the lower one is called *Feed box*. Shuttles are provided to connect these boxes. The seed delivery mechanism consists of a spindle, carrying a number of discs with a ring of cups attached to the periphery of each disc. The spindle with its frame and attachment is called *Feed barrel.* When the spindle rotates, one disc with its set of cups rotates and picks up few seeds and drops them into small hoppers. The cups have two faces, one for larger seeds and other for smaller seeds. The seed rate is controlled by the size of the cups and the rate at which the seed barrel revolves. This type of mechanism is common on British seed drills (Fig.35).



Internal double run **Cup feed mechanism**

Fig. 35. Seed metering mechanisms in seed drill

11.2.4 Cell feed seed metering mechanism

It is a mechanism in which seeds are collected and delivered by a series of equally spaced cells on the periphery of a circular plate or wheel.

11.2.5 Brush feed seed metering mechanism

It is a mechanism in which a rotating brush regulates the flow of seed from the hopper. A number of bullock drawn planters in the country have brush feed mechanism.

11.2.6 Auger feed seed metering mechanism

It is a distributing mechanism, consisting of an auger which causes a substance to flow evenly in the field, through an aperture at the base or on the side of the hopper. Many of the fertilizer drills of the country have got Auger feed mechanism.

11.2.7 Picker wheel seed metering mechanism

It is a mechanism in which a vertical plate is provided with radially projected arms, which drop the large seeds like potato in furrows with the help of suitable jaws.

11.2.8 Star wheel seed metering mechanism

It is a feed mechanism which consists of a toothed wheel, rotating in a horizontal plane and conveying the fertilizer through a feed gate below the star wheel.

11.2 Furrow openers

The furrow openers are provided in a seed drill to open up furrows before dropping the seeds, which facilitate the placement of seed and fertilizers at a desired uniform depth and spacing. Furrow openers play a very significant role in placing the seed and fertilizers at the moist zone of the soil. The seed tube conducts the seed from the feed mechanism into the boot from where they fall into the furrows.

11.2.1 Type of furrow openers

In general, two main types of furrow openers used with ferti-drills are: (i) rotating type openers i.e., single disc and double disc type, and (ii) fixed type openers i.e., shovel type and shoe type (Fig.36).

Shovel type furrow openers are widely used in seed drills. There are best suited for stony or root infested fields. These shovels are bolted to the flat iron shanks at the point where boots are fitted which carry the end of the seed tubes. In order to prevent shock loads due to obstructions, springs are provided. It is easy in construction, cheaper and easily repairable.

11.2.2 Shoe type furrow openers

It works well in trashy soils where the seed beds are not smoothly prepared. They are made from two flat pieces of steel welded together to form a cutting edge. It is specially suited for black cotton soil. Shoe is made of carbon steel having minimum carbon content of 0.5 percent with a minimum thickness of 4 mm.

11.2.3 Disc type furrow openers: They are of two types (Fig.36);

(a) Single disc type and (b) Double disc type.

(a) **Single disc type furrow openers**: Disc type furrow openers are found suitable where plant debris or trash mulches are used. It is a furrow opener consisting of one concave disc and set at an angle while operating, shifts the soil to one side making a small ridge. The disc is kept clean by two scrapers, one toe shaped at the convex side and one “T” shaped at the concave side.

The disc penetrates well in the soil, cuts all the trashes and clods in the field. It works in sticky soils also, but the discs are costly and maintenance work is bit difficult.

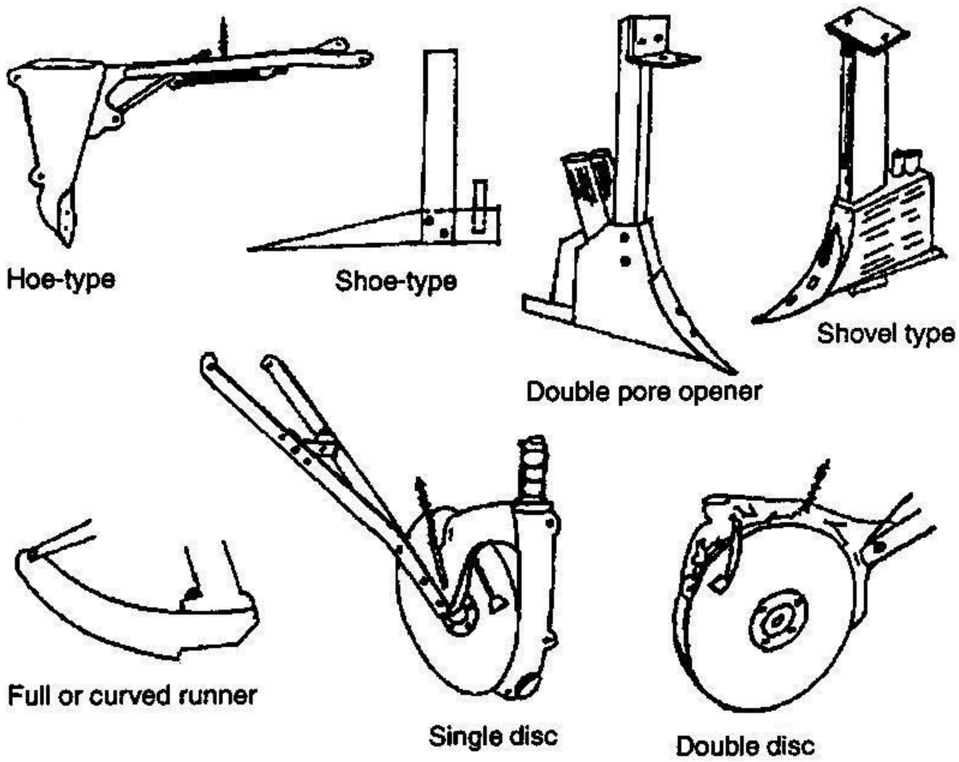


Fig. 36. Types of furrow openers

(b) **Double disc type furrow openers**: In double disc type furrow opener, there are two flat discs, set at an angle to each other. The discs open a clean furrow and leave a small ridge in the centre. The seeds are dropped between the two discs, providing a more accurate placement. It is suitable for the trashy lands. Seed drills attached with tractors having high speeds, usually have this type of furrow opener.

11.3 Calibration of seer drill and seed-cum-fertilizer drill

The procedure of testing the seed drill for correct seed rate is called calibration of seed drill. It is necessary to calibrate the seed drill before operating in the field to get a predetermined seed rate of the machine. The following steps are to be followed for calibration of seed drill or seed-cum-fertilizer drill.

Step 1: Determine the nominal width (W) of drill.

$$W = M \times S$$

Where M is the number of furrow openers and S is the spacing between the openers in metre and W is in metre.

Step 2: Find the length of a strip (L) having nominal width W necessary to cover 1/25th of a hectare.

$$L = \frac{10000}{W} \times \frac{1}{25} = \frac{400}{W} m$$

Step 3: Determine the number of revolutions (N) the ground wheel has to make to cover the length of the strip (L).

$$\pi \times D \times N = \frac{400}{W}$$

$$\therefore N = \frac{400}{\pi \times D \times W} \text{ rpm}$$

Step 4: Raise the seed drill in such a way that the ground wheels turn freely. Make a mark on the drive wheel and a corresponding mark at a convenient place on the body of the drill to help in counting the revolutions of the drive wheel.

Step 5: Put selected seed and fertilizer in the respective hoppers. Place a sack or a container under each boot for seed and fertilizers.

Step 6: Set the rate control adjustment for the seed and the fertilizer for maximum drilling. Mark this position on the control for reference.

Step 7: Engage the clutch or on-off adjustment for the hoppers and rotate the drive wheel at the speed N.

$$N = \frac{400}{\pi \times D \times W} \text{ rpm}$$

Step 8: Weigh the quantity of seed and fertilizer, dropped from each opener and record on the data sheet.

Step 9: Calculate the seed and fertilizer, dropped in kg/ha and record on the data sheet.

Step 10: Repeat the process by suitable adjusting the rate control till desired rate of seed and fertilizer drop is obtained.

Problem 1: The following results were obtained while calibrating a seed drill. Calculate the seed rate per hectare.

No. of furrow openers – 8

Spacing between furrows – 15 cm

Diameter of drive wheel – 1.5 m

RPM of the drive wheel – 600

Seed collected – 25 kg.

Solution:

Effective width of seed drill = 8 ×15 = 120 cm = 1.2 m

Circumference of drive wheel = $\pi \times 1.5$ m

Area covered in one revolution = $\pi \times 1.5 \times 1.2$ =5.66 m^2

Area covered in 600 revolutions = 5.66 ×600 = 3396 m^2

Seed dropped for 3396 m^2 = 25 kg

Seed dropped/ha = $\frac{25 \times 10000}{3396}$ = 73.6 kg

Seed rate = 73.6 kg

Problem 2: Calculate the cost of seeding one hectare of land with bullock drawn seed drill of 5×30 cm size. The speed of bullocks is 3 kmph. Hire charges of bullocks is Rs. 100/- per pair, hire charges of seed drill is Rs.200/- per day and wage of operator is Rs.200/- per day of 8 hours.

Solution:

Width of seed drill = 5×30 = 150 cm = 1.5 m

Area covered per hr = width × speed = 1.5 ×3×1000 =4500 m^2 =0.45 ha

To cover 0.45 ha of area, one hour is required

To cover one ha of area, time requirement = $\frac{1}{0.45}$ = 2.22 hr

Time taken/ha = 2.22 hr

Cost of seeding/hr = $\frac{100 + 200 + 200}{8}$ = Rs. 62.50/-

Cost of seeding/ha = 62.5 ×2.22 = 138.75/-

Problem 3: A fluted feed seed drill has eight furrow openers of single disc type. The furrow openers are spaced 30 cm apart and the main drive wheel has a diameter of 110 cm. How many turns of main drive wheel would occur when the seed drill has covered one hectare of area.

Solution:

Circumference of drive wheel = $\pi \times 110$ = 345.7 cm

Total width of seed drill = 8 × 30 = 240 cm

Area covered per revolution = 345.7 × 240 = 82968 cm^2 = 8.29 m^2

Number of turns per ha = $\frac{10000}{8.29}$ = 1206.3

Problem 4: Maximum yield of maize is obtained with a population of 30,000 plants per hectare. The rows are 140 cm apart and an average emergence of 80% is expected. Find: (a) How many seeds per hill should be planted if hills are 140 cm apart? (b) What would be seed spacing if crop is drilled?

Solution:

Number of seeds per ha = $\frac{30000}{0.80}$ =37500

Area covered per hill = 140 × 140 = 19600 cm^2 = 1.96 m^2

No. of hills per ha = $\frac{10000}{1.96}$ = 5102

(a) No.of seeds per hill = $\frac{37500}{5102}$ = 7.35 rounded to 8

(b) Total length of row = $\frac{10000}{1.4}$ = 7142.85 m

Spacing of drilled seed = $\frac{7142.85}{37500}$ = 0.19 m =19 cm.

11.4 Rice transplanter

Two methods are used for raising rice cop in India, namely upland cultivation (direct seeding) and wetland cultivation (direct seeding and seedling transplanting). Rice transplanting by hand is very tedious, expensive and labour consuming operation. Many attempts have been made to develop manual as well as self-propelled rice transplanter for transplanting of rice seedlings in rice growing countries such as Japan, China, Korea and India. The manual rice transplanter consists of frame, movable tray and seed picking fingers (Fig.37). Mat type seedlings are placed in the inclined trays. Fingers pick up the seedlings when they are pushed downward and place them in the prepared soil. Plant-to-plant spacing can be controller by the operator. Transplanters are available in 5-6 rows with comb type fingers. It‟s working capacity varied from 0.3-0.4 ha/day and requires two persons, one for operating the transplanter and other for filling the tray with mat seedlings.

The self propelled rice transplanter consists of air-cooled gasolines engine, main clutch, running clutch, planting clutch, seeding table, float, star wheel, accelerator lever, ground wheel, and handle and linkage mechanism. Seedlings are grown in special seedling trays in controlled environment called mat seedlings. When seedlings are 25-30 day-old, they are uprooted and placed in slanting seedling trays. Power from the engine is transferred to main clutch from where it is transferred to planting and a running clutch. The fingers on four bar linkage mechanism catch 3-4 seedlings at a time separate them from the mat and place it in the puddle soil. A float supports the machine on the water while working in the field. There are two end wheels that facilitate the movement of the transplanter. A marker is provided to demarcate the transplanting width during operation. The machine maintains row to row and plant to plant spacing. The planting capacity of the machine is about 0.05-0.1 ha/hr. These transplanters are now commercially available in India.

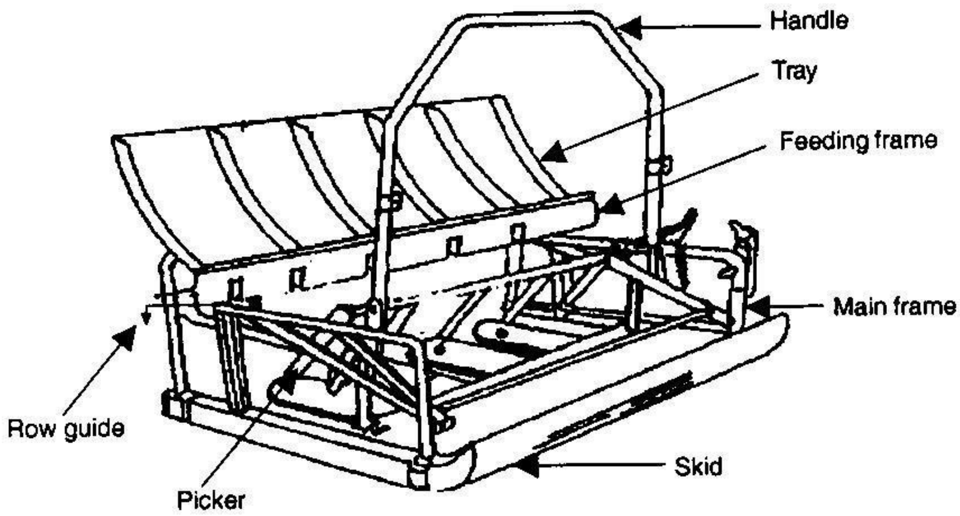


Fig. 37. Manual rice transplanter

Lecture No.12

Harvesting equipment – sickles, self propelled reaper, alignment and registration. Combines, functions of combines.

12.1 Harvesting plants

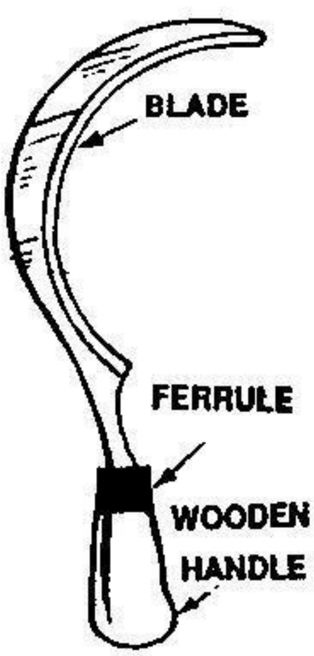
The operation of cutting a plant is achieved by four different actions. (1) slicing action with a sharp smooth edge, (2) tearing action with a rough, serrated edge, (3) high velocity single element impact with sharp or dull edge, and (4) a two element scissor type action. Generally, manual harvesting involves slicing and tearing actions that result in plant structure failure due to compression, tension or shear. The serrated sickle combines a slicing and a sawing action. Sickles with serrated edges do not require the repeated sharpening needed by smooth edge sickles.

Single element impact cutting is an economical method of cutting unrestrained vegetation and has been widely used in rotary lawn mowers, forage choppers, and some tractor mounted cutter bar. Usually a single element, sharp edged blade requires a velocity of about 10 m/second for impact cutting. A dull edged, single element blade requires a velocity of about 45 m/second.

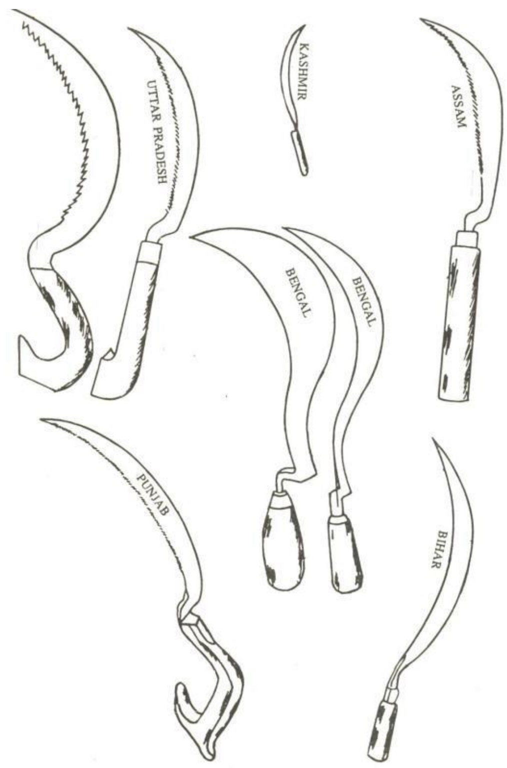
The two element scissors action is the most widely used for harvesting agricultural crops. The reciprocating cutter bars that are commonly used for harvesting paddy/wheat use this principle. The inclined angle between the cutting edges is about 38 degrees. The serrated blades permit a larger inclined angle because the plants can not easily slip between the two cutting edges. Reciprocating cutter bars do an excellent job of harvesting but are characterized by the high energy, losses, short dynamic imbalance, and restricted operating speeds. Improvements have been relatively limited by the high inertial and frictional forces involved in this type of mechanism.

12.2 Sickle

It is a simple harvesting tool. It is used for harvesting crops and cutting other vegetations (Fig.38). It is essentially consists of a metallic blade and a wooden handle. Blade is the main metallic part of the sickle. It is desirable to make the blade of carbon steel. It is made in a curved shape. The tooth of serrated sickle is made sharp for efficient working in the field. The handle of the sickle is made of well seasoned wood. The forged end of the blade for fixing the handle is called tang. The plain or serrated edge in the inner side of the blade is called cutting edge. Protective metallic bush fitted at the junction of the blade and the handle to keep the tang tight in the handle is called ferrule. Harvesting by sickle is very slow and labour consuming device.



Sickle



Indian sickles

Fig. 38. Various types of sickles

12.3 Mower

Mower is a machine to cut herbage crops and leave them in swath. The conventional mower has the following main parts (Fig.39):

a) Frame to support moving parts

b) Power transmitting unit to receive and transmit motive force

c) Cutter bar to cut crops and separate it from uncut portion.

d) Wheels for transport and for operating the cutting mechanism

e) Auxiliary parts to lift and drop the cutter bar

Frame

The frame of the mower is a heavy casting which supports other parts and provides openings for main axle, countershaft and crankshaft. It also provides space for gears, clutch and bearings. The lever for lifting the cutter bar is attached to the frame.

Power transmitting unit

In bullock drawn mowers, the power transmitting unit consists of main axle, gears, crankshaft, crank wheel and pitman. The main axle receives power from one of the transporting wheels. A spur gear mounted on the main axle drives the spur pinion on one end of the countershaft in the gear box. The crank wheel and the pitman are fixed on the outer end of the crankshaft. The reciprocating (back and forth) motion is transmitted to the pitman, which in turns operates the knife in the cutter bar. The knife is connected to the pitman with a ball and socket joint. The knife makes about 1600 cutting strokes per minute. In order to engage or disengage the driving unit, generally a dog clutch is provided on the counter shaft so that the man can operate it by foot from the seat.

The tractor drawn semi-mounted or mounted type mowers are operated by the P.T.O. shaft. In this case, the cutting mechanism is driven independently of the forward speed of the mower. A shaft is connected with the PTO shaft, which drives a V pulley with the help of a universal joint. The V pulley rotates another smaller pulley on the crank shaft of the machine and reciprocating motion is transmitted to the cutter bar. Other basic components of the machine are the same as that of bullock drawn mower with some variations in size and minor accessories.

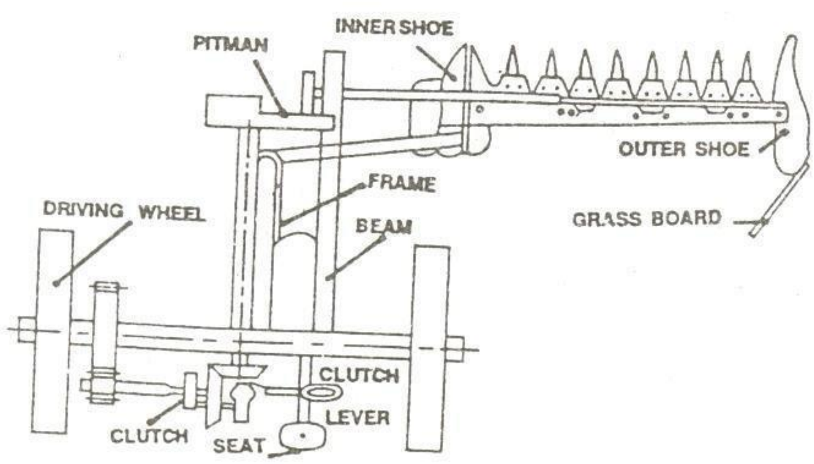


Fig.39 . Components of reciprocating type mower

Cutter bar

It is an assembly comprising of fingers, knife section, ledger plate, wearing plate, knife guides (clips) and shoes (Fig.40). It is used for cutting grasses and forage. It is made of high grade steel. It works like a knife. The knife is a metal bar, on which triangular shaped sections are mounted. The cutting edges of these knife sections are mostly smooth edges. The knife sections move back and forth and cut plants in both directions. The section of knife should always stop at the centre of the guard on each stroke. The length of the stroke is 7.5 cm. Ledger plate is a hardened metal, inserted in a finger over which knife sections move to give a scissor like cutting action. Knife clips hold the knife sections down against ledger plates but allow it to move freely. Knife clips are placed together with wearing plates to absorb the rearward thrust of the crop to the knife. Wearing plate is a hardened steel plate, attached to the finger bar to form a bearing surface for the back of the knife. A badly worn wearing plate or a loose knife clip may allow the knife to bend.

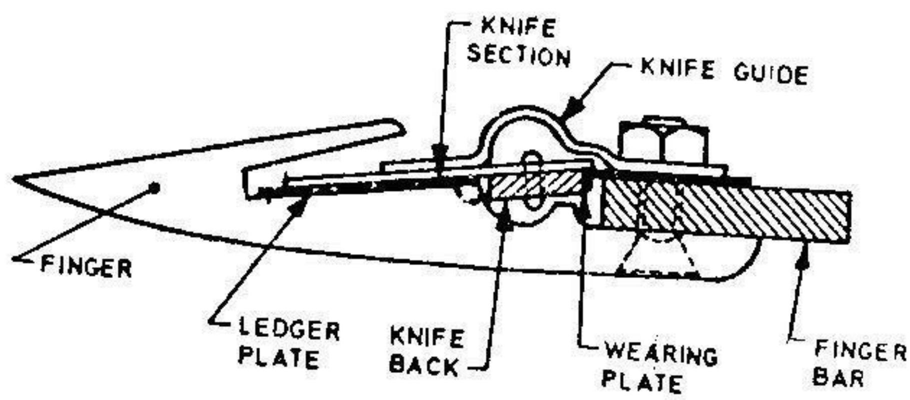


Fig. 40. Components of cutter bar

Pitman is a type of connecting rod which is pinned to the crankshaft with the help of a pin. It transmits reciprocating motion to a knife head. Wooden pitman is commonly used for the mowers.

A shoe is always provided on each end of the cutter bar to regulate the height of cut above the ground. The inner shoe is larger in section and is placed at the inner end of the cutter bar. The outer shoe is placed at the outer end and is smaller in section. The inner shoe has a larger area of contact with the ground than the outer one. This results in smooth and easy sliding of the cutter bar on the ground. Grass board is provided at the outer end of the mower, which causes the cut plants to fall towards the cut material. The angle of the grass board can be changed for different crops.

Wheels

Early imported mowers had a pair of wheels made of cast iron with sufficient width and number of lugs to develop better grip in the soil. Now pneumatic wheels have been introduced. Because of the ratchet and pawl arrangements, the transport wheels transmit power to the knife.

Auxiliary parts

There is a lever provided within the easy reach of the operator to enable him to lift the cutter bar from his seat. In addition to this, all animal drawn mowers are provided with a foot lift so that the cutter bar can be raised when turning at corners or to avoid obstructions. A hand lever is also provided to adjust the height of the cut.

Registration and Alignment

As the pitman arm moves the knife back and forth, the centre of the knife section must stop in the centre of the guard on each stroke, when it is in operating condition (Fig.41). This is called **registration**. It is essential for an even job of cutting, and unclogging of the cutter bar. Adjustment is commonly made by moving the entire cutter bar in or out with respect to the pitman.

On most of the mowers, the outer end of the cutter bar is carried a little ahead of the inner end to overcome the pressure exerted by the standing crop on the cutter bar, while it is under working condition. In general, the cutter bar is set at about 88° to the direction of motion, i.e., inward lead of 2°. This is called **lead** and gives better cutting. When the cutter bar is properly aligned, the knife and pitman run in a straight line. The lead can be measured by stretching a string parallel to the pitman up to the outer end. Generally, 2 cm lead per metre length of cutter bar is adequate.

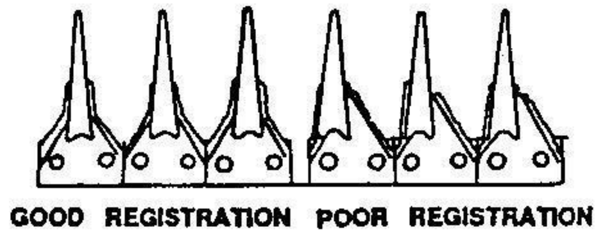


Fig. 41. Registration of mower

12.4 Combine harvester

Combine harvester is a machine designed for harvesting, threshing, cleaning and collecting the grain while it moves over the land. All the five operations are carried out in single operation of the harvester. The machine is versatile and with minor adjustments can handle a variety of crops. The size of the combine is indicated by the width of cut, it covers in the field.

Combine harvester in its primitive form was introduced in Germany and U.S.A. in late 19th century and became popular in next decades. In India, though a few tractor drawn combine harvesters manufactured by Minneapolis Moline U.S.A, and self-propelled Russian combine harvesters were available with some Govt. farms and landlords. However, between 1970-73 introduction of E512 GDR combine in Punjab, Haryana and M.P. was made in a big way. This was another revolution in the farm mechanization sector. Gradually indigenous production started with the manufacture of a Swaraj 8100 combine harvester in organized sector by M/s Punjab Tractors Ltd., which followed manufacturing of the machine in small sector in a small way.

Surprisingly in 30 years of its production on commercial scale in India there are 60 more manufacturers with a production capacity of 5 to 150 combines per year. On an average about 800 combines are added every year on Indian farms. All these manufacturing units are located in the state of Punjab.

12.3.1 Functions of combine harvester

1. cutting the standing crops
2. Feeding the cut crops to threshing unit
3. Threshing the crops
4. Cleaning the grains from straw
5. Collecting the grains in a container

Lecture No.13

Plant protection equipment – types of sprayers, constructional features of knapsack sprayer, hand compression sprayer, foot sprayer, rocker sprayer and power sprayer, care and maintenance of sprayers.

13.0 Sprayers

Insect pests and weeds cause considerable damage to the commercial crops. If not controlled in time, the entire crop gets lost and, therefore, farmers are likely to suffer in many ways. Among the important methods of weed control and plant protection systems, the following methods have been recognized as the effective and economical ones under different situations:

a) Mechanical control

b) Chemical control

c) Biological control

d) Agronomical methods

e) Bio-physical methods

f) Fire as control

The mechanical control of weeds is most widely used in India and in many developing countries due to the availability of farm labour at relatively low rates of wages. Whereas, the chemical method of plant protection has been universally accepted due to saving of time, labour and its effectiveness with relatively low expenditure. In developing countries, combination of chemical and mechanical methods of weed control has been successfully accepted. The chemicals for protecting the plants from various injurious or organisms need to be applied on plant surfaces in the form of sprays, dusts, mist etc. Sprayers and dusters are available in many forms for this purpose.

13.1 Sprayers

Sprayer is a machine to apply fluids in the form of droplets. Sprayer is used for the following purpose: (i) application of fungicides to minimize fungal diseases, (ii) application of insecticides to control insect pests, (iii) application of herbicides to remove weeds and (iv) application of micronutrients on the plants. The main functions of sprayer are: (i) to break the liquid into droplets of effective size, (ii) to distribute them uniformly over the plants, and (iii) to regulate the amount of liquid to avoid excessive application

13.2 Desirable quality of sprayer

(a) The sprayer should produce a steady stream of spray materials in the desired fineness of the particle so that the plants to be treated may be covered uniformly.

(b) It should deliver the liquid at sufficient pressure so that it reaches all the foliage and spreads uniformly over the surface of the plant

(c) It should be light weight, sufficiently strong, easily workable and repairable.

13.3 Sprayer's classification

Based on **power source**, sprayers may be classified as:

(i) Hand operated machines – suitable for small holdings. They are operated at pressure ranging from 1 to 7 kg/cm^2.

(ii) Power operated machines – suitable for treating a large area. They are operated at pressure ranging from 20 to 55 kg/cm^2.

(iii) Air planes – suitable for large scale work.

Based on **spray volume**, sprayers may be classified as:

(i) High volume sprayer - More than 400 litres of spray liquid per hectare is used.

(ii) Low volume sprayer – Spray volume ranges between 5 to 400 litres per hectare is used.

(iii) Ultra-Low volume sprayer – Spray volume less than 5 litres per hectare is used.

Based on **working principle**, sprayers may be classified as:

(i) Hydraulic energy sprayers

(ii) Compression sprayers

13.4 Hydraulic energy sprayers

In this category of sprayers, hydraulic pressure is thrust upon the liquid by the hand operated pumps. As a result, the liquid is forced through the nozzle in the form of a spray of droplets (diameter in the range of 300-400mµ). Sprayers of this type are high volume, high pressure and suitable for complete coverage of both ground and field crops.

13.4.1 Bucket type sprayer

It consists of a hand operated single or double acting pump (Fig.42), which may be placed into any ordinary bucket containing spraying solution. Plunger rod is hollow and serves as the compression chamber. Liquid is discharged in both suction and delivery strokes, hence a continuous application can be made. One hand operates plunger, while another hand keeps the pump in stable position. This pump is mostly made of brass. It is very light and easily handled and develops sufficient pressure to spray small gardens and low trees. It develops a pressure of 4 -10 kg/cm^2.

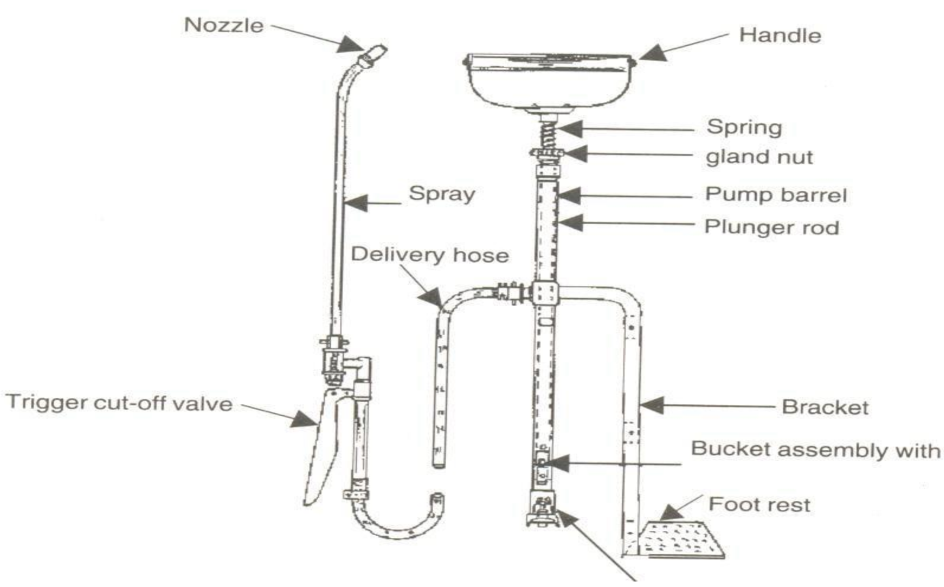


Fig. 42. Line diagram of bucket type sprayer

13.4.2 Knapsack sprayer

It is very common type of sprayer, is provided with a pump and a large air chamber permanently mounted in a 9 to 22.5 lts tank. The handle of the pump extending over the shoulder or under the arm of operator, which makes it possible to pump with one hand and spray with other hand. Spray liquid is delivered through the delivery system, consisting of lance and nozzle, which is connected with the pump by a flexible hose. A uniform pressure can be maintained by keeping the pump in operation. It is generally carried on the back of the operator. It is quite useful for spraying small trees, shrubs and row crops up to 2.5 m height. These sprayers are useful because of their simplicity in operation, durability and for diverse use including spraying bushes of tea and coffee (Fig.43).

One man can spray about 0.4 – 0.5 ha in a day, thus spraying about 90 lts of spray liquid. A pressure of 3 -5 kg/cm^2 is maintained in the pressure chamber.

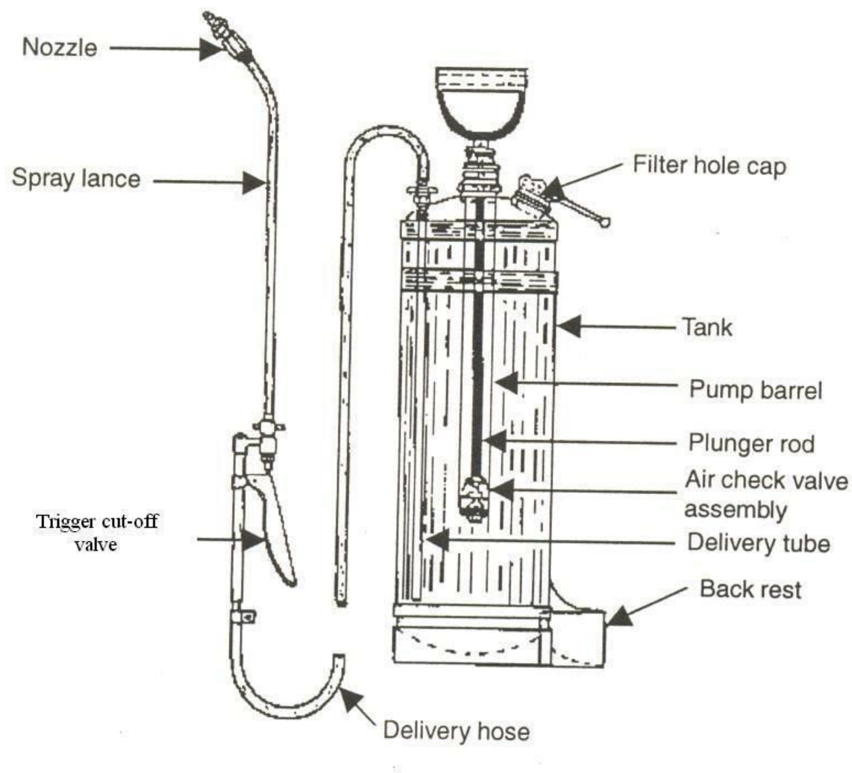


Fig. 43. Line diagram of knapsack sprayer

13.4.3 Foot - operated sprayer

It is also called pedal pump (Fig.44). It consists of a plunger assembly, stand, suction hose, delivery hose and an extension rod with nozzle. One end of suction hose is fitted with a strainer and other end with a flexible coupling. Similarly, one end of delivery hose is fitted with a cut-off valve and other end with a flexible coupling. An additional container is required to hold spray fluid, as this sprayer does not have a built-in tank. Continuous pedaling is required for uniform spray. It can develop a pressure of 17-21 kg/cm^2. It is easy to operate and can be used for spraying tall crops and fruit trees up to 4 m height. Sprayer can be used to spray trees up to 6 m height with additional hose.

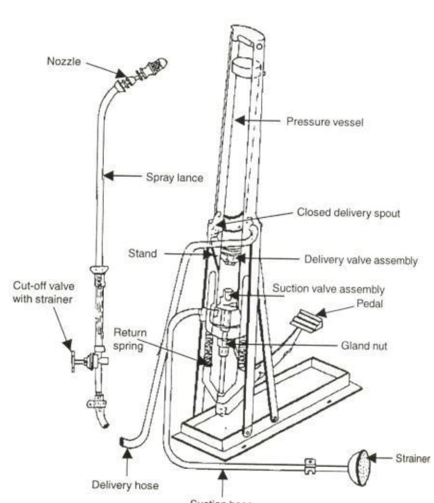


Fig. 44. Line diagram of foot operated sprayer

13.4.5 Rocking sprayer

This type of sprayer consists of a lever operated pump assembly which rests on a wooden platform (Fig.45). Suction hose with a strainer is immersed in a separate container containing the spray liquid. Delivery system consists of a separate pressure chamber, a flexible hose, spray lance, and a spray nozzle. The lever attached to the pump is operated by the rocking- forward and backward movement of the handle. Pressure is developed in the pressure chamber, which may attain pressure of 14-18 kg/cm^2. Such sprayers are used for spraying tall plants like coconut and arecanut trees, and sugar cane plants. Uniform spraying can be done if sufficient pressure is maintained in the pressure chamber. It needs two persons to operate the sprayer, one for operating the pumping system and another for the application of spray liquid.

13.5 Compression Sprayers

In these types of sprayers, air is compressed into the container by the compression air pump. When sufficient pressure is developed, then the delivery system is operated to obtain spray in the form of fine droplets. The compressed air forces the liquid through the nozzle and the desired type of spray is achieved. For this purpose, the tank is usually filled to three fourths of its capacity, leaving one-fourth volume for the compressed air. The air pump is fitted vertically inside the container which acts as a force pump.

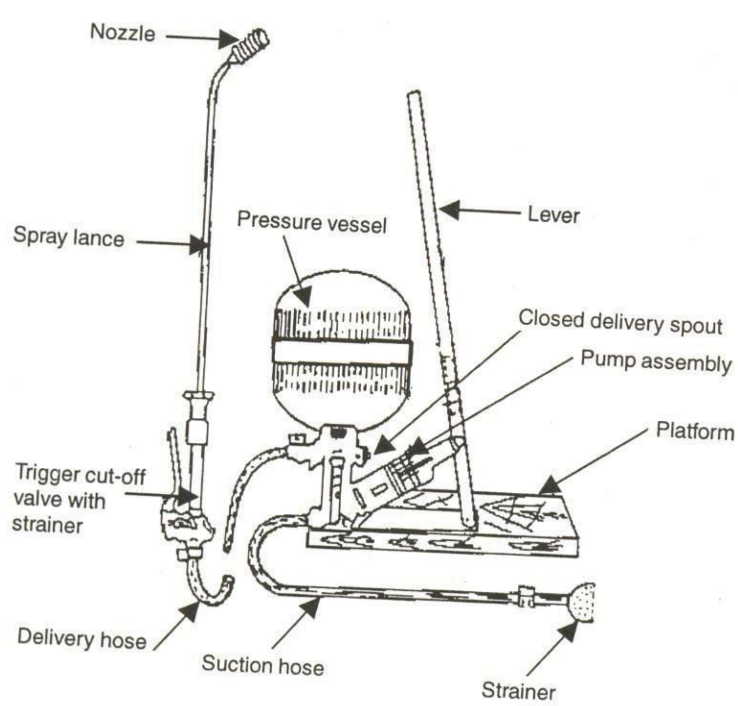


Fig. 45. Line diagram of rocking sprayer

13.5.1 Hand compression sprayer

The compressed air sprayer consists of an air pump, is fitted vertically inside the airtight chamber. The outlet pipe is suspended in the liquid in the chamber, the end running into the bottom of the chamber, the other end is provided with a nozzle. The chamber is usually filled to three fourths of its capacity, leaving one-fourth volume for the compressed air. Before spraying, the pressure is developed by pumping air into the chamber and continued till sufficient pressure is built. When sufficient pressure is developed, then the delivery system is operated to obtain spray in the form of fine droplets. The tank capacity is usually 14 lts. Frequent pumping must be done to maintain the required pressure.

13.5.2 Hand atomizer

This is the smallest type of hand sprayer used to treat the plants in home garden or nursery and to apply fly spray in the house.

13.6 Power sprayers

Power sprayers are operated usually with IC engines. The prime mower capacity varies from 1 to 5 hp. The pressure pump is operated by a small power unit ensuring a constant steady pressure. These sprayers are essentially high volume sprayers and operated at pressure ranges from 20 to 55 kg/cm^2. These machines are usually portable type. Sometimes, power sprayers are operated by the PTO shaft of the tractor. Power sprayers can cover much larger area, and do the job efficiently.

A power sprayer essentially consists of: (i) prime mower, (ii) tank, (iii) agitator, (iv) air chamber, (v) pressure gauge, (vi) pressure regulator, (vii) strainer, (viii) boom and (ix) nozzles (Fig.46).

Prime mower: Prime mower is needed to supply power to the power sprayer. It is usually internal combustion engine. The power generally varies from 1 to 5 HP.

Tank: Steel tank is widely used to prevent corrosion. Plastic tanks are also getting popular due to freedom from corrosion and ease of moulding into smooth shape. A covered opening, fitted with a removable strainer is provided for easy filling, inspection and cleaning. A drain plug is provided at the bottom of tank for draining the liquid.

Agitator: Agitators are needed to agitate the liquid in the tank. Propeller or paddle type mechanical agitators are provided to agitate the liquid. Horizontal shaft with flat blades rotating at about 100 to 200 rpm may be used. Paddle tip speed in excess of 2.5 m/s may cause foaming.

Air chamber: An air chamber is provided on the discharge line of the pump to level out the pulsations of the pump thereby providing a constant nozzle pressure,

Pressure gauge: It is provided on the discharge line to guide the operator regarding spray pressure. It should be under specified limit.

Strainer: It is provided in the suction line between the tank and the pump to remove dust, dirt and other foreign materials.

Boom: It is driven by a tractor, has a long boom in a horizontal plane on which nozzles are fixed at specified spacing. The boom can be adjusted vertically to suit the height of plants in different fields.

Nozzle: It is used to break the liquid into the desired spray and deliver it to plants.

13.6.1 Care and maintenance of sprayer

(i) All washers and packings should be soaked in oil or water before use.

(ii) The ends of the nozzle should be unscrewed and cleaned before starting the work.

(iii) When spraying is over, the sprayer should be operated for sometime with clean water to remove sediments from the pressure vessel and the discharge tube.

(iv) Special attention has to be paid in case of power sprayers for the following:

(a) Lubricating oil of the engine should be changed for every 100 working hours unless otherwise advised by the manufacturers.

(b) Do not disturb the packing until a leak is observed.

(c) The spray pump should not be worked at more than recommended pressure.

(d) Oil level in the pump of the engine should be checked every time and all grease points should be greased once in a day.

(e) Recommended oils and fuels should always be used in the engine.

(f) Nozzle should be thoroughly cleaned after use by blowing air through it.

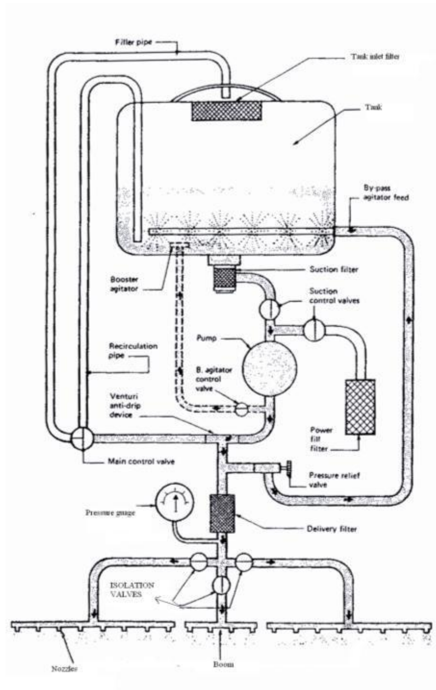


Fig. 46. Line diagram of power sprayer

Lecture No.14

Dusters – hand rotary and power operated dusters, care and maintenance of dusters.

Duster is a machine to apply chemical in dust form. Dusters make use of air streams to carry pesticides in finely divided dry form on the plants. A duster essentially consists of: (a) hopper, (b) agitator, (c) feed control, (d) fan or blower and (e) delivery nozzle.

14.1 Types of dusters

14.2 Plunger type hand duster

This machine consists of a chamber for the dust, outlet, a cylinder with piston, piston rod and handle. Sometimes the dust chamber is placed below the cylinder. By moving the piston back and forth in the cylinder, dust is forced through the outlet. This type of duster is suitable for dusting a small area.

14.3 Rotary type hand duster

This type of duster (Fig.47) is provided with an enclosed fan geared to a hand crank and a hopper holding the dust. It is equipped with an agitator to stir the dust and a regulator to control the discharge opening. The duster is usually fastened to the operator by means of shoulder strips. The right hand is used for cranking and the left hand to guide the discharge tube. These dusters can hold about 3.6 to 4.5 kg of dust and are large enough to treat 0.4 to 0.6 hectare of cropped area in a day. Ordinarily they are not found suitable for dusting over 3 meters height.

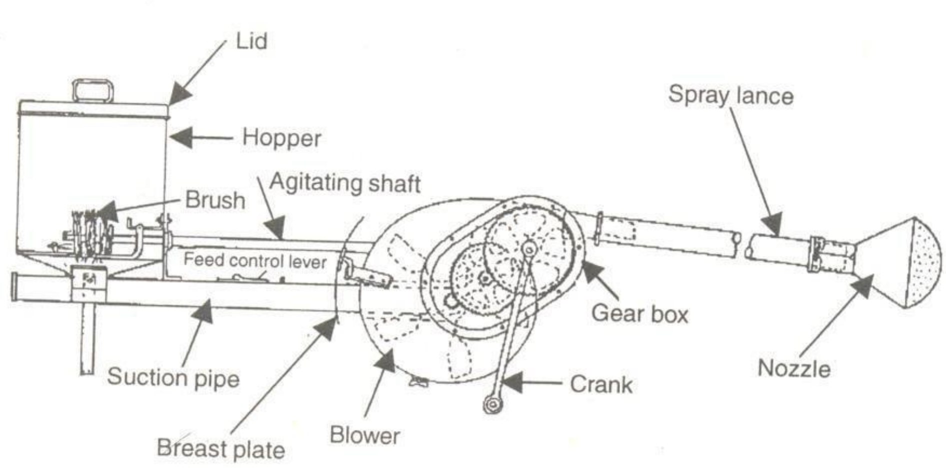


Fig.47. Line diagram of rotary duster

14.4 Power duster

The power duster of small capacity is generally mounted on the back of the operator. It consists of cylindrical container, blower, high speed engine and discharge hose pipe. The cylindrical container is provided with two compartments, one for gasoline, and the other for the powder to be dusted. The blower is directly mounted on the crankshaft of the high speed (4000 rpm) air cooled engine. The air pressure is utilized to agitate the dust in the container in order to blow it through the flexible hose pipe. The direction of the dust is regulated by a movable delivery spout suitably fitted with the unit. The dust can be blown up to about 6 meters height. Such a duster can cover about a hectare in a day. This type of duster can be converted into a sprayer with little modifications. Portable type power dusters are also in use. They are mounted on two wheel trolleys.

14.5 Care and maintenance of dusters

(i) Duster should be thoroughly cleaned before and after use with a suitable brush.

(ii) The hopper should be filled with dust about half of its capacity.

(iii) The lid of the hopper should be closed during the operation.

(iv) In rotary dusters, the handle should be cranked at 30 to 35 rpm for efficient performance.

(v) Before and after use of the duster, the dust from the fan box, suction pipe and hopper should be thoroughly blown out.

(vi) Pieces of paper, gunny bag and other foreign materials should be prevented from getting into the hopper.

(vii) The agitator parts and dust feed should be occasionally checked for blockage by foreign matter.

Lecture No.15

Tractor mounted equipments for land development and soil conservation – functions of bund former, ridger, and leveling blade.

15.1 Bund Former

It is used for making bunds or ridges by collecting the soil (Fig.48). Bunds are required to hold water in the soil, thereby conserve moisture and prevent runoff. The size of the bund former is determined by measuring the maximum horizontal distance between the two rear ends of the forming boards. It is operated by both animal and tractor. Bund former consists of: (i) forming board, (ii) beam and (iii) handle. Forming board is made of mild steel of thickness 1.6 mm for light soil and 2 mm for medium and heavy soils.

15.2 Ridger

It is an implement (Fig.49) which cuts and turns the soil in two opposite directions simultaneously for forming ridges. It is also known as furrower. Ridger is used to form ridges, for sowing row crop seeds and plants in well tilted soil. The ridger is also used for forming field channels or furrowers, earthing up and similar other operations. Ridgers are also known as riding plough and double mould board plough.

A ridger consists of beam, clevis, frog, handle, mould boards, braces, share, and sliding shoe. The ridger generally has V-shaped or wedge shaped share, fitted to the frog. The nose or the tip of the share penetrates into the soil and breaks the earth. The mould boards lift, invert and cast aside the soil, forming deep channels and ridges of the required size.

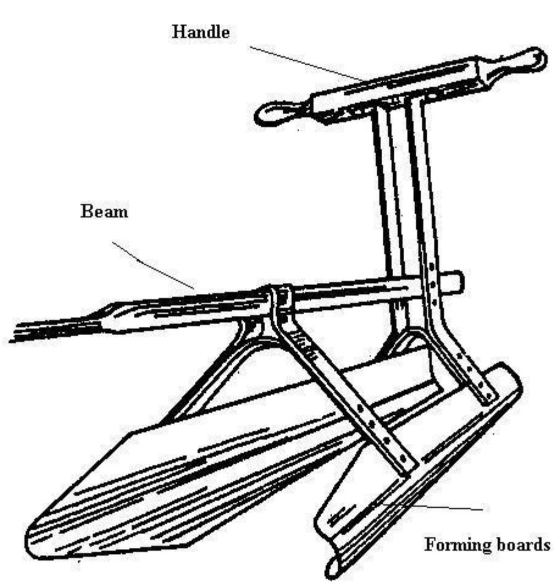


Fig. 48. Bund former

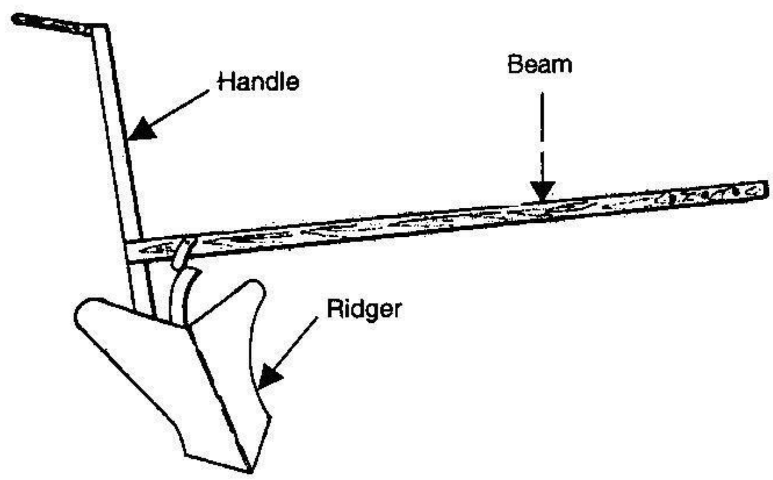


Fig. 49. Ridger

15.3 Leveller

In irrigated areas, land leveling is an essential operation for farming. Level fields receive uniform penetration of irrigation water with high efficiency. The possibility of water logging and soil erosion is reduced considerably. Land leveling is usually done in the slack season when the field is free from crops.

Wooden logs or planks are the most common type of field levelers used by farmers. They are operated in ploughed land to collect loose soil from high spots and dump it into depressions. The other improved type of land leveler which is used on the large farms, is called the leveling *karaha* (scoop) or scraper.

15.4 Animal drawn soil scoop

Soil scoop is used in excavating ditches, cleaning drains and moving soil over short distances (Fig.50). The implement is pulled by a pair of bullocks. Two men are needed to operate it. One man controls the bullocks and the other man does the loading and unloading. It consists of: (i) blade, (ii) soil trough, (iii) Hitching loop and (iv) handle.

Blade: It is made of high carbon steel with carbon content varying from 0.5 to 0.6%. The angle of the cutting blade varies from 12 to 15^0 only. The blade is riveted or bolted to the soil trough.

Soil trough: It is made of mild steel sheet. It has two handles on the sides at the rear end.

Hitching loop: Two ends of the loop are fitted to the side of the soil trough. The loop is made of mild steel round.

Handle: Two handles, are usually made of timber or mild steel flat.

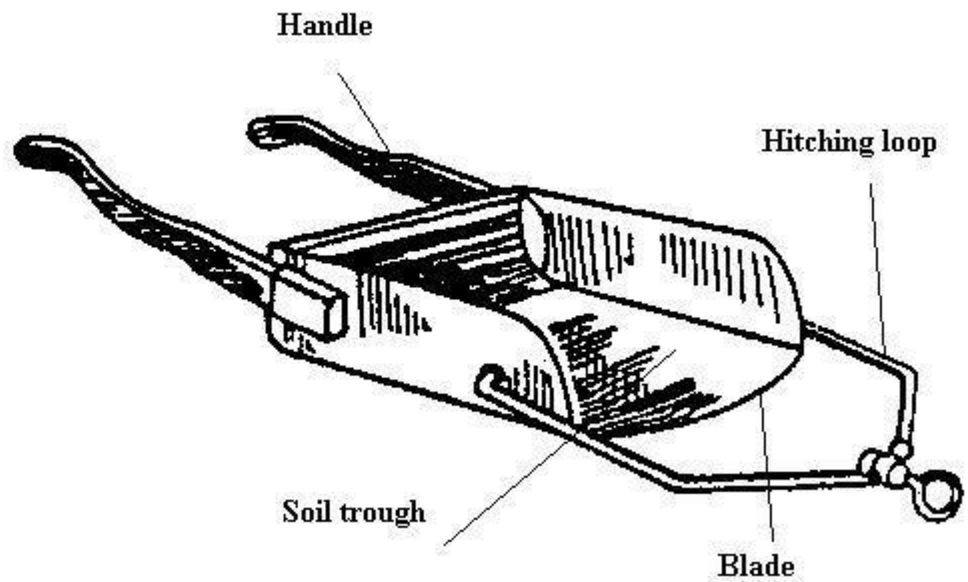


Fig. 50. Soil scoop

Lecture No.16

Farm mechanization – engineering intervention for production and productivity, percentage share of different power sources, level of mechanization of different operations (power sources).

16.0 Scope of mechanization

Agriculture is the most important sector of the Indian economy. Most of the farming is carried out on small holdings. About 78% of farm holdings belongs to small and marginal farmers, about 22% belongs to semi, medium and large farm holders. Moreover, the Indian farmers have the **lowest earnings per capita** because of the low yield per hectare from their holdings. Food grain production is almost stagnant (2001-2002: 212.85 million tones; 2006-2007:211.78 million tones). Whereas, population statistics shows that, India population was **1.065 billion** in July 2004, at present **1.128 billion** and projected population is **2 billion by 2101**. Mechanization is the only solution for increasing farm production per hectare to enable us to meet the food requirement of growing population. There is a positive correlation between application of improved technologies and the land productivity. The effective mechanization contributes to increase production in two major ways: the timeliness of operation and good quality of work

The requirement of power for certain operations like seed bed preparation, cultivation and harvesting becomes so great that the existing human and animal power in the country appears to be inadequate. As a result, the operations are either partially done or sometimes completely neglected, resulting in low yield due to poor growth or untimely harvesting or both. Yet Indian agriculture lacks farm power which needs to be increased from 1.25 kW/ha to at least 2.0 kW/ha. Draft animals and farm workers are important sources of farm power. Mechanization possibility is strongly influenced by: (i) farm size, (ii) cost of farm labour, and (iii) availability of suitable machines. The farming system continues to utilize manual labour, animal power and tractor based technology in almost all operations.

The economic progress of a nation depends directly upon availability of energy and its consumption for fruitful utilization. Increased energy input in agriculture directly or indirectly increases the production of crops. In order to bring more land under cultivation and to improve productivity, it is necessary to introduce other sources of power like tractors, power tillers, oil engines, self propelled combine harvester, electric motors and renewable energy (specially wind mills for water pumping). The availability of power from different sources has been given in Table 2.

Table 1: Availability of farm power in India

Year	Total power, kW/ha	Sources wise, %		
		Animate power (Human + animal)	Mechanical	Electrical
1951	0.25	97.4	2.1	0.5
1961	0.31	94.9	3.7	1.4
1971	0.36	79.2	16.3	4.5
1981	0.63	48.2	32.3	19.5
1991	0.92	34.5	34.7	30.8
1999 (Estimated)	1.25	21.0	44.2	34.8

Mechanization in India may have to be done at various levels. Broadly, it can be done in three different ways:

1. By introducing the improved agricultural implements on small size holdings to be operated by bullocks;
2. By introducing the small tractors, tractor-drawn machines and power tillers on medium size holdings to supplement existing sources;
3. By introducing the large size tractors and machines on the remaining holdings to supplement animal power source.

These machines will be helpful in providing power efficiently for good seedbed preparation which is quite essential for maximizing the germination of the seed. In addition to this, the mechanization of the following fields of agriculture is equally essential:

1. Shaping and leveling of farm fields for even distribution of irrigation water.
2. Development of planting and fertilizing machines.
3. Spraying and dusting machinery.
4. Mechanization of harvesting, threshing, winnowing and drying operations.

Improved agricultural tools and equipment are estimated to contribute to the food and agricultural production in India by savings in seeds (15-20%), fertilizers (15-20%), time (20-30%), and labour (20-30%); and also by increase in cropping intensity (5-20%), and productivity (10-15%).

There is a good scope of farm mechanization in India de to the following reasons: (i) improved irrigation facility in the area, (ii) introduction of high yielding varieties of seeds, (iii) introduction of high dose of fertilizers and pesticides for different crops, (iv) introduction of new crops in different crops of the country, and (v) multi-cropping system and intensive cultivation, followed in different parts of the country.

16.1 State of mechanization

Agricultural system all over the world has undergone changes in terms of cropping system, type of power sources used and application of inputs to achieve high level of productivities. Even in India, mechanization of agriculture has advanced considerably. In certain region, the level of mechanization has gone far ahead of the average level in the country. Human and animal power sources are no longer the predominant sources on Indian farms. Presently, India is the largest manufacture of tractors in the world accounting for about one third of the global production and more than 50 percent of tractors in <50 hp category. The country produced 3,45,172 tractor units in 2007-2008 of which 43,553 units were exported. There are 20 tractor manufacturers, 9 power tiller manufacturers and a number of agricultural implement and machinery manufacturers. Table 1 shows status of farm equipment manufacturing industries. Similarly about the hundred thousand pump sets are being installed on Indian farms annually. On the basis of annually critical review of the mechanization position, one observes that the shortage of labour and high labour wages are the main factors which strongly propel mechanization. Consequently, the more labour intensive operations, such pumping of irrigation water, land preparation and threshing are the first operations which are mechanized. Large amount of labour or draft power which can be replaced through machines provides a strong incentive to mechanize. Available mechanization technologies from the industrialized countries have limited scope of introduction in the developing world. Hence, indigenous solutions must be found for some of the mechanizations problems particularly for paddy production system. Efforts have to make to develop rice transplanter, rice harvester and appropriate rice milling machinery appropriate to the location specific conditions of South and South East Asian Countries.

Table 1: Status of farm equipment manufacturing industries

Equipment	Manufacturers in No.	Equipment	Manufacturers in No.
Agricultural tractors	20	Seed drills	2500
Power tillers	9	Ploughs, cultivators and harrows	5000
Earth mowers	3	Tractor parts and accessories	546
Pumps	600	Earth moving machinery & parts	188
Sprinkler sets	35	Diesel oil engine	200
Drip irrigation system	35	Rice processing industry	300
Plant protection equipment	300	Sugarcane crusher	50
Combines	48	Chaff cutter	50
Reapers	60	Dairy and food industries	500
Threshers	6000	Village craftsman	1 million

The engineering inputs in agriculture has helped the farmers in effective utilization of inputs and thereby increasing the productivity and adding value to the produce. The local farm industries have helped the farmers to supply desired improved farm machinery and post harvest equipment to modernize agriculture. To-day farmers use pumps, drip and sprinkler irrigation, cultivators, disc harrows, rotavators, seed drills, planters, pneumatic planters, power thresher, combine harvesters etc., manufactured by local industries. To meet the future food requirements, the farmers may require better production and processing technology such as precision agriculture, drip and fertigation, micro sprinkler, greenhouse modern processing and packaging technology for promotion of agri business and commercial agriculture.

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Lecture -1

Energy

Energy is the primary and most universal measure of all kinds of work by human beings and nature. Everything what happens in the world in the expression of flow of energy in one of its forms.

Technical conversion of energy has three different conversion stage namely:

Stage	Definition	Energy source
Primary energy	Original source	*e.g.* crude oil, coal not yet processed, natural uranium, solar, wind etc
Final energy/ secondary	Energy in the form that reaches the end user, hot water or steam	*e.g.,* gas, fuel, oil, petrol, electricity
Effective energy	Energy in form used by the end user	*e.g.,* light, radiation heat, driving force or vehicles

Energy Sources

The energy sources can be classified in a number of ways. The general classification of energy resources is an follows:

A. Based on the usability of energy

1. **Commercial sources of energy:** The energy sources like petroleum products (diesel, petrol and kerosene oil) and electricity, which are capital intensive, exemplify commercial sources of energy. Considering the fact that most of the commercial sources are also non-renewable and to some extent are imported to India, efforts are made to conserve such sources of energy.
2. **Non-commercial sources of energy:** Each and every energy source has some economic value. Some energy sources are available comparatively at low cost whereas others are capital intensive. The energy sources which are available cheaply are called non-commercial sources of energy whereas the ones which are capital intensive are called commercial energy sources. Human labour and bullocks exemplify the category of non-commercial source of energy.

B. Based on traditional use

1. **Conventional :** those energy sources which have been traditional used for many decades *e.g.* fossil fuels, nuclear and hydro
2. **Non-conventional:** Those energy sources which are considered for large scale use of oil crisis of 1973 are called non-conventional energy source *e.g.* solar, wind, biomass etc.

C. Based on long term availability

1. **Non – renewable /Exhaustible:** Those which are finite and do not get replenished after their consumption. Fossil fuels, nuclear, natural gas etc.
2. **Renewable resources:** Those which are renewed by nature again and again and their supply not affected by the rate of their consumption.

D. Base on origin

1. Fossil fuel
2. Wind energy
3. Solar energy
4. Biomass energy
5. Nuclear energy
6. Solar energy
7. Geothermal energy
8. Tidal energy
9. Hydro energy

Introduction to Renewable Energies

Renewable energy refers to energy resources that occur naturally and repeatedly in the environmental and can be harnessed for human benefit. These energy resources are inexhaustible within the time horizon of humanity. Examples of renewable energy systems include solar, wind, and geothermal energy (getting energy from the heat in the earth). We also get renewable energy from trees and plants, rivers, and even garbage. During recent years, due to the increase in fossil fuel prices and the environmental problems caused by the use of conventional fuels, we are reverting back to renewable energy sources such as solar, wind and hydraulic energies. Renewable energies are inexhaustible, clean and they can be used in a decentralized way (they can be used in the same place as they are produced).

Renewable Energy Source	**Technology / Application**
Solar	Photovoltaic (PV) cells to produce electricity and Solar thermal system for heating water/air
Wind	Wind turbine to pump water, produce electricity or for any other mechanical use
Water	Hydro-electric, wave and tidal systems to produce electricity
Biomass	Direct combustion of gas produced from biomass, or biogas, to generate electricity and/or heat - e.g. wood stoves or larger commercial operations
Geothermal	Using the temperature of the earth to produce

	electricity and/or heat
Ocean energy (wave and Tidal energy)	Ocean to operate a heat engine to produce a work output and generated electricity

Advantages of renewable energy

- These sources of energy are renewable and there is no danger of depletion. These recur in nature and are in-exhaustible.
- The power plants based on renewable sources of energy don"t have any fuel cost and hence negligible running cost.
- Renewable are more site specific and are used for local processing and application. There is no need for transmission and distribution of power.
- Renewable have low energy density and more or less there is no pollution or ecological balance problem.
- Most of the devices and plants used with the renewables are simple in design and construction which are made from local materials, local skills and by local people. The use of renewable energy can help to save foreign exchange and generate local employment.
- The rural areas and remote villages can be better served with locally available renewable sources of energy. There will be huge savings from transporting fuels or transmitting electricity from long distances.

Disadvantages of renewable energy

- Low energy density of renewable sources of energy need large sizes of plant resulting in increased cost of delivered energy.
- Intermittency and lack of dependability are the main disadvantages of renewable energy sources.
- Low energy density also results in lower operating temperatures and hence low efficiencies.
- Although renewable are essentially free, there is definite cost effectiveness associated with its conversion and utilization.
- Much of the construction materials used for renewable energy devices are themselves very energy intensive.
- The low efficiency of these plants can result in large heat rejections and hence thermal pollution.
- The renewable energy plants use larger land masses.

Lecture -2

Biomass energy

The material which has life is called Biomass. Other words, the material contained in the bodies of living organism (plants and animals) is said to be Biomass or plant matter/ organic matter. The energy obtained from organic matter, derived from biological organism is known as biomass energy.

Solar energy → Photosynthesis → Biomass → Energy generation

Biomass include wood, leaves, animal waste, crops, bones, and scales or any other organic matter and Biomass energy is the utilization of energy stored in this organic matter.

The ultimate source of bio mass energy is sun. Plants absorb the energy from the sun in a process called photosynthesis. The chemical energy stored in plants get passed on to animal and human beings that eat them. The average efficiency of photosynthetic conversions of solar energy into biomass energy is estimated to be 0.5 to 1.0 %.

Biomass is a renewable energy source. The organic matters are burned directly to produce heat or they are refined to produce fuel like ethanol or other alcoholic fuels.

Biomass characteristics

The main constituents of any biomass material are (i) lignin (ii) hemicellulose (iii) cellulose (iv) mineral matter (v) ash. Wood is a solid lingocellulose material naturally produced in tree and shrubs, made up 40-50 % cellulose, 20-30 % hemicellulose and 20-30 % lignin. The percentage of the above components of biomass varies from species to species. Evaluation of biomass resource as potential energy feedstocks generally requires information about their composition, heating value, production yields (in the case of energy crops) and bulk density.

Bio mass resources

Biomass resources for energy production are widely available in forest areas, rural farms, urban refuse and organic waste from agro-industries.

Biomass resources fall into three categories:

1. Biomass in its Traditional solid mass (*Wood and Agriculture residue*) To burn the bio mass directly
2. Biomass in its non-traditional solid mass (*converted into liquid fuels*) The biomass is converted into ethanol and methanol to used liquid fuel
3. *To ferment the biomass anaerobically* to obtain a gaseous fuel called biogas

Biomass conversion Routes in produce energy

1.	Physical	➢ Densification of biomass into solid briquettes
2.	Agrochemical	➢ Fuel extraction (solid & liquid) from freshly cut plant
3.	Thermo chemical	➢ Combustion ➢ Carbonization ➢ Pyrolysis ➢ Gasification ➢ Liquefaction ➢ Anaerobic diagestion to methane (Bio Gas)
4.	Biochemical	➢ Ethanol fermentation ➢ Hydrogen formation cell

Direct combustion for heat

Direct combustion is the simplest and most common method of capturing the energy contained within biomass. The technology is well understood and commercially available. Combustion or burning is a *exothermic* chemical reaction between a fuel (usually a hydrocarbon) and an oxidant accompanied by the production of heat or both heat and light. In a complete combustion reaction, a compound reacts with an oxidizing element, such as oxygen and the products are compounds of each element in the fuel with the oxidizing element.

Three things are needed for effective burning:

- High enough temperatures
- Enough air, and
- Enough time for full combustion

If not enough air gets in, combustion is incomplete and the smoke is black from the unburned carbon. If too much air gets in the temperature drops and the gases escape unburned, taking the heat with them. Therefore, the right amount of air is very important to gives the best utilization of fuel. One problem with this method is its very low efficiency (2-5 %). With an open fire most of the heat is wasted and is not used.

A simpler example can be seen in the combustion of hydrogen and oxygen:

$$\mathbf{2H_2 + O_2 \longrightarrow 2H_2O\ (g) + heat}$$ result is water vapour]

Types of combustion:

A. **Rapid:** Rapid combustion is a form of combustion in which large amounts of heat and light energy are released, which often results in a fire. This is used in a form of machinery such as internal combustion engines.
B. **Slow:** Slow combustion is takes place at low temperatures. Cellular respiration is an example of slow combustion

C. **Complete:** In complete combustion, the reactant will burn in oxygen, producing a limited number of products. When a hydrocarbon burns in oxygen, the reaction will only yield carbon dioxide and water. When a hydrocarbon or any fuel burns in air, the combustion products will also include nitrogen. The complete combustion is almost impossible to achieve.

D. **Incomplete:** Incomplete combustion occurs when there isn't enough oxygen to allow the fuel to react completely with the oxygen to produce carbon dioxide and water, also when the combustion is quenched by a heat sink such as a solid surface or flame trap.

Pyrolysis:

Biomass can be converted into gases, liquids and solids through pyrolysis at temperature of 200 to 500 °C by heating in a closed vessel in absence of oxygen. The residue is then the char - more commonly known as charcoal - a fuel which has about twice the energy density of the original and burns at a much higher temperature.

Pyrolysis is most commonly used for organic materials. It occurs spontaneously at high temperatures In general; it produces gas and liquid products and leaves a solid residue richer in carbon content. Pyrolysis is heavily used to produce charcoal, activated carbon, methanol and other chemicals from wood, to convert ethylene dichloride into vinyl chloride to make PVC, to convert biomass into syngas, to turn waste into safely disposable substances, and for the cracking of medium-weight hydrocarbons from oil to produce lighter ones like gasoline.

The products of pyrolysis of wood are nearly

1. charcoal -25 %
2. Wood gas -20 %
3. Pyroligneous acid -40 %
4. Wood oil -15 %

The rate of pyrolysis depends on several factors like

- Composition of material
- Heating rate
- Residence time
- Temperature level

Similarly, another term gasification is also the pyrolysis adopted to produce maximum amount of secondary fuel gases.

Gasification

Biomass gasification is a thermochemical decomposition process in controlled air. It is conversion process of solid, carbonaceous fuel into combustible gas mixture, normally known as **producer gas** (or wood gas, water gas, synthesis gas syngas)

This is done by partially burning and partially heating the biomass (using the heat from the limited burning) in the presence of charcoal (a natural by-product of burning biomass). The gas can be used in internal combustion engines.

Gasification is a process that converts carbonaceous materials, such as coal, petroleum, biofuel, or biomass, into carbon monoxide and hydrogen by reacting the raw material, such as house waste, or compost at high temperatures (>700°C) with a controlled amount of oxygen. Gasification is a method for extracting energy from many different types of organic materials. Almost any type of organic material can be used as the raw material for gasification, such as wood, biomass, or even plastic waste.

The advantage of gasification is that using the syngas is potentially more efficient than direct combustion of the original fuel. Syngas may be burned directly in internal combustion engines or used to produce methanol and hydrogen. Gasification of fossil fuels is currently widely used on industrial scales to generate electricity.

In essence, a limited amount of oxygen or air is introduced into the reactor to allow some of the organic material to be "burned" to produce carbon monoxide and energy, which drives a second reaction that converts further organic material to hydrogen and additional carbon dioxide.

Chemical reactions in gasification

Gasification is quite complex thermochemical process. Splitting of gasifier into strictly separate zone is not realistic, but nevertheless conceptually essential. Four distinct processes take place in a gasifier; drying of the fuel, pyrolysis, combustion and reduction.

Drying zone

Biomass fuels consist of moisture ranging from 5 to 35% at the temperature above 120 °C, the moisture is removed and converted to steam, in the drying, fuels do not experience any kind of decomposition. Depending on the kind of rector, the fuel composition and size of fuel drying may require several minutes to accomplish or may occur almost instantaneously.

Pyrolysis zone

At about 400°C, the complex structure of biomass begins to breakdown with the release of gases, vapours and liquid. Many of these released components are combustible and contribute significantly to the heating value of the product gas from the gasifier. The ratio of products is influenced by the chemical composition of biomass fuels and their operating condition. Reaction times range from milliseconds to minutes. Reaction yields range from mostly liquids to exclusively low molecular weight gases e.g. volatile gases, oil, char and tar.

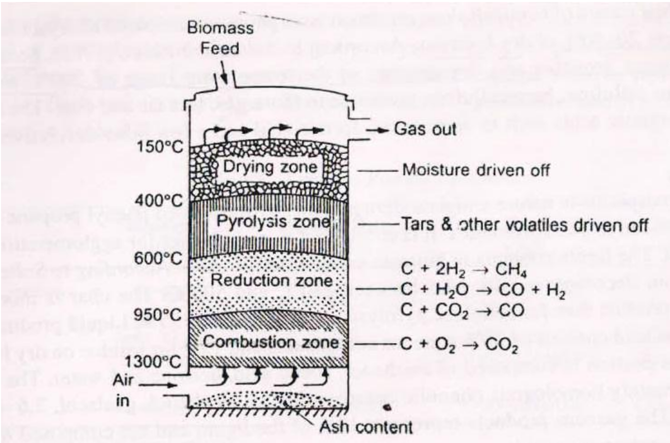
Oxidation/combustion zone

As the temperature approaches 700°C, the char begins to react with oxygen, introduced air in the oxidation zone contains inert gases such as nitrogen and argon besides oxygen and water vapours. The oxidation take place at the temperature of 700 to 1300°C. heterogeneous reaction take place between oxygen in the air and solid char fuel, producing carbon dioxide and water vapour

$$C + O_2 = CO_2 + 393800\ {}^{kJ}/_{kg\ mol}\ (Exothermic\ reaction))$$

Hydrogen in the fuel reacts with oxygen in the air blast, producing steam

$$H_2 + \frac{1}{2}O_2 = H_2O + 242000\ {}^{kJ}/_{kg\ mol}\ (Exothermic\ reaction)$$



Reduction Zone

In reduction zone, a number of high temperature chemical reactions take place in the absence of air. Most of the reactions are endothermic and the heat released during exothermic reaction in oxidation is also utilized in reaction zone. Hence temperature of gas goes down in this zone. The temperature in the zone ranges from 800-1000°C.

$$C + CO_2 = 2\,CO - 172600\frac{kJ}{kg\ mol}\ (Boudouard\ reaction)$$

$$C + H_2O = H_2 + CO - 131000\frac{kJ}{kg\ mol}\ (Water\ gas\ reaction)$$

$$CO + H_2O = CO_2 + H_2 + 42000\frac{kJ}{kg\ mol}\ (Water\ shift\ reaction)$$

$$C + 2H_2 = CH_4 + 75000\frac{kJ}{kg\ mol}\ (Hydrogeneration\ \ reaction)$$

Hence final gas produces in the gasifier is composed of mainly CO and H_2

Producer gas

- Producer gas obtained through gasification is the mixture of combustible and non-combustible gases
- The quantity of constituents of gas depends upon the type of fuel and operation

- Heating value of gas 4.5 to 6 MJ/m^2

Content of producer gas

1. Carbon monoxide -15 to 30 %
2. Hydrogen - 10 to 20 %
3. Methane - less than 4 %
4. Nitrogen -45- 60 % (non combustible)
5. Carbon dioxide - 5 to 15 % (non combustible)

Application of producer gas

Thermal application: cooking, water heating, stem generation, drying etc.
Motive power: I C engine as water pumping
Electricity: I C engine and gas turbine etc.

Type of Gasifiers

Gasifiers are generally classified according to the method of contacting fuel, direction of air / gas movement, type of bed and type of fuel used. The most important classification of gasifier is based on type of bed.

A. Fixed bed
    1. Up draught
    2. Down draught
    3. Cross draught

B. Fluidized bed

Up–Draft Gasifiers (Counter Current Gasifiers): In this design the biomass moves down wards as the gasification process goes on. The air is taken from the bottom of the gasifier and the producer gas leaves the gasifier from the top portion. This means the producer gas moves counter to the direction of flow of biomass. Wide variety of biomass feedstock is suitable for this design, even with relatively higher moisture contents. Since hot gases passes through biomass, the moisture is driven off. One of the major disadvantages of this design is that the pyrolysis products are not routed through combustion zone and hence the gas cleaning becomes very expensive.

- This type of gasifier is easy to build and operate
- The gas produced has practically no ash but contains tar and water vapour because of passing of gas through the un-burnt fuel.
- Up draft gasifiers are suitable for tar free fuels like charcoal

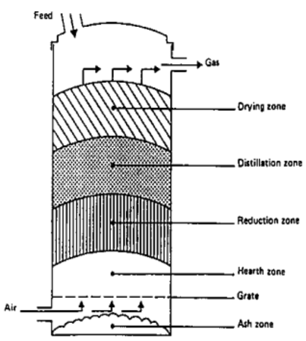


Fig. Updraft Gasifier

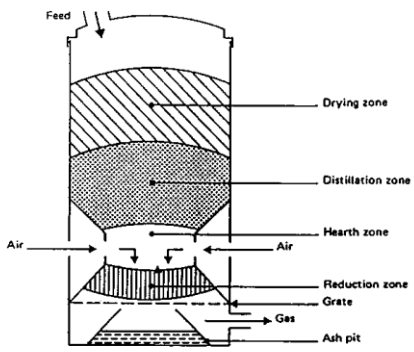


Fig. Down draft Gasifier

Downdraft Gasifier (Co current gasifiers): In this design, biomass is fed from the top and air intake is from the top or from the sides also. The producer gas is collected from the bottom of the reactor, moving in the same direction to biomass feeding and air. Since the producer gas moves through the hearth zone, the chances of proper combustion of tar and char are expected. This design requires biomass with minimum moisture content (+15%) and uniformity in size for proper pyrolysis. The producer gas carries away high temperatures, lowering the overall efficiency. Since the gas flows through oxidation zone chances of carrying higher amounts of ash, particulate matter in the gas necessitating efficient gas cleaning mechanism. The gasifiers are suitable for fuels like wood and agricultural wastes. They are cheap and easy to make. They may be used to power generation upto above 150 kW.

Cross Draft Gasifier: Cross-draught gasifiers, schematically illustrated in Figure 2.9 are an adaptation for the use of charcoal. Charcoal gasification results in very high temperatures (1500 °C and higher) in the oxidation zone which can lead to material problems. In cross draught gasifiers insulation against these high temperatures is provided by the fuel (charcoal) itself.

Advantages of the system lie in the very small scale at which it can be operated. Installations below 10 kW (shaft power) can under certain conditions be economically feasible. The reason is the very simple gas-cleaning train (only a cyclone and a hot filter) which can be employed when using this type of gasifier in conjunction with small engines.

A disadvantage of cross-draught gasifiers is their minimal tar-converting capabilities and the consequent need for high quality (low volatile content) charcoal.

It is because of the uncertainty of charcoal quality that a number of charcoal gasifiers employ the downdraught principle, in order to maintain at least a minimal tar-cracking capability.

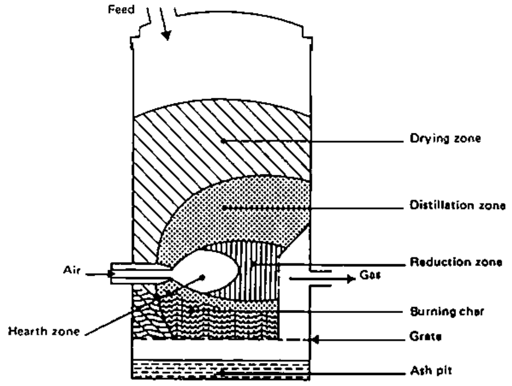


Fig. Cross draft Gasifier

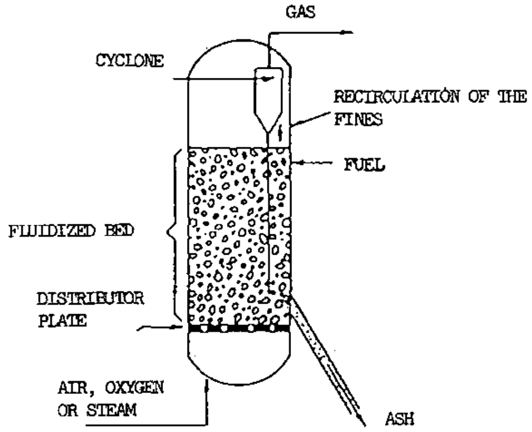


Fig. Fluidized bed gasifier

Fluidized bed gasifier: The operation of both up and downdraught gasifiers is influenced by the morphological, physical and chemical properties of the fuel. Problems commonly encountered are: lack of bunkerflow, slagging and extreme pressure drop over the gasifier. Air is blown through a bed of solid particles at a sufficient velocity to keep these in a state of suspension. The bed is originally externally heated and the feedstock is introduced as soon as a sufficiently high temperature is reached. The fuel particles are introduced at the bottom of the reactor, very quickly mixed with the bed material and almost instantaneously heated up to the bed temperature. As a result of this treatment the fuel is pyrolysed very fast, resulting in a component mix with a relatively large amount of gaseous materials. Further gasification and tar-conversion reactions occur in the gas phase. Most systems are equipped with an internal cyclone in order to minimize char blow-out as much as possible. Ash particles are also carried over the top of the reactor and have to be removed from the gas stream if the gas is used in engine applications.

The major advantages of fluidized bed gasifiers, and others, stem from their feedstock flexibility resulting from easy control of temperature, which can be kept below the melting or fusion point of the ash (rice husks), and their ability to deal with fluffy and fine grained materials (sawdust etc.) without the need of pre-processing. Problems with feeding, instability of the bed and fly-ash sintering in the gas channels can occur with some biomass fuels.

Other drawbacks of the fluidized bed gasifier lie in the rather high tar content of the product gas (up to 500 mg/m^3 gas), the incomplete carbon burn-out, and poor response to load changes.

Particularly because of the control equipment needed to cater for the latter difficulty, very small fluidized bed gasifiers are not foreseen and the application range must be tentatively set at above 500 kW (shaft power).

Lecture -3

Anaerobic diagestion to methane (Bio Gas)

Anaerobic digestion is the decomposition of organic waste to gaseous fuel by bacteria in an oxygen free environment. The process occurs in stages to successively break down the organic matter in to simpler organic compounds. The final product, known as biogas is a mixture of methane, carbon dioxide and some trace gases. Biogas is also known as the swamp gas, sewer gas, fuel gas, marsh gas, wet gas and in Indian more commonly as gobar gas.

Composition of biogas

Sr. No	Constituents	Formulae	Proportion in percentage
1	Methane gas	CH_4	50-65
2	Carbon dioxide	CO_2	30-45
3	Hydrogen	H_2	1- 3
3	Nitrogen	N_2	0-5
4	Oxygen	0_2	0.01
5	Hydrogen sulphide	M_2 S	1-2

Basics of anaerobic digestion

The treatment of any slurry or sludge containing a large amount of organic matter utilizing bacteria and other organisms under anaerobic condition is commonly referred as anaerobic digestion.

Anaerobic digestion consists of the following three phase.

(i) Hydrolysis phase,
(ii) Acid formation phase
(iii) Methane formation phase

Hydrolysis

Large molecules are breakdown into smaller size by enzymes which in turn are decomposable by bacteria. The organic substances such as polysaccharide, protein and lipid are converted into mono-saccharide, peptide, amino acids, and fatty acids. Then they are further converted into organic acids (acetate, propionate and butyrate). Cellulytica bacteria help to reduce chains and branches. Cellulytica bacteria is of two types mesophilic (30°- 40°) and thermophilic (50°- 60°).

Acid formation

Acid phase which simple organic materials are converted into simpler acids such as volatile fatty acids. Acetic acid is one common by-product of digestion of fats, starch and proteins. Methane bacteria are strictly anaerobic and can produce methane either by fermenting acetic acid to from methane and carbon dioxide, or by reducing carbon dioxide to methane using hydrogen gas. Acetic acid is to react with methaogenic bacteria resulting in methane formation. Acetic acid accounts for 70 % of methane produced.

Methane formation

Methanogenic bacteria react with acetic acid, ethyanol, carbon dioxide and hydrogen to produce methane. Methane forming bacteria slowly, in about 14 days at 25 °C complete the digestion. The remaining indigestible matter is referred as "slurry".

Cellulose + Nutrients

Extracellular Enzymes
Step-I (Hydrolysis)

$$(C_6H_{10}O_5)_n + nH_2O \xrightarrow{Hydrolysis} n(C_6H_{12}O_6)$$

Soluble glucose+ Nutrients

Acid Producing Bacteria
Step-II (Acid Phase)

$$C_6H_{12}O_6 = 2CH_3.CHOH.COOH$$

Lactic Acid

$$C_6H_{12}O_6 = CH_3CH_2.CH_2.COOH + 2CO_2 + 2H_2$$

Butyric Acid

$$C_6H_{12}O_6 = 2CH_3CH_2.OH + 2CO_2$$

Ethyl alcohol

$$+ \begin{bmatrix} Volatile \\ fatty\ acid \end{bmatrix} + CO_2 + H_2 + \begin{bmatrix} Other\ products \\ alcohols, lactate.etc \end{bmatrix}$$

Methane Producing Bacteria
Step-III (Methane Phase)

$$4H_2 + CO_2 = CH_4 + H_2O$$

$$2CH_3.CH_2.OH + CO_2 = 2CH_3.COOH + CH_4$$

$$CH_3.COOH = CH_4 + CO_2$$

$$2CH_3.CH_2.CH_2.COOH + 2H_{2+}CO_2 = 4CH_{3.}COOH + CH_4$$

$$CH_4 + CO_2$$

Details of biochemistry of anaerobic digestion process

Optimum conditions for biogas production

Parameters	**Optimum value**
Temperature	30-35 °C
pH	6.8-7.5
C/N Ratio	20-30:1
Solid content	8-10 %
Retention time	20-50

Feedstock for biogas plants

- ✓ Animal wastes:
- ✓ Human wastes
- ✓ Kitchen wastes
- ✓ Agriculture Wastes
- ✓ Aquatic plants
- ✓ Municipal wastes
- ✓ Industrial wastes
- ✓ Hens and ducks droppings

The calorific values of different fuels

Commonly used fuels	Calorific values in K.Cal.
Bio-gas	$4713/M^3$
Dung cake	2093/Kg
Firewood	4978/Kg
Diesel (HSD)	10550/Kg
Kerosene	10850/Kg
Petrol	11100/Kg

Factors involved in biogas production

Biogas production involves different physical, chemical and biological process for conversion of biodegradable organic materials to energy rich gas.

C/N ratio

The ratio of carbon to nitrogen present in the feed material is called C:N ratio. It is a crucial factor in maintaining perfect environment for digestion. Carbon is used for energy and nitrogen for building the cell structure. Optimum condition for anaerobic digestion to take place ranges from 20 to 30:1. This means the bacteria use up carbon about 20 to 30 times faster than they use up nitrogen.

When there is too much carbon in the raw astes, nitrogen will be used up first and carbon left over. This will make the digestion slow down and eventually stops. On the other hand if there is too much nitrogen, the carbon soon becomes exhausted and fermentation stops. The nitrogen left over will combine with hydrogen to form ammonia. This can kill or inhibit the growth of bacteria specially the methane producers.

Temperature:

Temperature affects the rate of reaction happening inside the digester. Increase in the ambient temperature increases the rate of reaction thus increasing the biogas production as well. Methane bacteria work best at a temperature of 35° - 38° C. The fall in gas production starts at 20°C and stops at a temperature of 10°C. Studies hawed that 2.25 m^3 of gas was produced from 4.25m^3 of cattle dung everyday when the digester temperature was 25°C. When the temperature rose to 28.3°C the gas production was increased by 50 per cent to 3.75 m° per day.

Retention time:

It is the theoretical time that particular volume of feedstock remains in the digester. In other words, retention time describes the length of time the material is subjected to the anaerobic reaction. It is calculated as the volume of digester divided by the feedstock added per day and it is expressed in days. Under anaerobic condition, the decomposition of the organic substances is slow and hence need to keep for long time to complete the digestion. In case of Indian digesters, where the feed stock is diluted with equal composition, so demarcation prevails between solid and liquid. In this case, biomass in the form of bacteria is washed out; hence the solid retention time (SRT) is equal to hydraulic retention time (HRT).

Loading rate

Loading rate is defined as the amount of raw material fed to the digester per day per unit volume. If the reactor is overloaded, acid accumulation will be more obviously affecting daily gas production. On the other hand, under loading of digester have negative impact in designed gas production.

Toxicity:

Though small quantities of mineral ions like sodium, potassium stimulates the growth of bacteria, the high concentration of heavy metals and detergents have negative impact in gas production rate. Detergents like soap, antibiotics, and organic solvents are toxic to the growth of microbes inside the digester. Addition of these substances along with the feed stock should be avoided.

pH or hydrogen ion concentration

To maintain a constant supply of gas, it is necessary to maintain a suitable pH range in the digester. pH of the slurry changes at various stages of the digestion. In the initial acid formation stage in the fermentation process, the pH is around 6 or less and much of CO_2 is given off. In the letter 2-3 weeks times, the pH increase as the volatile acid and N_2 compounds are digested and CH_4 is produced. The digester is usually buffered if the pH is maintained between 6.5 and 7.5. In this pH range, the micro – organisms will be very active and digestion will be very efficient. If the pH range is between 4 and 6 it is called acidic. If it is between 9 and 10 it is called alkaline. Both these are detrimental to the methanogenic (Methane production) organisms.

Total solid content

The raw cow dung contains 80-82% of moisture. The balance 18-20% is termed as total solids. The cow dung is mixed usually in the proportion of 1:1 in order to bring the total solid content to 8-10%. This adjustment of total solid content helps in digesting the materials at the faster rate and also in deciding the mixing of the various crop residues as feed stocks in biogas digester.

Feed rate

One of the prerequisites of good digestion is the uniform feeding of the digester so that the micro – organisms are kept in relatively constant organic solids concentration at all times. Therefore the digester must be fed at the same time every day with a balanced feed on the same quality and quantity.

Diameter to depth ratio

Studies reveal that gas production per unit volume of digester capacity was maximum, when the diameter to depth ratio was in the range of 0.66 to 1.00. One reason may be that because in a simple unstirred single stage digester the temperature varies at different depths. The most activity digesting sludge is in the lower half of the digester and this is less affected by changes in night and day temperature.

Nutrients

The major nutrients required by the digester are, C, H_2, O_2 N_2 P and S, of these nutrients N_2 and P are always in short supply and therefore to maintain proper balance of nutrients and extra raw material rich in phosphorus (night soil, chopped leguminous plants) should be added along with the cow dung to obtain maximum production of gas.

Degree of mixing

Bacteria in the digester have very limited reach to their food, it is necessary that the slurry is properly mixed and bacteria get their food supply. It is found that slight mixing improves the fermentation; however a violent slurry agitation retards the digestion.

Type of feed stocks

All plant and animal wastes may be used as the feed materials for a digester. When feed stock is woody or contains more of lignin, then digestion becomes difficult. To obtain as efficient digestion, these feed stocks are combined in proportions, Pre-digestion and finely chopping will be helpful in the case of some materials. Animal wastes are pre-digested. Plant wastes do not need pre-digestion. Excessive plant material may choke the digester.

Lecture -4

Types of biogas plants:

Biogas plants basically are two types

1. Floating dome type
   Eg. KVIC-type (KVIC- Khadi Village Industries Commission)
2. Fixed dome type
   E.g. Deenabandu model

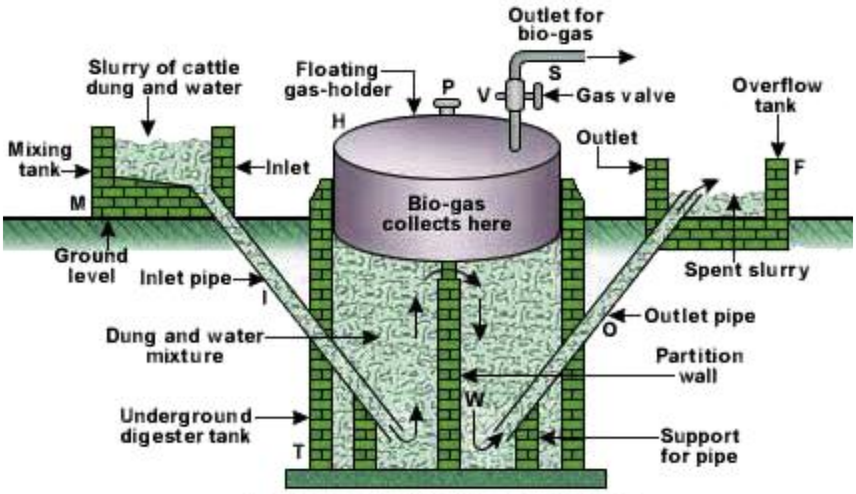
Base Pre-requisites of Biogas Plant Installation:

- The land should be leveled and at a higher elevation than the surroundings to avoid runoff water and soil should not be too loose of the area.
- The plant should be nearer to the place of gas use and to the cattle shed/ stable for easy handling of raw materials.
- The ground water table should not be very high.
- Adequate supply of water should be there at the plant site.
- The plant should get clear sunshine during most part of the day and the plant site should be well ventilated as methane mixed with oxygen is very explosive.
- A minimum distance of 1.5m should be kept between the plant and any wall or foundation or any source of drinking water purpose.
- It should be away from any tree to make it free from failure due to root interference.
- There should be adequate space for construction of slurry pits.
- Mechanical agitation of the scum layer and slight stirring of slurry improves gas production.
- The solid content in the slurry should be maintained between 7.5 to 10 per cent for optimum gas production.
- A carbon to nitrogen ratio of 20: 1 to 30: 1 is found to be optimum for bio-gas production. The CN ratio of cattle dung if approximate 25:1.

KVIC type biogas plant

This mainly consists of a digester or pit for fermentation and a floating drum for the collection of gas. Digester is 3.5-6.5 m in depth and 1.2 to 1.6 m in diameter. There is a partition wall in the center, which divides the digester vertically and submerges in the slurry when it is full. The digester is connected to the inlet and outlet by two pipes. Through the inlet, the dung is mixed with water (4:5) and loaded into the digester. The fermented material will flow out through outlet pipe. The outlet is generally connected to a compost pit. The gas generation takes place slowly and in two stages. In the first stage, the complex, organic substances contained in the waste are acted upon by a certain kind of bacteria, called acid formers and broken up into small-chain simple acids. In the second stage, these acids are acted upon by another kind of bacteria, called methane formers and produce methane and carbon dioxide.

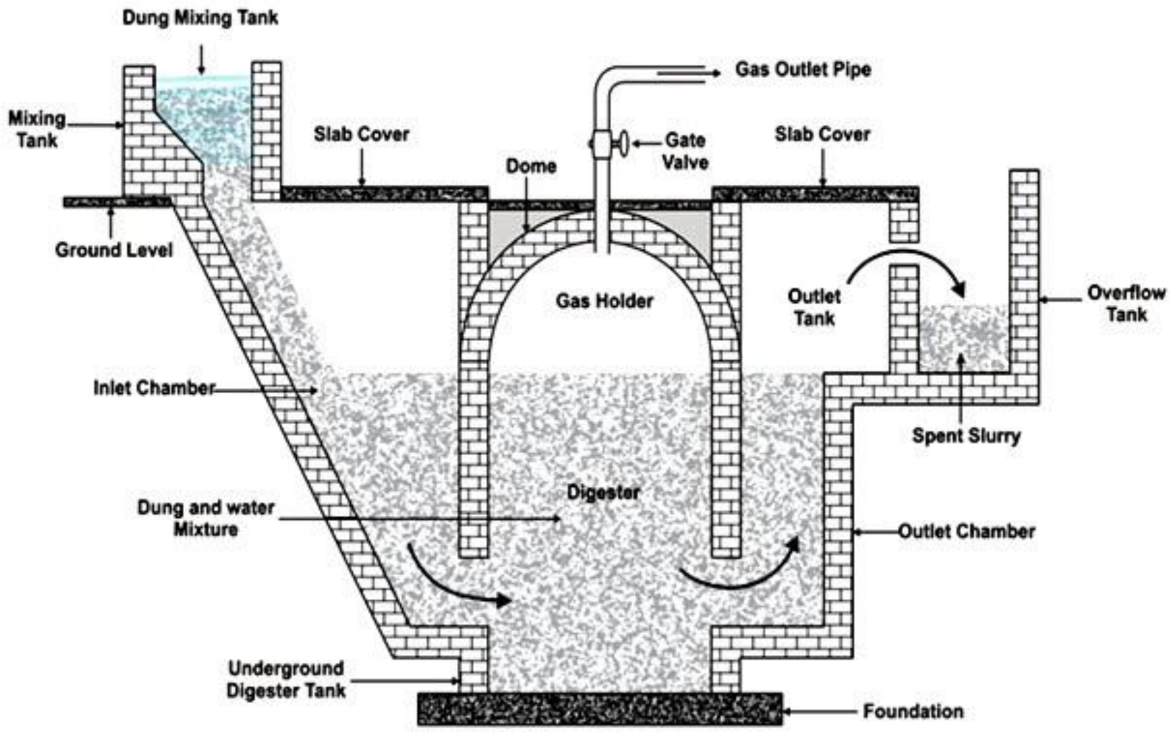
Gas holder: The gas holder is a dum constructed of mild steel sheets. This is cylindrical in shape with concave. The top is supported radically with angular iron. The holder fits into the digester like a stopper. It sinks into the slurry due to its own weight and rests upon the ring constructed for this purpose. When gas is generated the holder rises and floats freely on the surface of slurry. A central guide pipe is provided to prevent the holder from tilting. The holder also acts as a seal for the gas. The gas pressure varies between 7 and 9 cm of water column. Under shallow water table conditions, the adopted diameter of digester is more and depth is reduced. The cost of drum is about 40% of total cost of plant.



Floating gas-holder type bio-gas plant.

Janata type biogas plant:

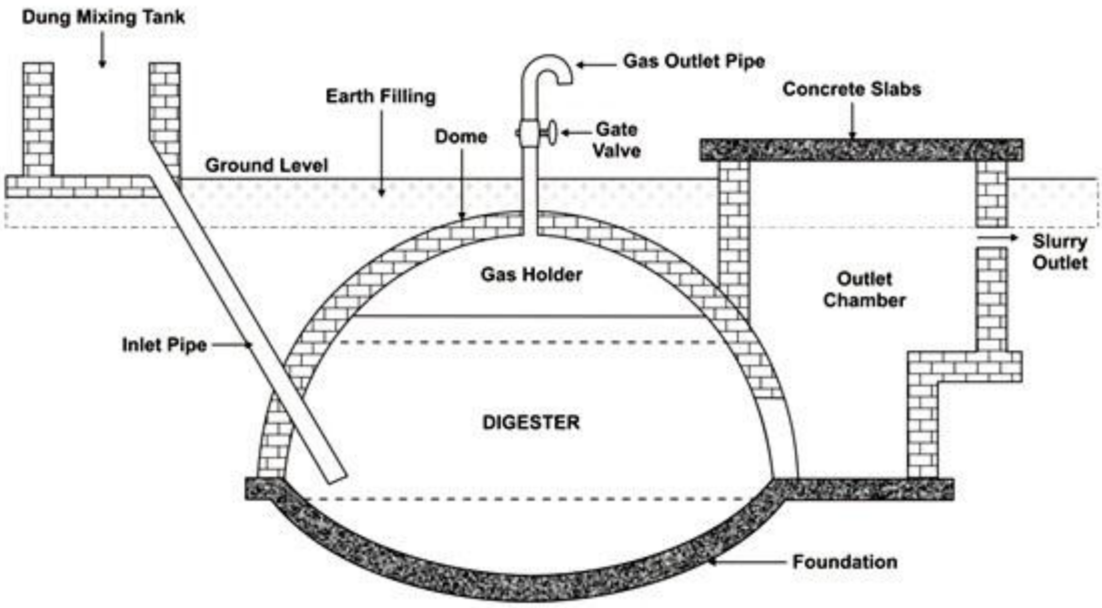
The design of this plant is of Chinese origin but it has been introduced under the name "Janata biogas plant" by Gobar Gas Research Station, Ajitmal in view of its reduced cost. This is a plant where no steel is used, there is no moving part n it and maintenance cost is low. The plant can be constructed by village mason taking some pre-explained precautions and using all the indigenously available building materials. Good quality of bricks and cement should be used to avoid the afterward structural problems like cracking of the dome and leakage of gas. This model have a higher capacity when compared with KVIC model, hence it can be used as a community biogas plant. This design has longer life than KVIC models. Substrates other than cattle dung such as municipal waste and plant residues can also be used in janata type plants. The plant consists of an underground well sort of digester made of bricks and cement having a dome shaped roof which remains below the ground level is shown in figure. At almost middle of the digester, there are two rectangular openings facing each other and coming up to a little above the ground level, act as an inlet and outlet of the plant. Dome shaped roof is fitted with a pipe at its top which is the gas outlet of the plant. The principle of gas production is same as that of KVIC model. The biogas is collected in the restricted space of the fixed dome; hence the pressure of gas is much higher, which is around 90cm of water column.



Janta model biogas plant

Deenbandhu biogas plant:

Deenbandhu model was developed in 1984, by Action for Food Production (AFPRO), a voluntary organization based in New Delhi. Schematic diagram of a Deenbandhu biogas plant entire biogas programme of India as it reduced the cost of the plant half of that of KVIC model and brought biogas technology within the reach of even the poorer sections of the population. The cost reduction has been achieved by minimizing the surface area through joining the segments of two spheres of different diameters at their bases. The Deenbandu biogas plant has a hemispherical fixed-dome type of gas holder, unlike the floating dome of the KVIC-design is shown. The dome is made from pre-fabricated ferrocement or reinforced concerete and attached to the digester, which has a curved bottom. The slurry is fed from a mixing tank through an inlet pipe connected to the digester. After fermentation, the biogas collects in the space under the dome. It is taken out for use through a pipe connected to the top of the dome, while the sludge, which is a by-product, comes out through an opening in the side of the digester. About 90 precent of the biogas plants in India are of the Deenbandhu type.



Deenbandhu model biogas plant

Comparison of floating and fixed gas holder type plants:

Floating gas holder type biogas plant		fixed gas holder type plants	
1	Initial cost of plant is high.	1	Initial cost, of plant is low
2	Floating gas holder is made up iron plate and has tendency of rusting and corrosion	2	No such problems of rusting and corrosion as there is no floating gas holder.
3	Maintenance expenditures are high.	3	Maintenance expenditures are low.
4	Life of plant is lower due to floating lias holder which may last, few years.	4	Life of plant is higher.
5	Plant, is not underground due floating gas holder hence land occupied by plant cannot be used for any other purposes.	5	Plant is under ground the upper land can be used for other purposes.
6	Its performance is very much affected by temperature variations.	6	Its performance is not much affected by temperature variations.
7	Other forms of biomass cannot be used except gobar and human excretes	7	Other forms biomass such as agro waste and municipal wastes can be used with some

			modifications.
8	Pressure of gas remains constant	8	Pressure of gas increases with increased gas production decrease with gas consumption.
9	Gas holder lank is needed to be fabricated in workshop and transported to the site	9	Separate gas holder is not required.
10	Fault finding and repairs are easy	10	Fault finding and repairs arc not easy
11	Higher depth of plant requires deeper excavation of land.	11	Lower depth of excavation reduces the cost of construction.

Gas consumption

Gas is used as cooking fuel but it is not yet used in lighting or power generation purposes in the developing country. Hence the size of biogas plant is decided on the basis number of persons in the family, types of food habit, types of utensils used in cooking etc. Daily need of gas per person varies from 0.28 to 0.42 cubic meter.

Following table shows the gas requirements for different applications.

Sr.	Applications	Requirement	Gas consumption in m^3/hr
1	Cooking	One person per day	0.24
2	Gas lighting	40 candle power	0.07
3	Mental lamp	100 candle power	0.13
4	Gas engine	Per one HP	0.45
5	Petrol engine	Per one liter petrol	1.4
6	Diesel engine	Per one liter diesel	1.6
7	Electric appliances	Per kwh or unit of electricity	0.60

Advantages and disadvantages of biogas:

Advantages:

1. Cost of equipments used for making biogas is less and equipments used are very simple.
2. Waste product obtained from digester is best quality of fertilizer and gives best yields.
3. Biogas can be used for lighting, running the engines, farms machines and cooking gas in the kitchen.
4. Distribution of gas has no problems of any gas leakages and fire.
5. Biogas is a best medium for cooking food.

6. Organic feed stocks used in the plants are easily available at all places..
7 Biogas plant gives efficiency as much as 60.

Disadvantages:

1 Biogas produced from biogas plant has to be used at nearby places only. It cannot be transported over long distances.
2 Biogas cannot be filled in the bottles.
3 Biogas plants require more area.
4 It cannot be established in urban area where availability of land is limited.

Gas production in different feed stocks

Different types of feed stocks give different rate of gas production. The size of digester can be determined by the types of biomass feed stocks. Following table shows rate of gas production from varieties of feed stocks:

Sr. No	Type of biomass	Nos of catties	Gas produced per kg of biomass in m^3	Daily gas availability in m^3
1	Cow dung	10	0.36	0.36
2	Buffalo dung	10	0.36	0.36
3	Morse dung	15	0.36	0.54
4	Pig dung	02	0.078	0.18
5	Chicken droppings	018	0.062	0.011
6	Human excrete	0.40	0.072	0.028

Plant size, feed stock, and gas consumption in cooking:

Sr.	Plant size in m^3	Daily biomass in kg	No. of cattle	No Cross breed cattle	Cooking needs in no. of persons
1	1	25	2	1	Up to 4
2	2	50	4	2	48
3	3	75	6	3	8 12
4	4	100	8	4	12 16
5	6	150	12	6	20 24
6	8	200	16	8	30 34
7	10	250	20	10	40 45
8	15	375	30	15	50 55
9	20	500	40	20	80 85

Lecture -5

Design of digester

The energy available from a biogas digester is given by

$$E = \eta H_b V_b$$

Where, η is the combustion efficiency of burner, boiler etc. (~60 %) H_b the heat of combustion per unit volume of biogas and V_b the volume of biogas.

$$E = \eta H_m f_m V_b$$

Where, Hm is the heat of combustion of methane and fm the fraction of methane in the biogas

The volume of biogas is given by

$$V_b = CM_0$$

Where, C is the biogas yield per unit dry mass of whole input dry mass of whole input and M_0 is the mas of dry input.

The volume of fluid in the digester is given by

$$V_f = \frac{M_0}{\rho_m}$$

Where, ρ_m is the density of dry matter in the fluid

The volume of the digester is given by

$$V_d = V_f t_r$$

V_f is the flow rate of the digester fluid (water) and t_r is the retention time in the digester.

Exampal:1. Design an appropriate size of biogas plant for a family of 8 members owing two bullocks, one buffalo and 2 calves. The gas is required for cooking food and lighting one lamp of 100 candle power for 2h daily (As same density of slurry (p) = 1090 kg/m³)

Solution: Bullock dung = 2 x 15 = 30 kg

Buffalo dung = 1 x 15 = 15 kg

Calves dung = 5 x 2 = 10 kg

Total dung = 55 kg

We know that

1 kg dung produces 0.036 m³ gas

Total gas produced = 55 x 0.036 m³/day

=1.98 m³/day

1 day cooking required 0.24 m³/person

Gas required for cooking = 0.24 x 8

= 1.92 m³/person per hour

For lighting purpose = 0.13 m³/hour

For 2 hours = 0.13 x 2

= 0.26 m³/person

Total gas required = 1.92 + 0.26

= 2.18 m^3/daily use

Density of slurry = 10.99 kg/m^3

Wt of total charge = 55 + 55 = 110 kg/day

Volume of charge = 110/1090 = 0.1009 m^3

Digester volume = volume of daily charge x Re

= 0.1109 x 30 days

= 3.027 m^3

10 % extra is taken for digester volume

= 1.1 x 3.027

Digester volume = 3.33 m^3

$\pi/4 \times D^2 \times h = 3.33\ m^3$

Where d = diameter of digester

h = height of digester, D = 0.6 h

Or $\pi/4 \times (0.6h)^2 \times h = 3.33$

$h^3 = 3.33 \times \pi/4 \times 1/(0.6)^2$

$h^3 = 11.78\ m^3$

h = 2.275

And D = 0.6 x 2.275 = 0.6 x 2.275. = 1.365

Example:2. Calculate the theoretical power available of an ORP – 12 PV 500 wind mill at 12 mph wind speed

Power = ½ $\rho V^3 A$

Where, P = power of the wind mill watts

ρ = Air density 1.2 kg/m^3 at sea level

V = Wind velocity m/s

A = Frontal area of wind mill m^2 Rotor diameter = 5m

V = 12 x 1000/ 60 x 60 = 10/3 = 3.3 m/s

$P = ½ \times 1.2 \times (10/3)^3 \times (\pi/4) \times 5^2$

= 430 Watts

Example:3 Calculate the power of above wind mill at 24 km/h speed

Solution: We know that $P \infty V^3$

P_1 = 430 watts V_1 = 12 km/h

P_2 = ? V_2 = 24 km/h

$P_2 = P_1 (V_1/V_2)^3$

= 430 $(24/12)^3$

= 430 x 8

= 3440 watts

= 3.44 KW

Example:3 Calculate the power generation of a standalone wind energy generator of 50 m diameter at 40 km/h speed. The overall conversion efficiency of the machine is 40 % (percent)

$P = \frac{1}{2} \rho \, n \, V^3 A$ Watts

$V = 40 \times 1000/ 60 \times 60$

$= 109/9$ m/s

$A = \pi/4 \, D^2$

$= 3.14/4 \times 50 \times 50$

$= 1962 \, m^2$

Calculation of size of biogas plant:

Example: A farmer family has 7 members and 2 cows, 2 baby cows an d 1 buffalo. Calculate the size of biogas for this family.

- 1 cow gives 10 kg gobar and 0.36 m^3 gas
- 1 baby cow gives 5 kg gobar and 0.27 m^3 gas
- 1 buffalo gives 15 kg gobar and 0.54 m^3 gas

(1) Availability of biomass:

On the basis of we can calculate the daily biomass availability and essential gas production

2 cows give	20 kg gobar	0.72 m^3 gas
2 baby cows give	10 kg gobar	0.72 m^3 gas
1 buffalo give	10 kg gobar	0.54 m^3 gas

Total availability of gas 1.58 m^3 gas

(2) Gas consumption for the family:

6 members of the family shall consume	1.44 m^3 gas
100 candle lamp for 3 hours shall need	0.26 m^3 gas
Totally daily gas required	1.70 m^3 gas

Availability of gas on biomass availability is 1.58 m^3 gas while requirement of gas is 1.70 m^3 gas daily. Hence it is necessary to set up biogas plant of daily production capacity 2.00 m^3 gas to suffice the family need for energy. Of course family shall need to obtain additional biomass to run the plant at full capacity and to satisfy entire needs.

On the basis of gas consumption

Gas is used as cooking fuel but it is not yet used in lighting or power generation purposes in the developing country. Hence the size of biogas plant is decided on the basis number of persons in the family, types of food habit, types of utensils used cooking etc. Daily need of gas per person varies from 0.28 to 0.42 cubic meters. Following table shows the gas requirements for different applications.

Sr.	**Applications**	**Requirements**	**Gas consumption in m^3/hr**
1	Cooking	One person per day	0.24
2	Gas lighting	40 candle power	0.07

3	Mental lamp	100 candle power	0.13
4	Gas engine	Per one HP	0.45
5	Petrol engine	Per one liter petrol	1.4
6	Diesel engine	Per one liter diesel	1.6
7	Electric appliances	Per kwh or unit of electricity	0.60

On the basis of type of biomass:

Different types of feed stocks give different rate of gas production. The size digester can be determined by the types of biomass feed stocks. Following table shows rate of gas production from varieties of feed stocks.

Sr.	Type of biomass	Normal manual Kg/day	Gas produced per kg of biomass in m³/kg	Daily gas availability in m³
1	Cow dung	10	0.036	0.36
2	Buffalo dung	15	0.036	0.36
3	Pig dung	02	0.078	0.18
4	Chicken droppings	0.18	0.062	0.011
5	Human excrete	0.40	0.072	0.028

Example: Calculate (i) the volume of a biogas digester suitable for the output of six cows and (ii) the power available from the digester. The retention time is 14 days, temperature, 30°C; dry matter consumed 2.5 kg/day biogas yield, 0.24 m^3/kg, burner efficiency, 0.6; methane proportion 0.7; density of dry matter, 50 kg/m^3.

Solution: The mas of dry input (M_o) = 2.5 ×6 =15 kg/day

Fluid volume

$$V_f = \frac{M_0}{\rho_m}$$

ρ_m is the density of dry matter in the fluid

$$= \frac{15}{50} = 0.3\, m^3/day$$

The volume of the digester is given by

$$V_d = V_f t_r$$

V_f is the flow rate of the digester fluid (water) and t_r is the retention time in the digester.

$$= 0.3 \times 14 = 4.2\ m^3$$

The volume of biogas is given by

$$V_b = CM_0$$

Where, C is the biogas yield per unit dry mass of whole input dry mass of whole input and M_0 is the mas of dry input.

$$=0.24\times15=3.6$$

Energy available from a biogas digester

$$E = \eta\, H_m\, f_m V_b$$

Where, H_m is the heat of combustion of methane and f_m the fraction of methane in the biogas

E= 0.6×28×0.7×3.6= 42.336 MJ/day= 11.76kWh/day

Lacture-6

Bio fuels

Bio-diesel is a fuel, made from natural (biological) renewable resources which can be used directly in conventional diesel engines. Unlike fossil diesel, pure bio-diesel is biodegradable, non-toxic, essentially free of sulphur and aromatics and releases less emissions during combustion. Bio-diesel some times called FAME (fatty acid methyl ester) or FAEE (fatty acid ethyl ester). It can be produced from edible oils such as palm oil, soyabean oil, rape seed oil, sunflower oil and some other vegetable oils; animal fats and non-edible oils like jatropha, castor beans, pongamia pinnata. In Europe, rapeseed oil is the major feed stock used to make bio-diesel, with some sunflower oil is also used. Soyabean oil is the major feed stock to make the bio-diesel in USA. In tropical and subtropical countries, there are wider feed stocks have been considered including edible and non-edible oils. However, using edible oils to produce bio- diesel is not encouraged in China because China imports more than 400 million tones edible oils annually to satisfy its consumption needs. They tried to make biodisel from recycled waste oils but the scale of production is limited due to higher operating cost. One negative aspect of biodiesel is that, the purity of biodiesel changes during storage due to oxidative and hydrolytic reactions and availability of feed stock (raw material) for production.

Advantages of biodiesel

1. Produced from sustainable / renewable biological sources
2. Eco-friendly and oxygenated fuel
3. Sulphur free, less CO, HC, particulate matter and aromatic compounds emissions
4. Income to rural community
5. Fuel properties similar to the conventional fuel
6. Used in existing unmodified diesel engines

Production methods:

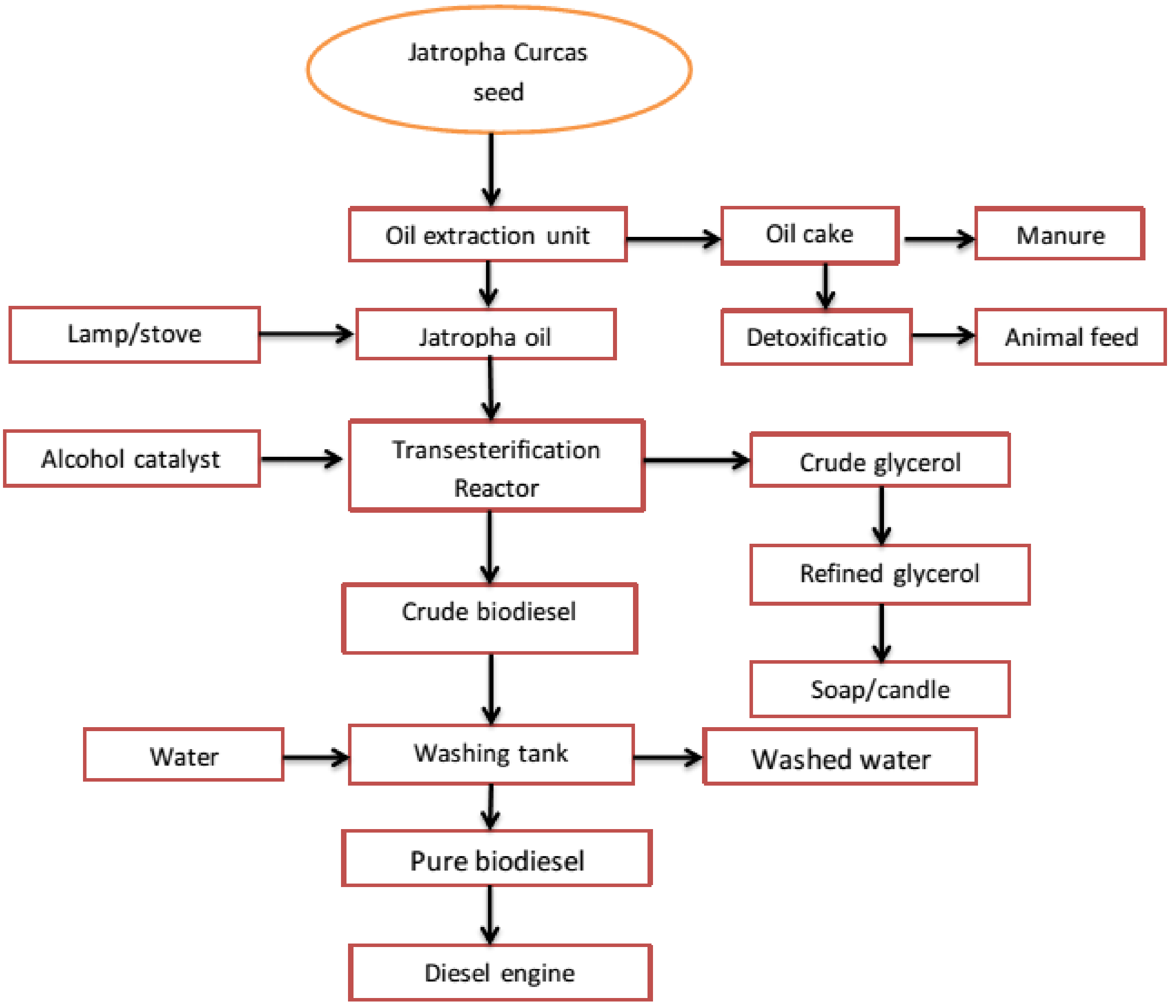
1. Preparation: care must be taken to monitor the amount of water and free fatty acids in the incoming biolipid (oil or fat). If the free fatty acid level or water level is too high it may cause problems with soap formation and the separation of the glycerin by-product downstream.
2. Catalyst is dissolved in the alcohol using a standard agitator or mixer.
3. The alcohol/catalyst mix is then charged into a closed reaction vessel and the biolipid (vegetable or animal oil or fat) is added. The system from here on is totally closed to the atmosphere to prevent the loss of alcohol.
4. The reaction mix is kept just above the boiling point of the alcohol (around 70 °C) to speed up the reaction. Some systems recommend the reaction take place anywhere from room temperature to 55 °C for safety reasons. Recommended reaction time varies from 1 to 8 hours; under normal conditions the reaction rate will double with every 10

°C increase in reaction temperature. Excess alcohol is normally used to ensure total conversion of the fat or oil to its esters.

5. The glycerin phase is much denser than biodiesel phase and the two can be gravity separated with glycerin simply drawn off the bottom of the settling vessel. In some cases, a centrifuge is used to separate the two materials faster.
6. Once the glycerin and biodiesel phases have been separated, the excess alcohol in each phase is removed with a flash evaporation process or by distillation. Care must be taken to ensure no water accumulates in the recovered alcohol stream.
7. The by-product (i.e., glycerin) contains unused catalyst and soaps, which are neutralized with an acid and sent to storage as crude glycerin.
8. Once separated from the glycerin, the biodiesel is sometimes purified by washing gently with warm water to remove residual catalyst or soaps, dried, and sent to storage.
9. Reduce expenditure on oil imports
10. Nontoxic, biodegradable and safety to handle

Biodiesel production

The process flowchart for biodiesel production from Jatropha curcas seeds and by products is shown in figure .



Ethanol from agricultural produce (Sugar cane and corn)

Non-petroleum fuels liquid fuels find use when petroleum fuels are scarce or costly. The scientists have been in search of new fuels to replace conventional fuels that are used in IC engines. Among all the fuels, alcohols, which can be produced from sugarcane waste and many other agricultural products, are considered the most promising fuels for the future. There are two types of alcohols: methanol (CH_3OH) and ethanol (C_2H_5OH). Ethanol has attracted a lot of attention as a transport fuel because it is relatively cheap non- petroleum-based fuel. Also, the emissions from the combustion of ethanol are much less than for fossile fuels. Ethanol, being a pure compound, has a fixed set of physical as well as chemical properties. This is in contrast to petrol and diesel, which are mixtures of hydrocarbons. But in countries like India, ethanol is a strong candidate since they posses the agricultural resources for it production. It is a more attractive fuel for India because the productive capacity from sugarcane crops is high, of the order of 1345 l/ha. Earlier, this fuel was not used in automobiles due to low energy density, high production cost and corrosion. The current shortage of gasoline has made it necessary to substitute ethanol as fuel in SI engines. At present, Brazil is the only country that produces fuel alcohol on a large scale from agricultural products (mainly sugarcane). Brazil was the first and biggest producer of cheapest bio-ethanol in the world. Second cheapest bio-ethanol is made from corn in the USA. Properties of ethanol and methanol are similar, with difference of only 5 -10%. Ethanol is superior to methanol as it has wider ignition limit (3.5 -17) than methanol (2.15 -12.8). Ethanol calorific value (26,880 kJ/kg) is considerably higher than methanol (19,740 kJ/kg). Ethanol is a much more superior fuel for diesel engines as its cetane number is compared to the cetane number of 3 for methanol. Ethanol is used in racing cars due to its very high heat of vaporization.

Manufacture of ethanol

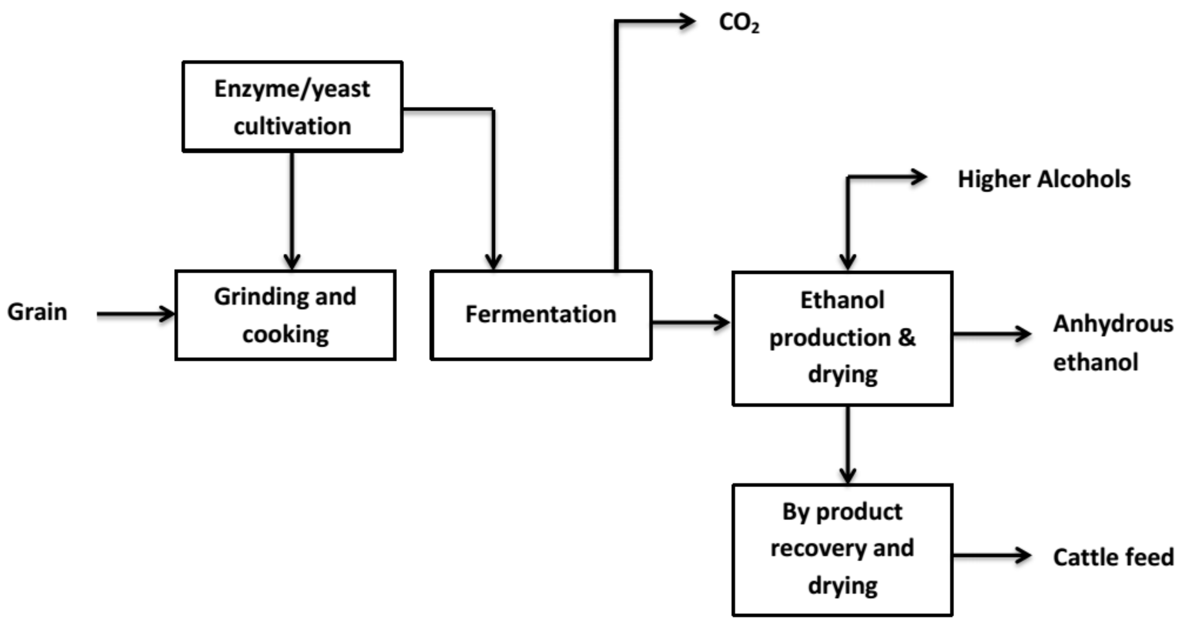
Three different feed stocks are available for ethanol production such as, sugar feed stock i.e., sugarcane and sugar beet; starch feed stock i.e., cereal grains and potato and cellulose feed stock i.e., forest products and agricultural residues.

Ethanol from starchy feed stock (grains

Ethanol production from cereal grains such as barley, wheat and corn is a much easier process than from cellulose material. The process includes several steps, as listed below:

a) Milling of grains
b) Hydrolysis of starch to sugar units
c) Fermentation by yeas
d) Distillation
e) Removal of water from ethanol

After grinding the raw material, it is mixed with water and enzymes to break down the starch to sugar units. The free sugar can be used by yeast or bacteria and converted to ethanol and carbon dioxide. As the concentration of ethanol increases to about 15%, fermentation is reduced, since high alcohol concentration kills the yeast or bacteria. It is then necessary to separate the ethanol from the other material in the fermentation tanks by distillation. Distillation increases the ethanol concentration up to about 95%. In order to remove the rest of the water from the ethanol solution, it must be dried by different drying agents to a concentration of 99.5% ethanol or absolute ethanol. Extractive distillation with benzene also yields anhydrous ethanol. It is possible to produce 1 litre of absolute ethanol from about 3 kg of wheat. The process flow chart for production of ethanol from grains is shown in fig.

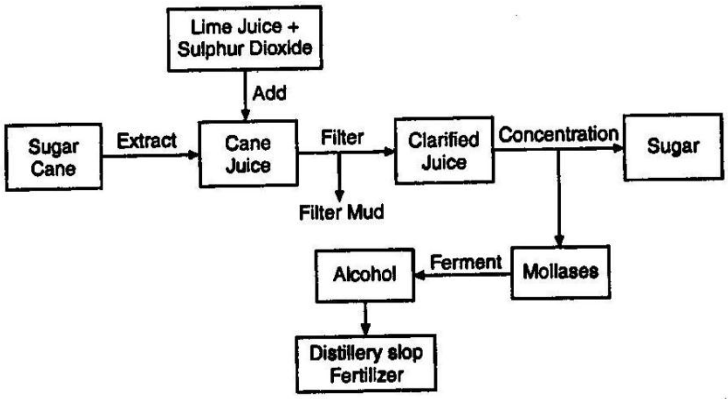


Process flow chart for the production of ethanol from corn

Ethanol production from sugar cane:

Ethanol production from sugarcane is one of the easiest and most efficient processes since sugarcane contains about 15% sucrose. The glycosidic bond in the disaccharide can be broken down into two sugar units, which are free and readily available for fermentation.

The cane is cut and the juice is extracted by maceration. After clarification, the juice is concentrated by boiling. The concentrated juice is fermented with yeast to produce raw ethanol. A series of distillation steps including a final extractive distillation with benzene are used to obtain anhydrous ethanol. The normal yield of ethanol is about 8.73 litres of alcohol per tonne of cane. The potential of ethanol production in India is about 475 litres per year. The process flow chart for production of ethanol from sugarcane is shown in fig.


Lime Juice + Sulphur Dioxide
Add
Sugar Cane
Extract
Cane Juice
Filter
Filter Mud
Clarified Juice
Concentration
Sugar
Mollases
Ferment
Alcohol
Distillery slop Fertilizer

Lacture-7

Biomass Briquetting – A Value Adding Technology for Agro Residues

Biomass plays a major part in fulfilling the energy needs of the developing countries. According to the world's energy topics, it is widely accepted that fossil fuel shortage, fuel increasing price, global warming including other environmental problems are critical issues. Therefore, biomass energy has been attracting attention as an energy source since zero net carbon dioxide accumulation in the atmosphere from biomass production and utilization can be achieved. The carbon dioxide released during combustion process is compensated by the carbon dioxide consumption in photosynthesis. Among several kinds of biomass, agro residues have become one of most promising choices. They are available as a free or almost free, indigenous and abundant energy source. But it is generally difficult to handle them because of its bulky nature, low combustion characteristics and copious liberation of smoke. The direct burning of these agro residues in domestic and industrial applications is inefficient and associated with wide scale air pollution. In order to achieve more efficient usage of agro residues, it is essential to densify them to compact pieces of definite shape and high thermal value. Briquetting is one of the several compaction technologies in the category of densification. The process of briquetting consists of applying pressure to a mass of particles with or without a binder and converting it into a compact product of high bulk density, low moisture content, uniform size and shape and good burning characteristics. Briquettes can be produced with the density of 1.2 to 1.4 g/cm3 from loose agro residues with a bulk density of 0.1 to 0.2 g/cm3.

Raw materials for briquetting

Almost all agro residues can be briquetted. Agro residues such as saw dust, rice husk, tapioca waste, groundnut shell, cotton stalks, pigeon pea stalks, soybean stalks, coir pith, mustard stalks, sugar cane bagasse, wood chips, tamarind pod, castor husk, coffee husk, dried tapioca stick, coconut shell powder are the commonly used raw materials for briquetting in India. All these residues can be briquetted individually and in combination with or without using binders. The factors that mainly influence on the selection of raw materials are moisture content, ash content, flow characteristics, flow characteristics, particle size and availability in the locality. Moisture content in the range of 10-15% is preferred because high moisture content will pose problems in grinding and more energy is required for drying. The ash content of biomass affects its slagging behaviour together with the operating conditions and mineral composition of ash. Biomass feedstock having up to 4% of ash content is preferred for briquetting. The granular homogeneous materials which can flow easily in conveyers, bunkers and storage silos are suitable for briquetting.

Briquetting Process

The series of steps involved in the briquetting process are

1. Collection of raw materials
2. Preparation of raw materials
3. Compaction
4. Cooling and Storage.

Collection of raw materials

In general, any material that will burn, but is not in a convenient shape, size or form to be readily usable as fuel is a good candidate for briquetting.

Preparation of raw materials

The preparation of raw materials includes drying, size reduction, mixing of raw materials in correct proportion, mixing of raw materials with binder etc.

Drying

The raw materials are available in higher moisture contents than what required for briquetting. Drying can be done in open air (sun), in solar driers, with a heater or with hot air.

Size reduction

The raw material is first reduced in size by shredding, chopping, crushing, breaking, rolling, hammering, milling, grinding, cutting etc. until it reaches a suitably small and uniform size (1to10 mm). For some materials which are available in the size range of 1 to 10 mm need not be size reduced. Since thesize reduction process consumes a good deal of energy, this should be as short as possible.

Shredding machine

Raw material mixing

It is desirable to make briquettes of more than one raw material. Mixing will be done in proper proportion in such a way that the product should have good compaction and high calorific value.

Compaction

Compaction process takes place inside the briquetting machine. The process depends on the briquetting technology adopted.

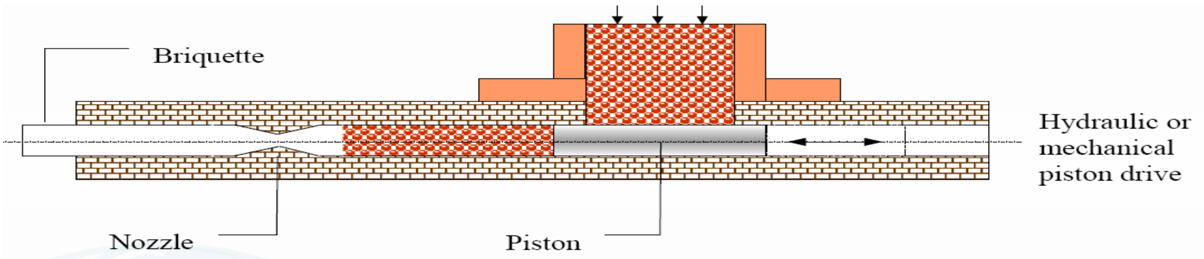
Briquetting Technologies

Briquetting technologies used in the briquetting of the agro residues are divided into three categories. They are (i) high pressure or high compaction technology, (ii) Medium pressure technology and (iii) low pressure technology. In high pressure briquetting machines, the pressure reaches the value of 100 MPa. This type is suitable for the residues of high lignin content. At this high pressure the temperature rises to about 200 – 250 °C, which is sufficient to fuse the lignin content of the residue, which acts as a binder and so, no need of any additional binding material. In medium pressure type of machines, the pressure developed will be in the range of 5 MPa and 100MPa which results in lower heat generation. This type of machines requires additional heating to melt the lignin content of the agro residues which eliminates the use of an additional binder material. The third type of machine called the low pressure machines works at a pressure less than 5 MPa and room temperature. This type of machines requires addition of binding materials. This type of machines is applicable for the carbonized materials due to the lack of the lignin material.

The high pressure compaction technology for briquetting of agro residues can be differentiated in to two types (i) hydraulic piston press type and (ii) screw press type. Among these two technologies hydraulic piston press type was predominantly used to produce briquettes in India, particularly in Tamil Nadu all the briquette producing firms' uses hydraulic piston press technology for briquetting. Mostly cylindrical shaped briquettes with 30 mm to 90 mm diameter were produced. All the commercial firms involved in briquette making produces 60 mm and 90 mm diameter briquettes.

A scheme of a hydraulic piston press briquetting technology

Feedstock



Cooling and Storage of briquettes

Briquettes extruding out of the machines are hot with temperatures exceeding 100oC. They have to be cooled and stored in dry place.

Uses for Briquettes

The most frequent applications for this type of fuel are of both a domestic and industrial nature; from fireplaces or stoves to boilers generating hot water and steam. Tea industries, wine distilleries, textile industries, and farms are the major sectors using briquettes. Briquettes are also used in gasification process for electricity production.

Advantages of agro residual briquettes:

- The process increase the net calorific value of material per unit volume
- End product is easy to transport and store
- The fuel produced is uniform in size and quality
- Helps solve the problem of residue disposal
- Helps to reduce deforestation by providing a substitute for fuel wood.
- The process reduce/eliminates the possibility of spontaneous combustion waste
- The process reduces biodegradation of residues

Necessary requirements to start a briquette production unit

1. Land requirement: Land area of minimum 1 acre is required for starting a briquette production unit to store the raw materials for briquetting and produced briquettes.

2. Raw materials: Continuous availability of raw materials is a major factor for profitable briquette production.

3. Drying facility to dry raw materials: The raw materials which are commonly available are with higher moisture content. So, any of the drying technologies such as solar driers/ heater/ hot air generator system is required to bring down the moisture content to an desirable level for briquetting.

4. Shredding machine: A shredding machine with minimum of 5 hp motor is required to powder the agro residues for briquetting.

5. Briquetting machine: A high pressure hydraulic piston press type briquetting machine powered by minimum of 50 hp motor is required to produce binderless briquettes from agro residues.

Lacture-8

SOLAR ENERGY

Sun is the largest source of energy. Energy radiated from the sun is electromagnetic waves reaching the plant earth in three separated region,

1. Ultraviolet - 6.4 % ($\lambda<0.38\mu m$)
2. Visible -48 % ($0.38\ \mu m <\lambda<0.78\mu m$)
3. Infrared -15.6 % ($\lambda>0.78\mu m$

When solar radiation (solar energy) is absorbed by a body it increases its energy. It provides the energy needed to sustain life in the solar system. It is a clean inexhaustible, abundantly and universally available energy and is the ultimate source of other various sources of energy.

The heat generation is mainly due to various kinds of fusion reactions , the most of energy is released in which hydrogen combine to helium.

$4(1H^1) \rightarrow 2He^4 + 26.3$ MeV

An effective black body temperature of sun is 5777K

Use of direct solar energy

- Solar thermal power plant
- Photolysis systems for fuel production
- Solar collector for water heating
- Passive solar heating system
- Photovoltaic, solar cell for electricity generation.

Use of indirect solar energy

- Evaporation, precipitation, water flow
- Melting of snow
- Wave movements
- Ocean current
- Biomass production
- Heating of earth surface
- Wind

Solar Constant*:* The rate at which solar energy arrives at the top of the atmosphere is called solar constant I_{sc}

Standard value of 1353 W/m² was adopted in 1953, but 1367 W/m², adopted by the world radiation center is known commonly used.

Extra-terrestrial solar radiation:

Solar radiation received on outer atmosphere of earth.

$$I_{ext} = I_{sc}\left[1.0 + 0.033\ \cos\left(\frac{360\ n}{365}\right)\right]$$

Where, n^{th} day of the year

Terrestrial solar radiation: The solar radiation reaches earth surface after passing through the atmosphere is known as terrestrial solar radiation or global radiation.

Direct or Beam radiation: It is the solar radiation propagating along the line joining the sum and the receiving object.

Diffuse radiation: It is the solar radiation scattered by aerosols, dust and molecules. It does have a unique direction.

Total radiation or Global radiation: The sum of beam and diffuse radiation is referred as total radiation.

Irradiance: the rate at which radiant energy is incident per unit area of the surface. The unit of Irradiance is W/m^2. It is used for beam and diffused radiation.

Radiant exposure (irradiation): the incident energy per unit area on a surface is found by integration of irradiance over a specified time usually an hour or a day. Its unit is J/m^2.

Radiant existence (Radiosity): The rate at which radiant energy (W/m^2) leaves a surface per unit area, by the combination of emission reflection and transmission.

Emissive power: The rate at which radiant energy (W/m^2) leaves a surface per unit area, by emission only.

Albedo: The energy reflected back to the space by reflection from clouds, scattered by the atmospheric gases and dust particles and by reflection from earth surface is called albedo of earth atmospheric system. 30 % of the incoming solar radiation back to extraterrestrial region through atmosphere from earth

Solar time

Zenith: the point directly over head is called zenith.

Air mass ratio: Air mass is defined as the ratio of the path length of radiation through the atmosphere, considering the vertical path at sea level as unity.

$$Air\ mass(m) = \frac{Path\ length\ traversed\ by\ beam\ radiation}{Vertical\ path\ length\ of\ atmosphere}$$

$$\boldsymbol{m = \sec\theta_z}$$

$$\boldsymbol{= \operatorname{cosec}\alpha}$$

$$(\alpha + \theta_z = 90°)$$

where, α is inclination angle and θ_z is zenith angle

Latitude (ϕ): the latitude of a location on earth surface is angle made by the radial line joining the given location to the center of the earth with its projection on the equator plane.

Declination (δ): It may be defined as the angular distance of the sun ray from the plane of earth equator.

$$\delta = 23.45 \times \sin\left[\frac{360}{365}(284+n)\right]$$

where, n =day of year counted from 1st of January.

Solar radiation measurement

Solar radiation measuring instruments are following type

Pyranometer: used to measure global radiation

Pyrheliometer: used to measure beam radiation

Pyranometer: It is used to measure total hemispherical radiation-beam plus diffuse on a horizontal surface. If shaded, a pyranometer measures diffuse radiation. Most of solar resource data come from pyranometers. The total irradiance (W/m^2) measured on a horizontal surface by a pyranometer is expressed as follows:

$I_{total} = I_{beam} \cos\theta + I_{diffuse}$

where, θ is the zenith angle (i.e., angle between the incident ray and the normal to the horizontal instrument plane.

Pyrheliometer: The pyrheliometer is a broadband instrument that measures the direct beam radiation. Consequently, the instrument should be permanently pointed toward the Sun. A two-axis Sun tracking mechanism is most often used for this purpose. The detector is a multi-junction thermopile placed at the bottom of a collimating tube provided with a quartz window to protect the instrument. The detector is coated with optical black. Its temperature is compensated to minimize sensitivity of ambient temperature fluctuations. The pyrheliometer aperture angle is 5°. Consequently, radiation is received from the Sun and a limited circumsolar region, but all diffuse radiation from the rest of the sky is excluded. A readout device is used to give the instant value of the direct beam irradiance. Its scale is adapted to the sensitivity of the particular instrument in order to display the value in SI units, Wm^{-2}.

Utilization of solar energy by technological processes

Heliochemical: By the process of photosynthesis, plants absorb the solar energy which maintains life the earth by productions of various types of foods. The energy is absorbed by the chemical reaction hence the process is called Heliochemical.

Helioelectrical: The solar energy is input to photovoltaic converters and power is output from it which is used for spacecraft etc.

Heliothermal: This process can be used for water heating of building etc.

Applications of solar energy

1. Heating and Cooling of buildings
2. Solar water and air heating
3. Salt production by evaporation of seawater
4. Solar distillations
5. Solar drying of agricultural products
6. Solar cookers
7. Solar water pumping
8. Solar refrigeration
9. Electricity generation through Photo voltaic cells
10. Solar furnaces
11. Industrial process heat
12. Solar thermal power generation

Lacture-9

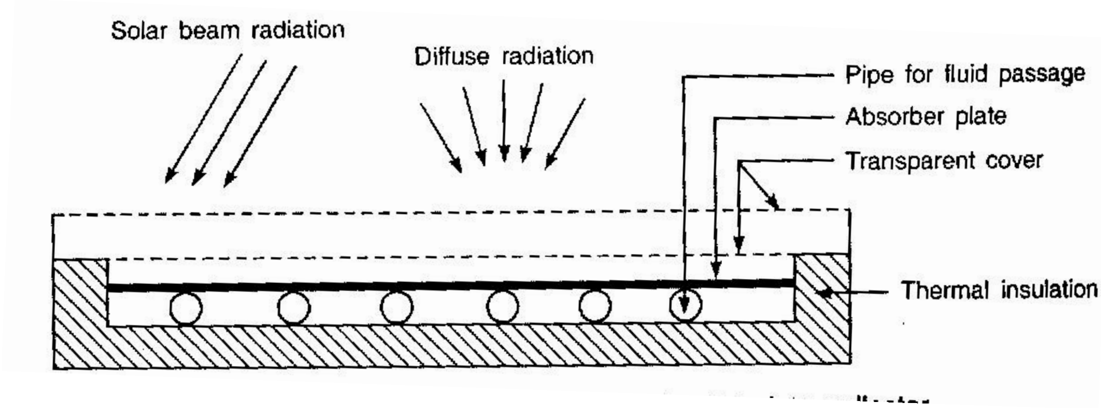
Application of solar energy

Solar Thermal Energy Collector

Solar Thermal Energy Collector: Solar thermal energy collector is equipment in which solar energy is collected by absorbing the radiation in an absorber and then transferring to a fluid. There are two type of collectors;

Flat Plate solar Collector:

This is the most common type of solar thermal collector. It is designed for operation in the low temperature range (ambient 60^{0}C) or in the medium temperature range (100 ^{0}C). It has no optical concentrator. Here the collector area and the absorber area are numerically same.



The flat plate collector consists of five major parts as given below:

A metallic flat absorber plate: It is made of copper, steel or aluminium (having high thermal conductivity) and having black surface. The thickness of the metal sheet ranges from 0.5 to 1.0 mm.

Tubes or channels: they are soldered to the absorber plate. Water flowing through these tubes takes away the heat from the absorber plate. The diameter of tubes is around 1.25 cm, while that of the header pipe which leads water in and out of the collector and distributes it to absorber tubes is 2.5 cm.

A transparent toughened glass sheet: of 5 mm thickness is provided as the cover plate. It reduces convection heat losses through a stagnant air layer between the absorber plate and the glass. Radiation loss are also reduced as the spectral transmissivity of glass is such that it transparent to short wave radiation and nearly opaque to long wave thermal radiation emitted by interior collector walls and absorbing plate.

Fiber glass insulation: Fiber glass of 2.5 to 8.0 cm thickness is provided at the bottom and on the sides in order to minimize the heat loss.

Encloses container: The commercially available collector have a face area of 2 m^2. The whole assembly is fixed on a supporting structure that is installed on a tilted position at a suitable angle facing south in northern hemisphere. For the whole year, the optimum tilt angle of collector is equal to the latitude of its location. During winter the tilt angle is kept 10-15^0 more than the latitude of the location, while in summer it should be 10-15^0 less than the latitude.

Working of solar flat plate collector:

The solar flat plate collector is provided with inlet through which water from the outside tank enters from downside header pipe. The water passes through the number of distributor pipe line. The water gets heated up while passing through these pipes. The heated water is collected in the upper header pipe and flows back to the side tank. IN this way water gets circulating through the collector where it absorb heat energy.

Water is circulating inside the collector due to thermosyphon effect in which heated water has tendency to move up. This is a natural circulation of water. In some collector the circulating pump is provided the pump circulates the water inside the collector system. Such type of circulation is called forced or pressurized water circulation system. It has better efficiency.

Advantages of flat plate collector:

1. They absorb heat from beam and diffused radiations.
2. They are passive heating system without any moving component.
3. They are simple in design and construction.
4. They can be easily fabricated using locally available materials.
5. Maintance is simple and without any expenders.
6. They are providing with water tank which can serve as tank to store daily requirements of water.
7. They can be easily installed unused spaces like roof top, balcony, window shades etc.

Solar flat plate collectors have following disadvantages:

1. They are bulky and difficult in transportation.
2. Their efficiency is around 60 percentage and less.
3. Pipe lines may get scale formation on inside surface. It reduces its heat transfer efficiency.
4. They cannot be used in the applications like power generation where very high temperatures are required.

Applications of flat plate collector:

The flat plate solar collectors are widely used now a days as they are gaining popularity with improved design.

1. They are used for water heating in homes, hotels, hospitals and industries etc.
2. They used for space and air heating.
3. They are used for making distilled water.
4. They are used for drying agricultural produce.
5. They are used for wood seasoning.

Concentrating Type solar Collector:

Here the receiving area of solar radiation is several times greater than the absorber area and the efficiency is high. Mirrors and lenses are used to concentrate sun rays on the absorber. The temperature of working fluid can be raised only up to 500 ^{0}C. For better performance, the collector is mounted on a tracking equipment to always face the sun with its changing position.

Advantages:

1. Reflecting surfaces required material and are structurally simpler than flat plate collectors.
2. The absorber area of a concentrator system is smaller than other.
3. Due to less area of heat loss and better insolation intensity.
4. Concentrating type collectors can be used for electric power generation.
5. Heat storage cost less.
6. Higher efficiency.
7. No-anti freeze required to protect the absorber.

Disadvantage:

1. Non-uniform flux on the absorber
2. High initial cost
3. Additional optical losses such as reflectance loss and the intercept loss
4. Out of the beam and diffuse solar radiation components, only beam component is collected in case of focusing collectors because diffuse components cannot be reflected and thus lost.

Solar cooking:

Solar cooker is a device in which food is cooked by the heat received from solar radiations.

Varieties of solar cookers have been designed using different materials and they are used by the people all over the world. Some of the types are given below.

Box type solar cooker:

This is simple flat plate solar cooker in the shape of box or suit case which can move anywhere we like to use. It is made up of double wall wooden or aluminum sheet metal box with operable glass lid. In between the wall, insulating materials like thermocol or glass wool is filled up. Inside surface of solar cooker is painted with non-shining black paint so that it can efficiently absorb the heat from solar radiations. There are following components of the box type solar cooker:

Outer box : It is made up from sheet metal and painted with black color which work as absorber plate to receive heat energy.

Inner box: It is also made from sheet metal and painted with black color which works as absorber plate to receive heat energy.

Insulation: In the space between the outer box and inner box insulating materials like glass wool or thermocol is filled up to prevent the loss of heat energy from the cooker.

Double glass lid: A lid which can close or open is provided over the empty space where food material is kept for cooking. It is double glass cover to prevent the radiation losses from the cooker, Ii permits the solar rays to enter the cooker but prevents to go out from the cooker.

***Mirror paneled outer lid*:** This is sheet metal cover to close or open the box of cooker. Inside surface of the cover is provided with flat reflecting mirror.

Cooking containers: The aluminum containers are kept in the space provided in the cooker. They are also painted with black color on outer surface to absorb the heat energy. The food stuff is kept inside these containers.

Working of solar cooker:

The solar cooker is placed on the stand in the sunlight where direct beam radiations are falling. Its mirror cover lid is open and adjusted in such a way that the reflection of sun rays fall on the transparent double glass lid. The food materials like rice, vegetables for boiling or dry roasting are kept in the containers. Depending upon the intensity of sun rays the food gets cooked within one to three hours. In clear day with good sunshine it is possible to get food cooked in an hour.

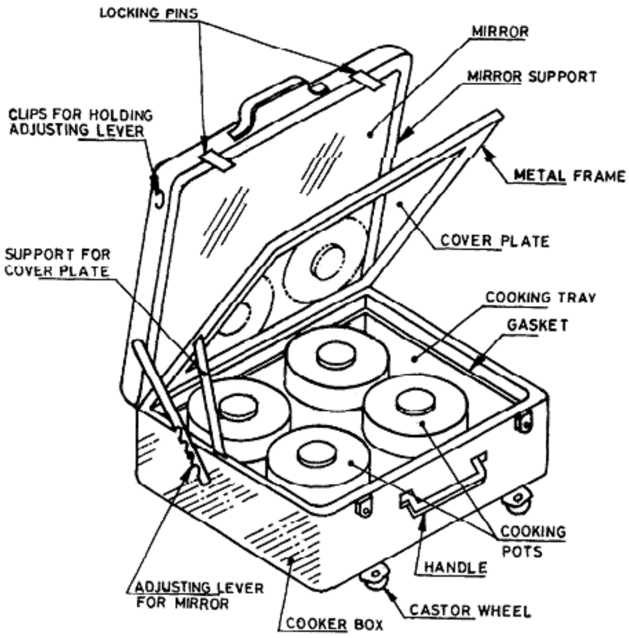


Fig. Construction of solar cooker

Concentrating collector solar cooker

In the concentrating solar cookers, the cooking pot is placed at the focus of a concentrating mirror. Concentrating type solar cooker is working on one or two axis tracking with a concentration ratio up to 50 and temperature up to 300°C, which is suitable for cooking. Concentrating cookers utilize multifaceted mirrors, Fresnel lenses or parabolic concentrators to attain higher temperatures. The concentrating type of solar cookers is further subdivided into parabolic dish/trough, cylindrical, spherical, and Fresnel. This type of cookers usually employs mirrors/reflectors to concentrate the total solar energy incident on the collector surface, so the collector surface is usually very wide and the temperature achieved is very high. Parabolic dish cooker has the highest efficiency in terms of the utilization of the reflector area because in fully steerable dish system there are no losses due to aperture projection effects. Also radiation losses are small because of the small area of the absorber at the focus. Additional advantages include higher cooking temperatures, as virtually any type of food can be cooked and short heat-up times.

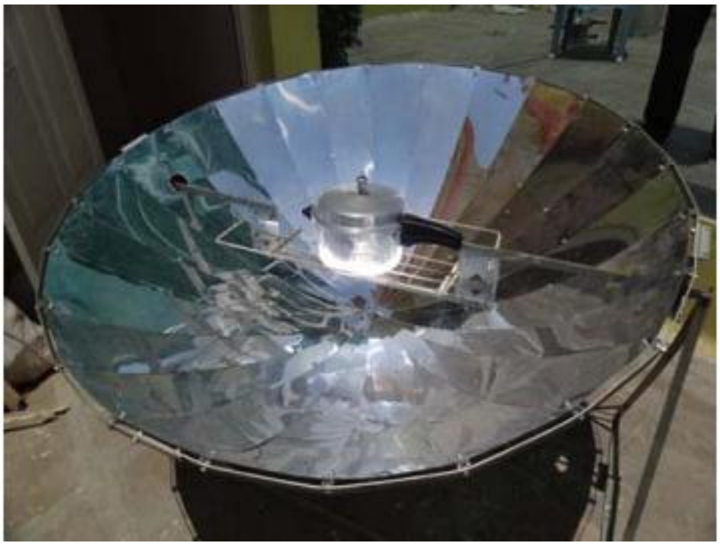


Fig Solar cooker

Solar dryer

Conventional method of drying is to spread the material in a thin layer on ground and let it exposed to the sun. Such a method has various disadvantages like,

- ❖ Accumulation of dust and harms due to insects
- ❖ Wastage of material due to birds
- ❖ Non uniform drying due to varying intensity of sun
- ❖ Larger area required for drying

All these difficulties are removed by using solar drier. There are two types of solar driers.

Natural convection solar drier:

Natural air-drying is an in bin drying system with the following typical characteristics:

- ❖ Drying process is slow, generally requiring 4 to 8 weeks.
- ❖ Initial moisture content is normally limited to 22 to 24%.

- ❖ Drying results from forcing unheated air through grain at airflow rates of 1 to 2 cfm/bu.
- ❖ Drying and storage occur in the same bin, minimizing grain handling.
- ❖ Bin is equipped with a full-perforated floor, one or more high capacity fans, a grain distributor and stairs
- ❖ Cleaning equipment is used to remove broken kernels and fines.

Description of Cabinet drier

It can be of fixed type and also of portable type. Generally it has an area of about 3 x 5 m^2 glass sheet fixed at the top at an angle of about 0 to 30^0. Holes are provided at the bottom and at the topsides for airflow by natural convection. Wire meshed black tray is provided to the material to be dried.

Forced convection solar dryer (Hot air system)

In these, the collectors are provided with duct. Generally, a duct of 2.5 cm depth is provided. It is made out of two plates welded together lengthwise. Cold air is blown through a blower into the collectors, which gets heated during the passage through it. The hot air thus available is then used for drying the products kept on the shelves of driers. This hot air takes away the moisture of the products and is let out through a properly located outlet.

1. Absorber with ducting
2. Blower with motor and
3. Drying bin

Description: This drier has three main components viz., flat plate collector, blower and drying bin. The area of the collector is 8 m^2. It is divided into 4 tray each having 2m x 1m absorber area. The absorber is made out of corrugated G.I. sheet and is painted with dull black color. Another plain G.I. sheet placed 5 cm below the absorber plate creates air space for heating. This sheet is insulated at the bottom with glass wool and is supported at the bottom with another plain G.I. sheet. The absorber is covered at the top with two layers of 3 mm thick plain glass. The unit is supported on all sides with wooden scantling and is placed at 11^0 to the horizontal facing south. Baffle plates are provided in the air space. The air space is open at the bottom to suck atmospheric air and at the top it is connected to a duct leading to suction side of the blower. The blower is of 80 m^3 / min, capacity run by 3HP electric motor. The delivery side of the blower is connected to the plenum chamber of a circular grain

Forced Convection Solar Drier for Drying of Grains

For drying high moisture paddy the solar drier can be used. The different components of the drier are air heater, air ducts and blower and grain drying chamber. The flat plate collector used for heating the air has an efficiency of 60% and rise in ambient air temperature is 13 ˚C. Freshly harvested paddy can be dried and it may take about 7-8 hours to bring the moisture content from 30% to 16% (d.b.). After drying the grains, the milling quality can be tested. The use of solar air heater for drying of grains indicates that 10-15 °C rise in the temperature of the air is enough to reduce the relative humidity of the air to 60% or less which is quite useful for drying of cereal grains. To the level consists of safe moisture content for storage 500 kg of paddy could be dried from 30 to 40 % moisture content in a period of 6 hours on bright sunny day by using air flow rate 4 m^3/min, with temperature rise 8-10°C. Solar drier consists of air heater, blower drying chamber, air distribution system and thermal storage system. The heated air is blown to drying chamber by blowers of the centrifugal type to handle large quantity of air. Batch type or continuous flow type drying chamber artificially creates the necessary radiation to reduce moisture. Hot air from the collector is sucked by a blower through the inlet pipe and is being forced into the drying chamber. An auxiliary heating system to supplement heat requirement may be arranged. This type of auxiliary systems and thermal storage systems for collecting extra energy during daytime, take care of the night operations.

Solar Pond:

A solar pond is large-scale solar thermal energy collector with integral heat storage for supplying thermal energy. A solar pond can be used for various applications, such as process heating, desalination, refrigeration, drying and solar power generation.

Solar pond is simply a pool of salt water which collects and stores solar thermal energy. The saltwater naturally forms a vertical salinity gradient also known as a "Halocline", in which low- salinity water floats on top of high-salinity water. The layers of salt solutions increase in concentration (and therefore density) with depth. Below a certain depth, the solution has a uniformly high salt concentration.

When solar energy is absorbed in the water, its temperature increases, causing thermal expansion and reduces density. If the water is fresh, the low-density warm water would float to the surface, causing convection current. The temperature gradient alone causes a density gradient that decreases with depth. However the salinity gradient forms a density gradient that increases with depth, and this counteracts the temperature gradient, thus preventing heat in the lower layers from moving upwards by convection and leaving the pond. This means that the temperature at the bottom of the pond will rise to over 90 °C while the temperature at the top of the pond is usually around 30°C.

There are 3 distinct layers of water in the pond:

- ❖ The top layer, which has a low salt content.
- ❖ An intermediate insulating layer with a salt gradient, which establishes a density gradient that prevents heat exchange by natural convection.
- ❖ The bottom layer, which has a high salt content.

The top layer is cold and has relatively little salt content. The bottom layer is hot- up to100°C (212°F) - and is very salty. Separating these two layers is the important gradient zone. Here salt content increases with depth. Water in the gradient cannot rise because the water above it has less salt content and is therefore lighter. The water below it has a higher salt content and is heavier. Thus, the stable gradient zone suppresses convection and acts as a transparent insulator, permitting sunlight to be trapped in the hot bottom layer from which useful heat may be withdrawn or stored for later use. The heat trapped in the salty bottom layer can be used for many different purposes, such as the heating of buildings or industrial hot water or for generating electricity.

The Bhuj (Gujarat) solar pond is first-ever solar pond in India to have connected itself to an end-user- supplying industrial process heat to the Kutch Dairy. The pond covers an area of 6000 square metres. Avoiding use of imported membrane lining, the project developed a cost-effective, indigenous lining scheme, using locally mined clay and plastics. While the pond attained a record 99.8 °C under stagnation, stability of the salinity gradient was maintained even at such elevated temperatures.

Solar still/ solar desalination

The basic principle behind solar distillation is simple and replicates the natural process of water purification. A solar still is an air tight basin that contains saline or contaminated water (i.e. feed water). It is enclosed by a transparent top cover, usually of glass or plastic, which allows incident solar radiation to pass through. The inner surface of the basin is usually blackened to increase the efficiency of the system by absorbing more of the incident solar radiation. The feed water heats up, then starts to evaporate and subsequently condenses on the inside of the top cover, which is at a lower temperature as it is in contact with the ambient air. The condensed water (i.e. the distillate) trickles down the cover and is collected in an interior trough and then stored in a separate basin. This system is also known as passive solar still, as it operates solely on sun`s radiation. The amount of solar radiation that is absorbed is a function of the absorptivity and depth of the water. The remaining energy eventually reaches the blackened basin liner, where it is mostly absorbed and converted into thermal energy. At this stage, the water heats up, resulting in an increase of the temperature difference between the cover and the water itself. Heat transfer takes then place as radiation, convection and evaporation from the water surface to the inner part of the cover. The evaporated water condenses and releases latent heat. This last one is then lost through convection and radiation together with the remaining convective and radiative heat.

Solar Still Operation

Water to be cleaned is poured into the still to partially fill the basin. The glass cover allows the solar radiation to pass into the still, which is mostly absorbed by the blackened base. This interior surface uses a blackened material to improve absorption of the sunrays. The water begins to heat up and the moisture content of the air trapped between the water surface and the glass cover increases. The heated water vapor evaporates from the basin and condenses on the inside of the glass cover. In this process, the salts and microbes that were in the original water are left behind. Condensed water trickles down the inclined glass cover to an interior collection trough and out to a storage bottle. Feed water should be added each day that roughly exceeds the distillate production to provide proper flushing of the basin water and to clean out excess salts left behind during the evaporation process. If the still produced 3 litres of water, 9 litres of make-up water should be added, of which 6 litres leaves the still as excess to flush the basin.

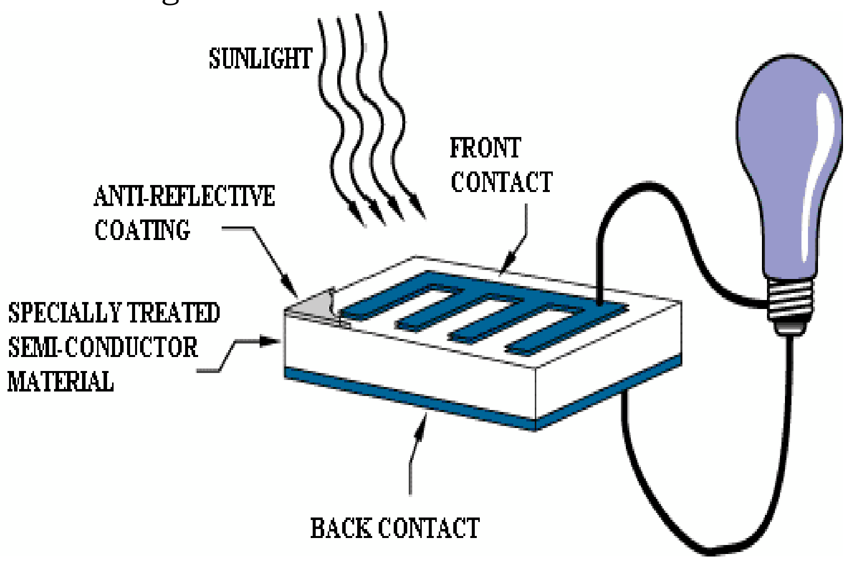
Lacture-10

Solar Photovoltaic System

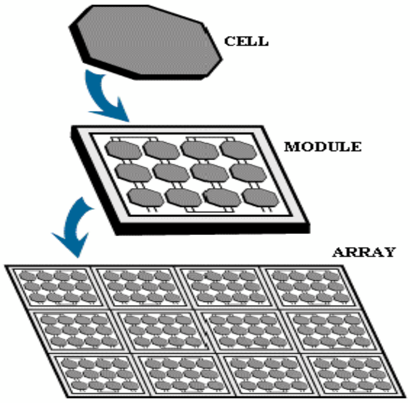
Photovoltaic system (PV) is the technology of solar cells for energy by converting solar energy (sunlight, including ultra violet radiation) directly into electricity. A *solar cell* or *photovoltaic cell* is a device that converts light directly into electricity by the photovoltaic effect. Combination of cells are used to make solar panels, it is called *solar modules, or photovoltaic arrays*. The photovoltaic effect refers to photons of light knocking electrons into a higher state of energy to create electricity. Solar cells produce direct current electricity from light, which can be used to power equipment or to recharge a battery. An inverter is required to convert the DC to AC.

How do Photovoltaics Work?

Solar cells are made of the some kinds of semiconductor materials, such as silicon. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive side (p-type) and negative side (n-type), forming an electrical circuit, the electrons can be captured in the form of an electric current-that is, electricity. This electricity can then be used to power a load, such as a light or a tool.



These devices have theoretical efficiency of the order of 25 %. Actual operation efficiency is less than half this value and decrease fairly rapidly with increasing temperature. Large number of cells has been manufactured with area 2 × 2 cm, efficiency approaching 10 % and operating at 28°C. The efficiency is the power developed per unit area of array divided by the solar energy flux in the free space (1.353 kW/m^2)



Operation of a PV cell

Due to the low voltage of an individual solar cell (typically 0.5V), several cells are combined into photovoltaic modules, which are in turn connected together into an array. The electricity generated can be either stored, used directly or fed into a large electricity grid powered by central generation plants (grid-connected/grid-tied plant) or combined with one or many domestic electricity generators to feed into a small grid.

Multiple cells can be clubbed together to form a Module and multiple modules can be wired together to form an Array. In general, the larger the area of a module or array, the more electricity will be produced. Photovoltaic modules and arrays produce direct- current (dc) electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

Application of PV system

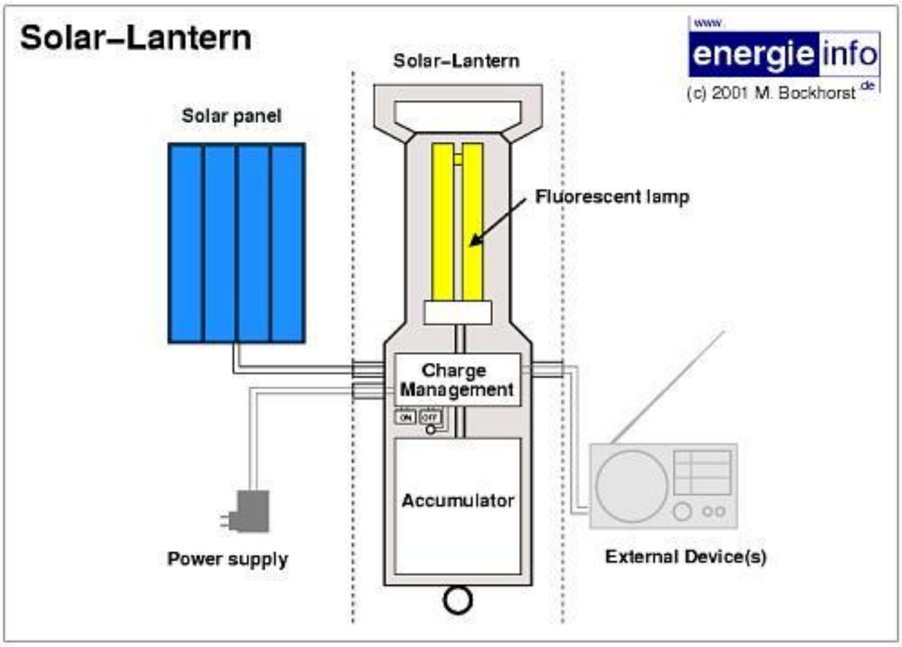
Solar Lantern:

The lantern is basically a portable lighting device suitable for either indoor or outdoor lighting, covering a full range of 360 degrees. A solar Lantern is made of three main components - the solar PV panel, the storage battery and the lamp. The operation is very simple. The solar energy is converted to electrical energy by the SPV panel and stored in a sealed maintenance-free battery for later use during the night hours. A single charge can operate the lamp for about 3-6 hours.

Advantages:

- Charges from the sun
- Up to 6 hours of light
- Zero running cost
- Extremely Bright light (equivalent to 60Watt tungsten light)
- Very solid, durable design
- Portable, easy to carry anywhere
- Long life, maintenance free battery
- Wall mounting option

- Versatile; charge it suing Solar, AC charger or Car Charger
- Emergency function: Lights on automatically in power cuts



A LED based solar lantern system aims at providing solar electricity for operating LED lights for specified hours of operation per day. Light Emitting Diode (LED) is a device which emits light when an electric current passes through it. A Solar lantern is a lighting system consisting of a lamp, battery and electronics, all placed in a suitable housing, made of metal, plastic or fiber glass, and a PV module. The battery is charged by electricity generated through the PV module.

System Description

PV Module	12 V, 10 Wp
Battery	Sealed and Maintenance free type
Lamp	Compact Fluorescent Lamp (CFL), 7/ 9 W or LED
Working Time	3-6 hrs
Charging Time	6-8 hours / day
Warranty	10 Years for PV module, 1 year for electronics battery

Solar Street Lights:

This system is designed for outdoor application in un-electrified remote rural areas and is an ideal application for campus and village street lighting. The system is provided with battery storage backup sufficient to operate the light for 10-11 hours daily. The system is having automatic ON/OFF time switch for dusk to down operation and overcharge/deep discharge prevention cut- off with LED indicators.

The solar street light system comprise of:

- Solar PV Module
- 12 V, 75 Ah Tubular plate battery with battery box
- Charge Controller cum inverter (20-35 kHz)
- 11 Watt CFL Lamp with fixtures
- 4 metre mild steel lamp post above ground level with weather proof paint and mounting hardware.

The SPV modules are reported to have a service life of 15-20 years. Tubular Batteries (Sealed and Maintenance free type) provided with the solar street lighting system require lower maintenance; have longer life and give better performance as compared to pasted plate batteries used earlier. The systems electronic provide for over-charge and over-discharge cut-off essential for preventing battery and luminaries damages.

Power Consumption	28W(For LED consumption only, the system with power supply is about 36W)
Working Voltage	85-264VAC, 12 or 24VDC
Luminous Flux	2,100lm (equal to 75w HPS Lamp on 7m height pole or 150w HPS lamp on

Solar Fencing:

Solar Power Fencing system is safe, effective and reliable perimeter solutions. The systems utilize the latest solar power fence technology. Deterrence is provided through an electric pulse which is sent around the fence line every 1.2 seconds. The pulse delivers a SAFE, SHORT, yet SHARP SHOCK. Importantly, should someone attempt to breach the fence, the system reports the zone under attack. An alarm is sent to the monitoring center so they can dispatch a security guard ensuring the site is secure day and night.

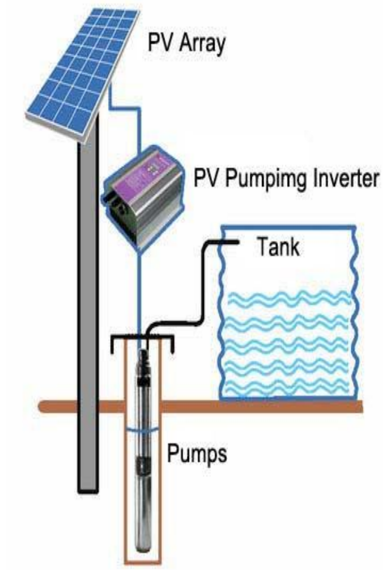
Solar Power Fencing systems can be standalone or linked with other security systems. It can be designed to meet the rigorous requirements of high-risk security installations, such as military installations and prisons, through to small commercial applications such as self storage facilities and vehicle sales yards.

Why go for solar power fencing?

- Growing, rationing of crops and pastures can be improved during slow growth periods.
- Keep animals, including wild and vermin, away.
- Separate various types and classes of animals.
- Fence off trees, rivers, eroding areas and roads.
- Substantial increase in the pasture production.
- The return of valuable animal manure more evenly over the grazing area than having it concentrated in specific areas.

Features:

- Easy Construction.
- Power fence can be erected to target species only.
- Low maintenance.
- Long lasting because of minimal physical pressure.
- All domestic and wild animals can be controlled economically.
- Modification of system to control a variety of animals is very easy.
- Discourages trespassers and predators.
- Not harmful. It gives a short, sharp but safe shock to the intruder.
- Perimeter protection
- Substantially reduces crop damage
- Environment friendly
- Uses solar energy and therefore non dependent on grid power
- Significantly reduces man-animal conflicts
- Effective wildlife management tool for use by park managers
- Cost effective and return on investment starts from day one.
- Works 24/7



Applications of electric Fence systems

Electric fence systems have varied application in Agriculture, Industrial and Forestry *or* Plantation sectors. With increasing crime in urban areas, this proven technology has now been adapted for domestic security applications, too.

Industrial: Security Electric Fence systems provide 100% protections against theft, Pilferage, arson, sabotage. The fence systems can also be integrated with other security devices like sirens, flood lights etc., making it impenetrable.

Domestic: The wall top system for residential applications is sleek, aesthetic and ideal for compounds, rooftops, farm houses and apartments.

Solar Water Pumping System:

The solar water pumping system is a stand-alone system operating on power generated using solar PV (photovoltaic) system. The power generated by solar cells is used for operating DC surface centrifugal mono-block pump set for lifting water from bore / open well or water reservoir for minor irrigation and drinking water purpose.

Advantages of solar pump sets:

- No fuel cost-uses abundantly available free sun light
- No conventional grid electricity required
- Long operating life
- Highly reliable and durable- free performance
- Easy to operate and maintain
- Eco-friendly
- Saving of conventional diesel fuel

Salient Features:

- Automatic start and shut off as per solar intensity
- Dry run protection (automatic switch off)
- Single phase 50 Hz AC input operating voltage range of 100-270 Volts
- Visual indication of faults through flickering LED displays
- Will not restart automatically for faults like dry run, phase imbalance, output short circuit; unless attended
- Controller is designed to accept DC voltages

Applications:

- Remote Villages, Homes, Cabins and Hunting Lodges
- Irrigation for remote orchards, gardens, and greenhouses
- Wildlife watering at wild game parks and farms
- Fish pond water level maintenance and aeration
- Surface water pumping for landscaping streams and waterfalls
- Cattle, Livestock and wildlife watering systems.

Parts of the solar water pumping system:

- Solar PV panel
- Motor-pump sets compatible with the photovoltaic array:

- Surface mounted centrifugal pump set or submersible pump set Pipe fittings

Lacture-11

Wind Energy

Wind results from air in motion. Air in motion arises from a pressure gradient. It has been estimated that 2% of the solar radiation falling on the face of the earth is converted to KE in the atmosphere and 30% of the KE occurs in the lowest 1000 m elevation. The energy available in the wind over the earth surface is 1.6 x 10^7 MW which is of the order of magnitude of present energy consumption on the earth. In India air speed values lies between 05-20 km/hr. Wind speed increase with height. They are measured at standard height of 10m where they are found to be 20-25% greater than close to the ground surface. Wind power is the conversion of wind energy into a useful form of energy, such as electricity, using wind turbines.

Wind Mill: A wind turbine is a rotating machine which converts the kinetic energy of wind into mechanical energy. If the mechanical energy is used directly by machinery, such as a pump or grinding stones, the machine is usually called a windmill.

Wind Turbine: If the mechanical energy is instead converted to electricity, the machine is called a wind generator, wind turbine, wind power unit (WPU), wind energy converter (WEC), or Aerogenerator

Wind Power

Wind possesses kinetic energy by virtue of its motion. Factors that determine the output from wind mill

1. Wind Speed
2. Cross Section of wind swept by rotor
3. Over all conversion efficiency of rotor, transmission system and generator/ pump.

Wind mill works on the principle of converting Kinetic energy (KE) of the wind into mechanical energy. Power is equal to energy per unit time

$$KE = \frac{1}{2}mv^2$$

$[\therefore m = \rho A v]$

$$KE = \frac{1}{2}\rho A v^3$$

where,

ρ = Air density (1.225 kg/m^3 at sea level and changes by 10% with altitude Area swept by the rotor)

$$A = \frac{\pi}{4}D^2$$

v = wind velocity

We can convert the expression for KE into power

$$P = \frac{1}{2}\rho A v^3$$

The term P/A is the wind power potential

$$\boldsymbol{\frac{P}{A} = \frac{1}{2}\rho v^3}$$

Power equation also written

$$P = \boldsymbol{\frac{1}{8}\pi D^2 \rho v^3}$$

From equation,

1. The wind power available is directly proportional to the air density
2. By doubling the diameter of the rotor the power will increase 4 fold
3. By doubling wind speed the power available will increase 8 fold

Wind machine intended for generating substantial amounts of power should have large rotors and be located in areas of high wind speed.

Power coefficient

The fraction of the free flow wind power that can be extracted by a rotor is called power coefficient. It is also called ideal or maximum, theoretical efficiency (η_{max}) of a wind turbine.

It is the ratio maximum power obtained from the wind, to the total power available in the wind.

$$Power\ coefficient(C_p) = \eta_{max} = \frac{Power\ output\ from\ wind\ machine}{Power\ available\ in\ wind}$$

The maximum theoretical power coefficient is equal to 16/27 or 0.593 for a horizontal axis wind machine. The factor 0.593 is known as the Betz coefficient.

Maximum power

The maximum power for ideal wind machine, with horizontal axis wind machine

$$P_{max} = \frac{8}{27\, g_c}\rho A v^3$$

$$= \frac{16}{27 g_c}\frac{1}{2}\rho A v^3 = \boldsymbol{0.593\left(\frac{1}{2}.\frac{\rho A v^3}{g_c}\right)}$$

than

$$\boldsymbol{P_{max} = 0.595\, P_{total}}$$

Forces on the blades and thrust on turbines

There are two types of forces which are acting on the blades. One is circumferential force acting in the direction of wheel rotation that provides torque and other is the axial force acting thrust that must be counteracted by proper machine design.

The circumferential force or torque

$$T = \frac{P}{\pi\, DN}$$

where,

T= torque kgf or newton
P= Power
D= diameter of turbine wheel
N= wheel revelations per unit time

$$P = \eta\, P_{total} = \eta.\frac{1}{2}.\frac{\rho A v^3}{g_c}$$

$$T = \eta.\frac{1}{2g_c}.\frac{\rho A v^3}{\pi DN}$$

Or

$$\boldsymbol{T = \eta.\frac{1}{8g_c}.\frac{\rho D v^3}{N}}$$

At maximum efficiency

$$\boldsymbol{T_{max} = \frac{12}{27g_c}.\frac{\rho D v^3}{N}}$$

The axial force or thrust

$$F_x = \frac{1}{2g_c}\rho A(v_i^2 - v_e^2)$$

$$\boldsymbol{F_x = \frac{\pi}{8g_c}\rho D^2(v_i^2 - v_e^2)}$$

The axial force on a turbine wheel operating at maximum efficiency where $v_e = 1/3\ v_i$

$$\boldsymbol{F_{x\,max} = \frac{\pi}{9g_c}\rho D^2 v_i^2}$$

We see that axial force is proportional to the square of the diameter of the turbine wheel, this limits turbine wheel diameter of large size.

Suitable places for erection of wind mill

1. Off shore and on the sea coast – wind energy availability is 2400 kWh/m^2/year
2. Mountains – 1600 kWh/m^2/year
3. Plains – 750 kWh/m^2/year

Places unsuitable for wind mill

1. Humid equatorial region. In these area wind velocity is minimum
2. Warm, windy countries where frequency of cyclones is more

Advantages of Wind Energy

1. It is renewable source of energy
2. Now polluting and no adverse influences on environment.
3. No fuel and no transportation is required
4. The cost of electricity production is comparatively low

Disadvantages

1. Wind energy is dilute and fluctuating in nature
2. It requires storage capacity
3. Machines operating on wind energy are noisy
4. Wind power machines are relatively have high overall weight (110 kg/kW)
5. Large area is required for wind mill
6. Efficiency of operation is poor and maintenance costs are high

Lacture-12

Types of wind mills

Wind mill is a machine for wind energy conversion. A wind turbine converts the kinetic energy of the wind's motion to mechanical energy transmitted by the shaft. A generator further converts it to electrical energy, thereby generating electricity.

1. Vertical axis wind mills: Ex. Savonius or S type wind mill (low wind velocity) Darrius wind mill (high wind velocity)
2. Horizontal axis wind mills: Ex. Single blade wind mills Double blade wind mills Multi blade wind mills Bicycle multi-blade type i.e., Sail type.

Parts of Common Wind Turbines

The main parts of the systems that comprise these wind turbines are:

1. The tower: Since velocities close to the ground are very low and there must be good clearance between the lower part of the blades and the ground, the wind turbines are placed on top of a tower at a significant height above the ground. The height of the tower depends on the diameter of the blade and is of the order of magnitude of the blade diameter, D, allowing a clearance of D/2, between the ground and the lower part of the blade. Thus, towers are between 30 and 100 m high. The tower is a simple structural element, usually made of reinforced concrete, which is designed to withstand the axial force and resulting moment generated by the wind turbine. It is typically thicker at the lower part and is usually designed as a hollow structure to allow easy access to the top for engine repairs at the turbine hub. Some older (and shorter) towers were designed as trusses made of metal.

2. The yaw bearings and yaw break: Because the wind turbine must rotate to face the instantaneous direction of the wind, the entire electricity producing system is pivoted on strong bearings that allow the rotation of the system around a vertical axis. The drag force on a downstream rotating vane or a simple rudder provides the force for this rotation. In order to avoid overshooting in the rotation of the electricity generating system and unnecessary power fluctuations, the yaw break system slows the rotational motion by providing damping.

3. The rotor blades*:* They are the most important part of the generating system, where the wind energy is imparted to the engine. They are very long, typically 30–100 m in diameter. The rotor blades are designed aerodynamically with pitch angles that vary with the distance from the hub and they are made of low weight and strong materials. Low density woven composites are now typically used for the turbine blades, which are typically hollow. The blades are connected to the hub, which extends to a horizontal metal shaft that becomes the prime mover of the engine. The shaft is supported by a series of bearings. In the more advanced and better optimized engines, a mechanism is put in place that changes the pitch of the blades to produce maximum power at the instantaneous wind velocity. These mechanisms are made of sensors and actuators, which measure the magnitude of the instantaneous wind velocity, adjust the position of the base of the blades inside the hub and, thus change the pitch of the entire blade. The actuator mechanisms are attached to the blades, rotate with them and are supported by their own pitch-control bearings.

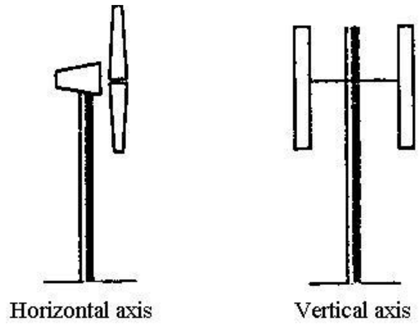
4. The gear box: In order to minimize the centrifugal stresses, the rotational speed of the blades at operating conditions is fairly low, typically of the order of 100 rpm. A gearbox steps up the rotational speed of the prime mover to reach a range 2,000–3,000 rpm and transmits the power to a secondary high rpm shaft, which is connected to the generator. A small fraction of the blade power is dissipated in the gear box by friction. For this reason, larger wind power engines may require a cooling system for their gearbox.

5. The generator*:* Both permanent magnet generators and generators with electromagnets (exciters) are used for the conversion of the mechanical power to electricity. The generators of the more modern and larger engines are rated in MW (typically 1–3 MW) and include power electronics, such as Variable Speed Constant Frequency devices (VSCF), which convert the variable frequency of the secondary shaft to a constant frequency. Any power spikes in the system are usually absorbed by the inertia of the rotor. One of the salient characteristics of wind power systems is that very high power fluctuations occur with relatively low wind velocity changes. For example, an increase of the wind velocity from 8 to 10 m/s (or 25%) would cause a power increase of almost 100%. Frequent power variations of this magnitude are undesirable because they are associated with high stresses on the blades, on the prime mover and gear as well as with strong power fluctuations on the electric grid. These types of problems are minimized by designing the wind turbines to produce almost constant power.

Vertical axis type wind mills

Vertical axis machines are of simple design as compared to the horizontal axis. The axis of rotation of vertical axis wind turbine is vertical to the ground and almost perpendicular to the wind direction. These turbines can receive wind from any direction. Hence complicated yaw devices can be eliminated. The generator and the gearbox of such systems can be housed at the ground level, which makes the tower design simple and more economical. Moreover, the maintenance of these turbines can be done at the ground level.

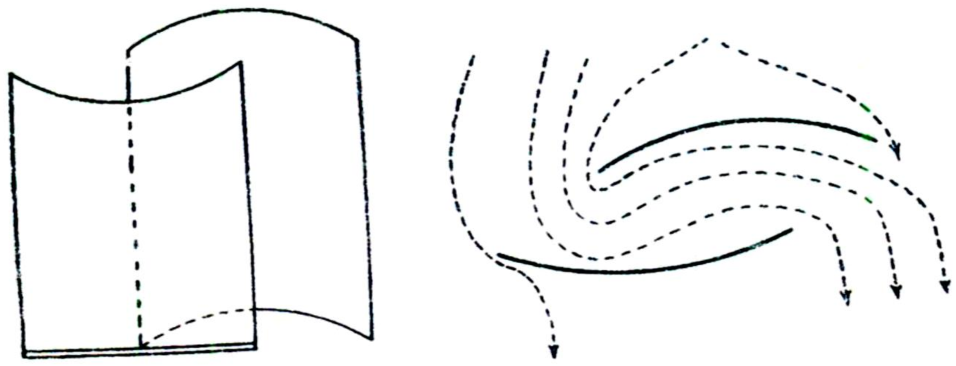
The major disadvantage of vertical axis machines are that, these turbines usually not self starting. Additional mechanism may be required to push and start the turbine, once it is stopped.



Schematic diagram horizontal and vertical axis wind mill

Savonius wind mill

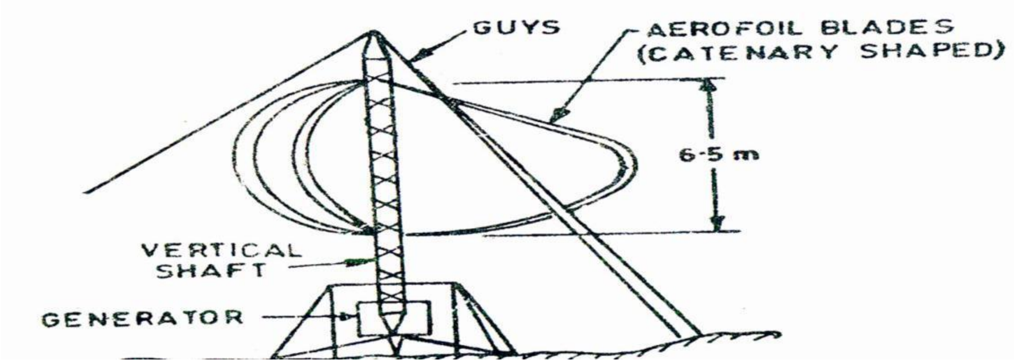
It works on the principle of cup anemometer. This was invented by S.J. Savonius in the year 1920. This machine has become popular, since it requires low wind velocity for operation. It consists of two half cylinders, which are mounted on a vertical axis perpendicular to the direction of wind, with a gap at the axis between the two cylinders (Fig.29). Two half cylinders facing each other forming a ‘s’ shaped cross-section. Irrespective of the wind direction, the rotor rotates such as to make the convex sides of the buckets head into the wind. From the rotor shaft, we can tap power for our use like water pumping, battery charging, grain winnowing etc. The main action of the wind is very simple, the force of the wind is greater on the cupped face than on rounded face. A low pressure is created on the convex sides of drums. Torque is produced by the 5 pressure difference between the two sides of the half cylinders facing the wind. This design is efficient but requires a large surface area. A savonius wind energy conversion system has vertical axes which eliminate the expensive power transmission system from the rotor to the axis. Since it is a vertical axis machine it does not matters much about the wind direction. The machine performs even at lower wind velocity ranges (i.e., 8 kmph).



Schematic diagram of savonius wind mill

Darrieus wind mill

It has two are three thin, curved blades with airfoils cross section and constant chord length. Both ends of blades are attached to a vertical shaft. Thus the force in the blade due to rotation is pure tension. This provides a stiffness to help withstand the wind forces it experiences. The blades can thus be made lighter than propeller type.



Schematic diagram of darrieus wind mill

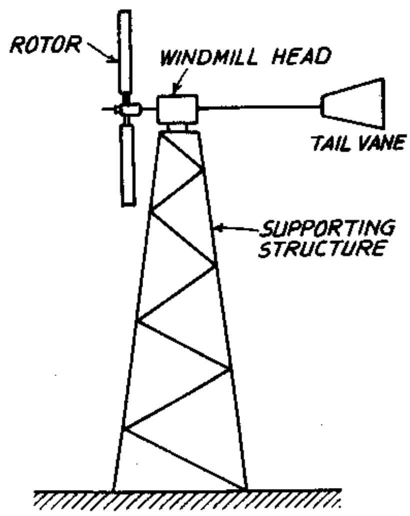
Lacture-12

Horizontal axis type wind mills

Horizontal axis wind turbines have their axis of rotation horizontal to the ground and almost parallel to the wind stream. Most of the commercial wind turbines fall under this category.

Horizontal axis machines have some distinct disadvantages such as low cut-in speed and easy furling. In general, they show relatively high power coefficient. However, the generator and gearbox of these machines are to be placed over the tower which makes its design more complex and expensive. Depending on the number of blades, horizontal axis wind turbines are further classified as single bladed, two bladed, three bladed and multi bladed. Single blade turbines are cheaper due to savings on blade materials. The drag losses are also minimum for these turbines. However, to balance the blade, a counter weight has to be placed opposite to the hub. Single bladed designs are not very popular due to problems in balancing and visual acceptability. Most of the present commercial turbines used for electricity generation have three blades.

The horizontal type wind mills have thin cross-section or more efficient thick cross-section of aerofoil blade. The blade is designed such that the tip of the blades makes a small angle with the plane of rotation and almost at right angles to the direction of wind. In a modern wind turbine, the velocity of blades is six times the wind velocity. Ideally, the blade should be twisted, but because of construction difficulties this is not always achieved. The horizontal axis wind mills generally have better performance. These are mainly used for electric power generation and pumping water.



Schematic diagram of horizontal axis wind mill

Horizontal axis propeller type wind mill with single blade

In this type of machine, a long blade is mounted on a rigid hub. Induction generator and gear box are arranged. If extremely long blades (60 m) are mounted on the hub, large blade root bending moments may occur due to tower shadow, gravity and sudden shifts in the wind directions. To reduce rotor cost, use of low cost counter weight is recommended for balancing long blade centrifugally.

- The blade is designed such that the tip of the blades makes a small angle with the plane of rotation and almost at right angles to the direction of wind.
- The generator and gearbox of these machines are to be placed over the tower which makes its design more complex and expensive.
- In a modern wind turbine, the velocity of blades is six times the wind velocity. Ideally, the blade should be twisted, but because of construction difficulties this is not always achieved.
- The horizontal axis wind mills generally have better performance. These are mainly used for electric power generation and pumping water.

Horizontal axis - two blade wind mill

In this type of design, rotor drives a generator through a step-up gear box. The blade rotor is designed to be oriented downwind of the tower. The components are mounted on a bedplate, which is attached on a pintle at the top of the tower. The rotor blades are continuously flexed by unsteady aerodynamic, gravitational and inertial loads, when the machine is in operation. If the blades are made of metal, flexing reduces their life due to fatigue loading. With rotor, the tower is also subjected to above loads, which may cause serious damage. If the vibrational modes of the rotor happen to coincide with one of the natural mode of vibration of the tower, then the mill may get damaged. Due to high cost of blades, the rotor with more than two blades is not recommended. Rotors more than two, say 3 or 4 blades would have slightly higher coefficient.

Horizontal axis-multi blade type wind mill: This type of design for multi blades is shown in fig.34, made from sheet metal or aluminum. The rotors have high strength to weight ratios and are strong enough to with stand a wind speed of 60 Kmph. This type of wind mills have good power coefficient, high starting torque, simple and are low in cost.

Sail type wind mill: It is recent development in wind mills. The blades are made by stretching out triangular pieces of canvas cloth or nylon or plastics. There is also variation in the number of sails used. It runs at 60 to 80 rpm. The horizontal axis types generally have better performance. They have been used for various applications but two major areas of interest are electric power generation, and pumping water.

COMPARISON OF HORIZONTAL AND VERTICAL AXIS WIND MILL

	Horizontal axis wind mill		Vertical axis wind mill
1.	Shaft of the rotor of wind mill as horizontal and is not very long.	1.	Shaft of the rotor of wind mill is vertical and it is very long and heavy.
2.	Wind mill tower is required to support rotor and generator.	2.	No such tower is needed and generator is kept at ground level.
3.	Its starting torque is less.	3.	Its starting torque is high.
4.	Tip to wind speed ratio is more and it gives more power.	4.	Tip to wind speed ratio is less and it gives less power.
5.	Rotor head changes the direction when wind direction is changed.	5.	Vertical shaft rotor does not require to change its directions. It runs by the winds coming from any directions.
6.	Wind mill support system has to bear total weight of rotor, blades and generator.	6.	Wind mill support system is made up of guy bars which does not require to bear the weight of rote and generator.
7.	Wind force on the rotor produces stress on every parts of the wind mill such as rotor, bearings and structures.	7.	Wind force on the rotor does not produce stress on all parts of the wind mill.
8.	The support structures required is very strong.	8.	Strong support structures are not very strong.
9.	The wind mills are very popular for power generation.	9.	The wind mills are not very popular for power generation.
10	Propeller type and multi blade American type are examples of horizontal axis wind mills	10	Savonius rotor and Darricus wind mills are vertical type wind mills.

Limitations:

1. Wind machines must be located where strong, dependable winds are available most of the time.
2. Because winds do not blow strongly enough to produce power all the time, energy from wind machines is considered "intermittent," that is, it comes and goes. Therefore, electricity from wind machines must have a back-up supply from another source.
3. As wind power is "intermittent," utility companies can use it for only part of their total energy needs.
4. Wind towers and turbine blades are subject to damage from high winds and lighting. Rotating parts, which are located high off the ground can be difficult and expensive to repair.
5. Electricity produced by wind power sometimes fluctuates in voltage and power factor, which can cause difficulties in linking its power to a utility system.

6. The noise made by rotating wind machine blades can be annoying to nearby neighbors.
7. People have complained about aesthetics of and avian mortality from wind machines.

Lecture No.1

Introduction

After the advent of green revolution, more emphasis is laid on the quality of the product along with the quantity of production to meet the ever- growing food requirements. Both these demands can be met when the environment for the plant growth is suitably controlled. The need to protect the crops against unfavourable environmental conditions led to the development of protected agriculture. Greenhouse is the most practical method of achieving the objectives of protected agriculture, where the natural environment is modified by using sound engineering principles to achieve optimum plant growth and yields.

1.1 History

A greenhouse is a framed or an inflated structure covered with a transparent or translucent material in which crops could be grown under the conditions of at least partially controlled environment and which is large enough to permit persons to work within it to carry out cultural operations.

The growing of off - season cucumbers under transparent stone for Emperor Tiberius in the 1st century, is the earliest reported protected agriculture. The technology was rarely employed during the next 1500 years. In the 16th century, glass lanterns, bell jars and hot beds covered with glass were used to protect horticultural crops against cold. In the 17th century, low portable wooden frames covered with an oiled translucent paper were used to warm the plant environment.

In Japan, primitive methods using oil -paper and straw mats to protect crops from the severe natural environment were used as long ago the early 1960s. Greenhouses in France and England during the same century were heated by manure and covered with glass panes. The first greenhouse in the 1700s used glass on one side only as a sloping roof. Later in the century, glass was used on both sides. Glasshouses were used for fruit crops such as melons, grapes, peaches and strawberries, and rarely for vegetable production.

Protected agriculture was fully established with the introduction of polyethylene after the World War II. The first use of polyethylene as a greenhouse cover was in 1948, when professor Emery Myers Emmert, at the University of Kentucky, used the less expensive material in place of more expensive glass.

The total area of glasshouses in the world (1987) was estimated to be 30,000 ha and most of these were found in North- Western Europe. In contrast to glasshouses, more than half of the world area of plastic greenhouses is in Asia, in which China has the largest area. According to 1999 estimates, an area of 6,82,050 ha were under plastic greenhouses (Table.1.1). In most of the countries, greenhouses are made of plastic and glass; the majority is plastic.

Glasshouses and rigid plastic houses are longer-life structures, and therefore are most located in cold regions where these structures can be used throughout the year. In Japan, year-round use of greenhouses is becoming predominant, but in moderate and warm climate regions, they are still provisional and are only used in winter.

In India, the cultivation in the plastic greenhouses is of recent origin. As per 1994-95 estimates, approximately 100 ha of India are under greenhouse cultivation.

Table: 1. Estimated world use of plastic greenhouses (1999)

Region	**Area (ha)**
Europe	1,80,000
Africa and the Middle East	55,000
America	22,350
Asia China - 3,80,000 Japan - 51,042 Korea - 2,200	4,50,000
World Total	**6,82,050**

Since 1960, the greenhouse has evolved into more than a plant protector. It is now better understood as a system of controlled environment agriculture (CEA), with precise control of air and root temperature, water, humidity, plant nutrition, carbon dioxide and light. The greenhouses of today can be considered as plant or vegetable factories. Almost every aspect of the production system is automated, with the artificial environment and growing system under nearly total computer control.

1.2 Greenhouse Effect

In general, the percentage of carbon dioxide in the atmosphere is 0.0345% (345 ppm). But, due to the emission of pollutants and exhaust gases into the atmosphere, the percentage of carbon dioxide increases which forms a blanket in the outer atmosphere. This causes the entrapping of the reflected solar radiation from the earth surface. Due to this, the atmospheric temperature increases, causing global warming, melting of ice caps and rise in the ocean levels which result in the submergence of coastal lines. This phenomenon of increase in the ambient temperature, due to the formation of the blanket of carbon dioxide is known as global warming due to greenhouse effect. (An increase in the concentration of greenhouse gases in the atmosphere is termed as greenhouse effect.)

The greenhouse covering material acts in a similar way, as it is transparent to shorter wave radiation and opaque to long wave radiation.

During the daytime, the short wave radiation enters into the greenhouse and gets reflected from the ground surface. This reflected radiation becomes long wave radiation and is entrapped inside the greenhouse by the covering material. This causes the increase in the greenhouse temperature. It is desirable effect from point of view of crop growth in the cold regions.

1.3 Advantages of Greenhouses

The following are the different advantages of using the greenhouse for growing crops under controlled environment:

1. Throughout the year four to five crops can be grown in a greenhouse due to availability of required plant environmental conditions.
2. The productivity of the crop is increased considerably.

3. Superior quality produce can be obtained as they are grown under suitably controlled environment.

4. Gadgets for efficient use of various inputs like water, fertilizers, seeds and plant protection chemicals can be well maintained in a greenhouse.

5. Effective control of pests and diseases is possible as the growing area is enclosed.

6. Percentage of germination of seeds is high in greenhouses.

7. The acclimatization of plantlets of tissue culture technique can be carried out in a greenhouse.

8. Agricultural and horticultural crop production schedules can be planned to take advantage of the market needs.

9. Different types of growing medium like peat mass, vermiculate, rice hulls and compost that are used in intensive agriculture can be effectively utilized in the greenhouse.

10. Export quality produce of international standards can be produced in a greenhouse.

11. When the crops are not grown, drying and related operations of the harvested produce can be taken up utilizing the entrapped heat.

12. Greenhouses are suitable for automation of irrigation, application of other inputs and environmental controls by using computers and artificial intelligence techniques.

13. Self-employment for educated youth on farm can be increased.

Lecture No.2

Classification of Greenhouses

Greenhouse structures of various types are used successfully for crop production. Although there are advantages in each type for a particular application, in general there is no single type greenhouse, which can be considered as the best. Different types of greenhouses are designed to meet the specific needs.

2.1 Greenhouse type based on shape

Greenhouses can be classified based on their shape or style. For the purpose of classification, the uniqueness of the cross section of the greenhouses can be considered as a factor. As the longitudinal section tend to be approximately the same for all types, the longitudinal section of the greenhouse cannot be used for classification. The cross sections depict the width and height of the structure and the length is perpendicular to the plane of cross section. Also, the cross section provides information on the overall shape of the structural members, such as truss or hoop, which will be repeated on every bay.

The commonly followed types of greenhouse based on shape are lean-to, even span, uneven span, ridge and furrow, saw tooth and Quonset.

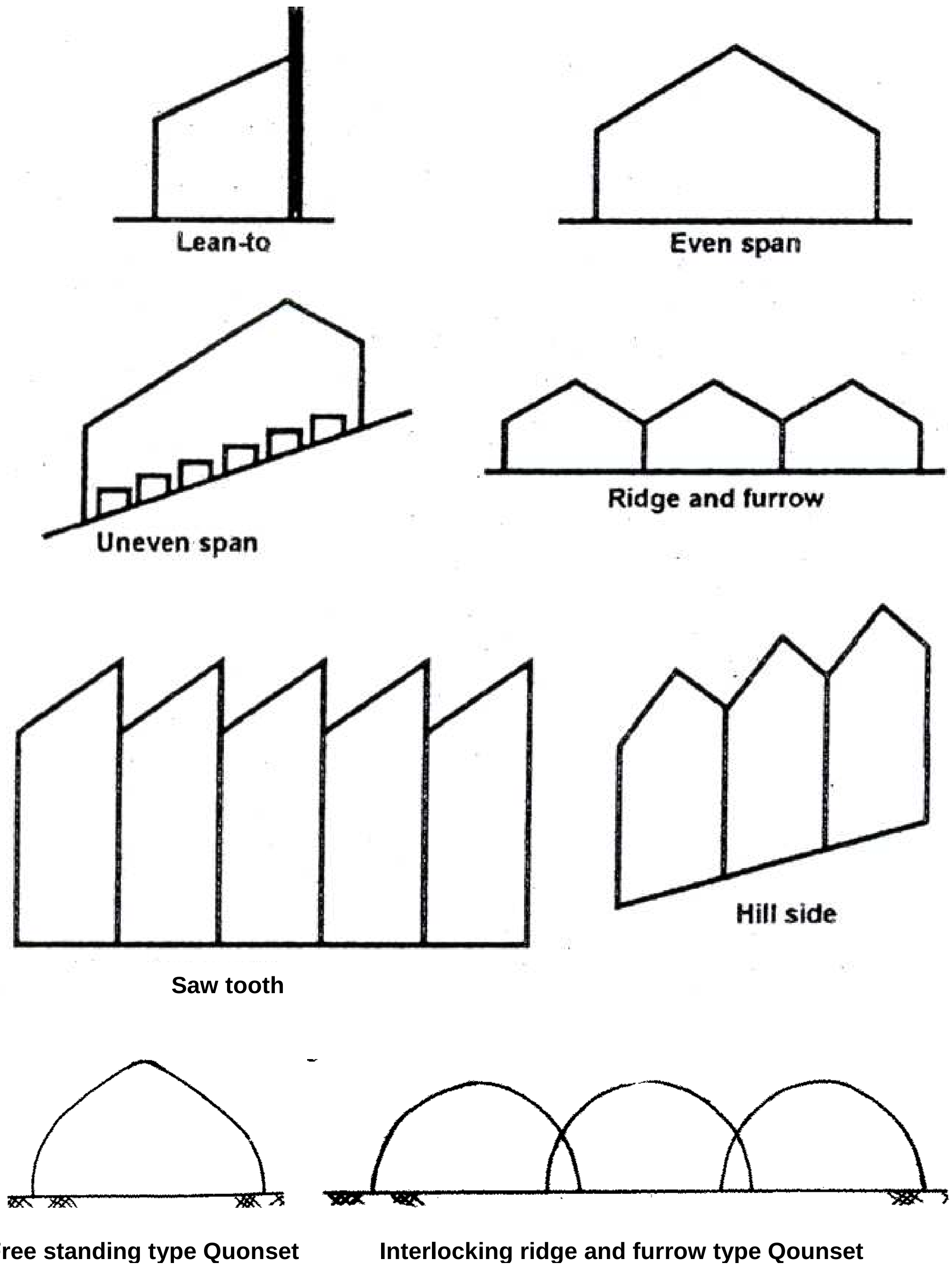
2.1.1 Lean-to type greenhouse

A lean-to design is used when a greenhouse is placed against the side of an existing building. It is built against a building, using the existing structure for one or more of its sides (Fig.1). It is usually attached to a house, but may be attached to other buildings. The roof of the building is extended with appropriate greenhouse covering material and the area is properly enclosed. It is typically facing south side. The lean-to type greenhouse is limited to single or double-row plant benches with a total width of 7 to 12 feet. It can be as long as the building it is attached to. It should face the best direction for adequate sun exposure.

The advantage of the lean-to type greenhouse is that, it usually is close to available electricity, water, and heat. It is a least expensive structure. This design makes the best use of sunlight and minimizes the requirement of roof supports. It has the following disadvantages: limited space, limited light, limited ventilation and temperature control. The height of the supporting wall limits the potential size of the design. Temperature control is more difficult because the wall that the greenhouse is built on, may collect the sun's heat while the translucent cover of the greenhouse may lose heat rapidly. It is a half greenhouse, split along the peak of the roof.

2.1.2 Even span type greenhouse

The even-span is the standard type and full-size structure, the two roof slopes are of equal pitch and width (Fig.1). This design is used for the greenhouse of small size, and it is constructed on level ground. It is attached to a house at one gable end. It can accommodate 2 or 3 rows of plant benches. The cost of an even-span greenhouse is more than the cost of a lean-to type, but it has greater flexibility in design and provides for more plants. Because of its size and greater amount of exposed glass area, the even-span will cost more to heat. The design has a better shape than a lean-to type for air circulation to maintain uniform temperatures during the winter heating season. A separate heating system is necessary unless the structure is very close to a heated building. It will house 2 side benches, 2 walks, and a wide center bench. Several single and multiple span types are available for use in various regions of India. For single span type the span in general, varies from 5 to 9 m, whereas the length is around 24 m. The height varies from 2.5 to 4.3 m.



Different Shapes of Greenhouses

2.1.3 Uneven span type greenhouse

This type of greenhouse is constructed on hilly terrain. The roofs are of unequal width; which make the structure adaptable to the side slopes of hill (Fig.2). This type of greenhouse is seldom used now-a-days as it is not adaptable for automation.

2.1.4 Ridge and furrow type greenhouse

Designs of this type use two or more A-frame greenhouses connected to one another along the length of the eave (Fig.2). The eave serves as furrow or gutter to carry rain and melted snow away. The side wall is eliminated between the greenhouses, which results in a structure with a single large interior, Consolidation of interior space reduces labour, lowers the cost of automation, improves personal management and reduces fuel consumption as there is less exposed wall area through which heat escapes. The snow loads must be taken into account in the frame specifications of these greenhouses since the snow cannot slide off the roofs as in case of individual free standing greenhouses, but melts away. In spite of snow loads, ridge and furrow greenhouses are effectively used in northern countries of Europe and in Canada and are well suited to the Indian conditions.

2.1.5 Saw tooth type Greenhouse

These are also similar to ridge and furrow type greenhouses except that, there is provision for natural ventilation in this type. Specific natural ventilation flow path (Fig.3) develops in a saw- tooth type greenhouse.

2.1.6 Quonset greenhouse

This is a greenhouse, where the pipe arches or trusses are supported by pipe purlins running along the length of the greenhouse (Fig.3). In general, the covering material used for this type of greenhouses is polyethylene. Such greenhouses are typically less expensive than the gutter connected greenhouses and are useful when a small isolated cultural area is required. These houses are connected either in free standing style or arranged in an interlocking ridge and furrow.

In the interlocking type, truss members overlap sufficiently to allow a bed of plants to grow between the overlapping portions of adjacent houses. A single large cultural space thus exists for a set of houses in this type, an arrangement that is better adapted to the automation and movement of labourers.

2.2 Greenhouse type based on utility

Classification of greenhouses can be made depending on the functions or utilities. Of the different utilities, artificial cooling and heating of the greenhouse are more expensive and elaborate. Hence based on the artificial cooling and heating, greenhouses are classified as greenhouses for active heating system and for active cooling system.

2.2.1 Greenhouses for active heating

During the night time, air temperature inside greenhouse decreases. To avoid the cold bite to plants due to freezing, some amount of heat has to be supplied. The requirements for heating greenhouse depend on the rate at which the heat is lost to the outside environment. Various methods are adopted to reduce the heat losses, viz., using double layer polyethylene, thermo pane glasses (Two layers of factory sealed glass with dead air space) or to use heating systems, such as unit heaters, central heat, radiant heat and solar heating system.

2.2.2 Greenhouses for active cooling

During summer season, it is desirable to reduce the temperatures of greenhouse than the ambient temperatures, for effective crop growth. Hence suitable modifications are made in the greenhouse so that a large volume of cooled air is drawn into greenhouse. This type of greenhouse either consists of evaporative cooling pad with fan or fog cooling. This greenhouse is designed in such a way that it permits a roof opening of 40% and in some cases nearly 100%.

2.3 Greenhouse type based on construction

The type of construction is predominantly influenced by the structural material, though the covering material also influences the type. Span of the house in turn dictates the selection of structural members and their construction. Higher the span, stronger should be the material and more structural members are used to make sturdy truss type frames. For smaller spans, simpler designs like hoops can be followed. Therefore based on construction, greenhouses can be broadly classified as wooden framed, pipe framed and truss framed structures.

2.3.1 Wooden framed structures

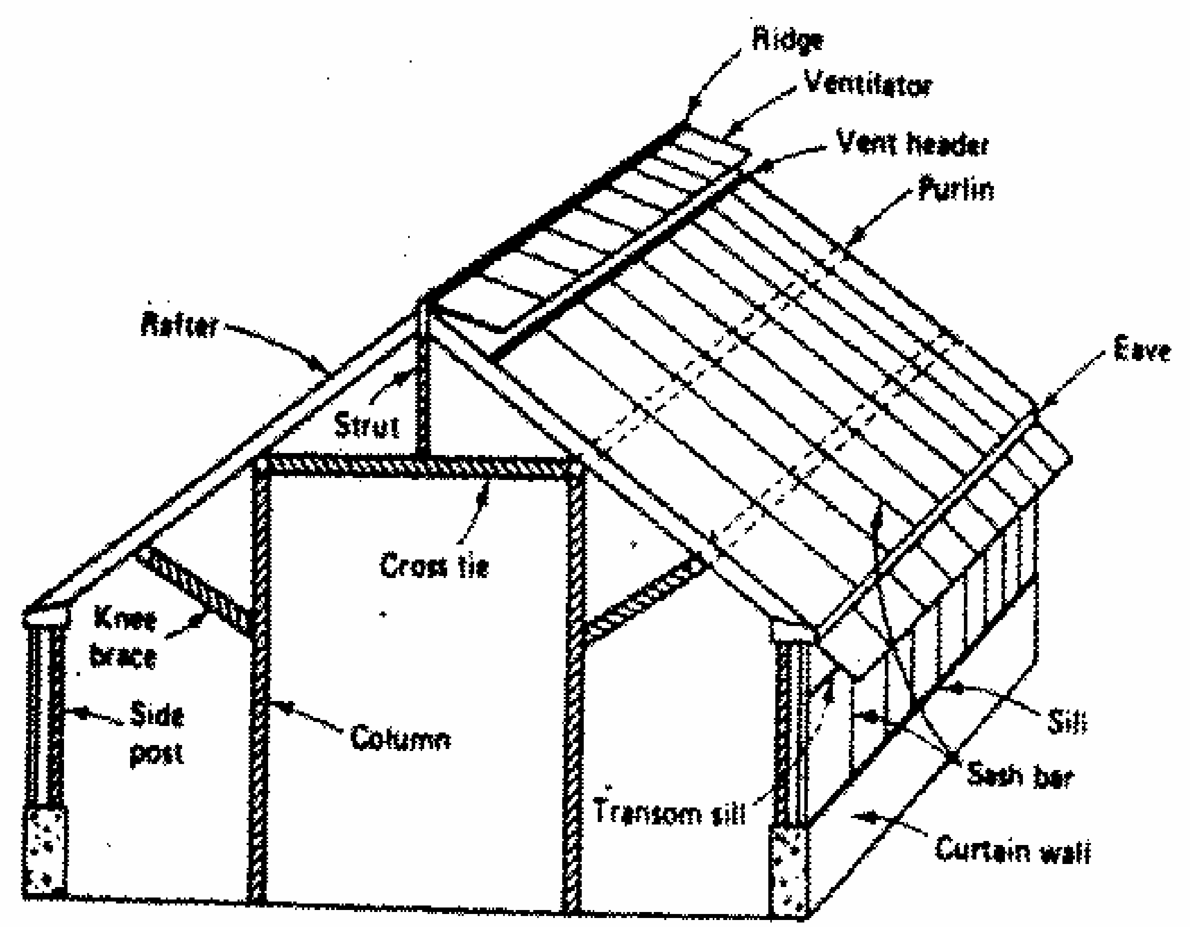
In general, for the greenhouses with span less than 6 m, only wooden framed structures are used. Side posts and columns are constructed of wood without the use of a truss. Pine wood is commonly used as it is inexpensive and possesses the required strength. Timber locally available, with good strength, durability and machinability also can be used for the construction.

2.3.2 Pipe framed structures

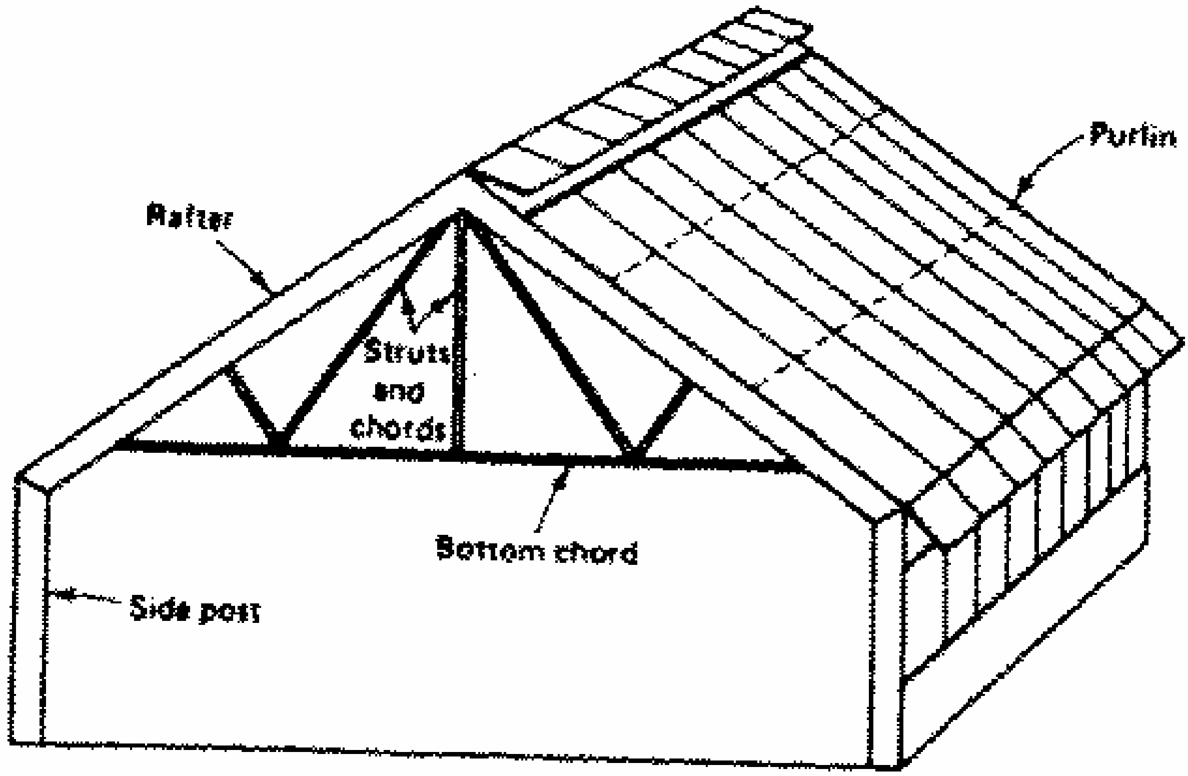
Pipes are used for construction of greenhouses, when the clear span is around 12m (Fig.4). In general, the side posts, columns, cross ties and purlins are constructed using pipes. In this type, the trusses are not used. The pipe components are not interconnected but depend on the attachment to the sash bars for support.

2.3.3 Truss framed structures

If the greenhouse span is greater than or equal to 15m, truss frames are used. Flat steel, tubular steel or angular iron is welded together to form a truss encompassing rafters, chords and struts (Fig.4). Struts are support members under compression and chords are support members under tension. Angle iron purlins running throughout the length of greenhouse are bolted to each truss. Columns are used only in very wide truss frame houses of 21.3 m or more. Most of the glass houses are of truss frame type, as these frames are best suited for pre-fabrication.



Pipe Framed Greenhouse Structure



Truss Framed Greenhouse Structure

2.4 Greenhouse type based on covering materials

Covering materials are the major and important component of the greenhouse structure. Covering materials have direct influence on the greenhouse effect inside the structure and they alter the air temperature inside the house. The types of frames and method of fixing also varies with the covering material. Based on the type of covering materials, the greenhouses are classified as glass, plastic film and rigid panel greenhouses.

2. 4.1 Glass greenhouses

Only glass greenhouses with glass as the covering material existed prior to 1950. Glass as covering material has the advantage of greater interior light intensity. These greenhouses have higher air infiltration rate which leads to lower interior humidity and better disease prevention. Lean-to type, even span, ridge and furrow type of designs are used for construction of glass greenhouse.

2.4.2 Plastic film greenhouses

Flexible plastic films including polyethylene, polyester and polyvinyl chloride are used as covering material in this type of greenhouses. Plastics as covering material for greenhouses have become popular, as they are cheap and the cost of heating is less when compared to glass greenhouses. The main disadvantage with plastic films is its short life. For example, the best quality ultraviolet (UV) stabilized film can last for four years only. Quonset design as well as gutter-connected design is suitable for using this covering material.

2.4.3 Rigid panel greenhouses

Polyvinyl chloride rigid panels, fibre-glass reinforced plastic (FRP), acrylic and polycarbonate rigid panels are employed as the covering material in the Quonset type frames or ridge and furrow type frames. This material is more resistant to breakage and the light intensity is uniform throughout the greenhouse when compared to glass or plastic. High grade panels have long life even up to 20 years. The main disadvantage is that these panels tend to collect dust as well as to harbor algae, which results in darkening of the panels and subsequent reduction in the light transmission. There is significant danger of fire hazard.

2.5 Shading nets

There are a great number of types and varieties of plants that grow naturally in the most diverse climate conditions that have been transferred by modern agriculture from their natural habitats to controlled crop conditions. Therefore, conditions similar to the natural ones must be created for each type and variety of plant. Each type of cultivated plant must be given the specific type of shade required for the diverse phases of its development. The shading nets fulfill the task of giving appropriate micro-climate conditions to the plants. Shade nettings are designed to protect the crops and plants from UV radiation, but they also provide protection from climate conditions, such as temperature variation, intensive rain and winds. Better growth conditions can be achieved for the crop due to the controlled micro-climate conditions “created” in the covered area, with shade netting, which results in higher crop yields. All nettings are UV stabilized to fulfill expected lifetime at the area of exposure. They are characterized of high tear resistance, low weight for easy and quick installation with a 30-90% shade value range. A wide range of shading nets are available in the market which are defined on the basis of the percentage of shade they deliver to the plant growing under them.

Lecture No.3

Plant Response to Greenhouse Environment

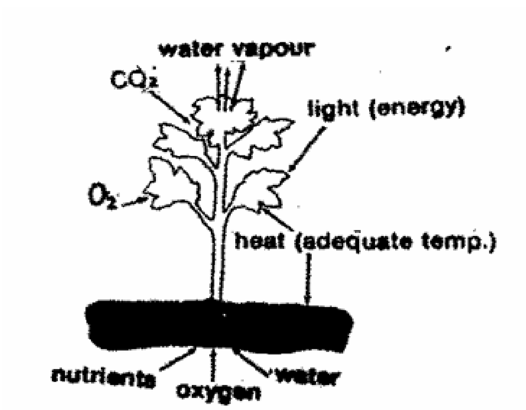
The productivity of a crop is influenced not only by its heredity but also by the microclimate around it. The components of crop microclimate are light, temperature, air compositions and the nature of the root medium. In open fields, only manipulation of nature of the root medium by tillage, irrigation and fertilizer application is possible. Even in this case, the nature of the root medium is modified but not controlled. The closed boundaries in greenhouse permit control of any one or more of the components of the micro climate.

3.1 Light

The visible light of the solar radiation is a source of energy for plants. Light energy, carbon dioxide (CO_2) and water all enter in to the process of photosynthesis through which carbohydrates are formed. The production of carbohydrates from carbon dioxide and water in the presence of chlorophyll, using light energy is responsible for plant growth and reproduction. The rate of photosynthesis is governed by available fertilizer elements, water, carbon dioxide, light and temperature. The photosynthesis reaction can be represented as follows:

$$CO_2 + \text{Water} + \text{Light energy} \xrightarrow[\text{Plant nutrients}]{\text{Chlorophyll}} \text{Carbohydrates} + \text{Oxygen}$$

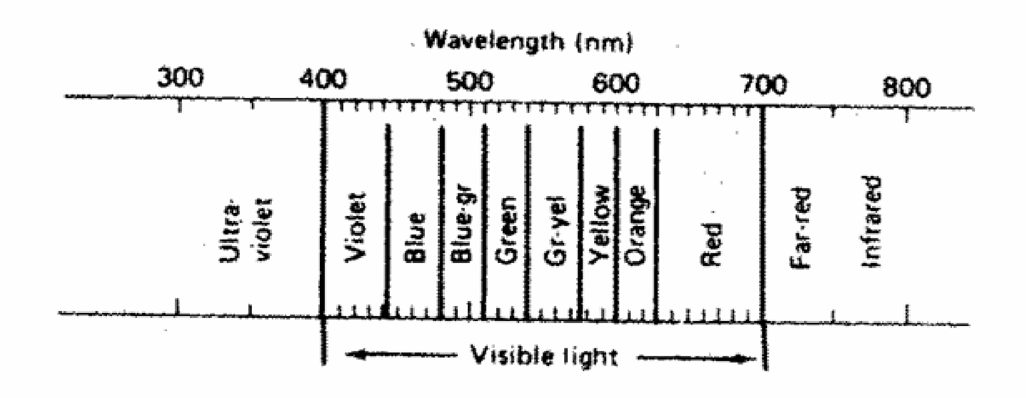
Considerable energy is required to reduce the carbon that is combined with oxygen in CO_2 gas to the state in which it exists in the carbohydrate. The light energy thus utilized is trapped in the carbohydrate. If the light intensity is diminished, photosynthesis slows down and hence the growth. If higher than optimal light intensities are provided, growth again slows down because of the injury to the chloroplasts.



Micro-climatic components influencing the plant growth

The light intensity is measured by the international unit known as Lux. It is direct illumination on the surrounding surface that is 1 meter from a uniform point source of 1 international candle. Greenhouse crops are subjected to light intensities varying from 129.6 klux on clear summer days to 3.2 klux on cloudy winter days. For most crops, neither condition is ideal. Many crops become light saturated, in other words, photosynthesis does not increase at light intensities higher than 32.3 klux. Rose and carnation plants will grow well under full summer light intensities. In general, for most other crops foliage is deeper green if the greenhouse is shaded to the extent of about 40% from mid spring (May) to mid fall (August and September). Thus, it is apparent that light intensity requirements of photosynthesis vary considerably from crop to crop.

Light is classified according to its wave length in nanometers (nm). Not all light is useful in photosynthesis process. UV light is available in the short wavelength range, i.e. less than 400nm. Large of quantities of it is harmful to the plants. Glass screens are opaque to the most UV light and light below the range of 325nm. Visible and white light has wavelength of 400 to 700nm.



Spectrum of solar radiation

Far red light (700 to 750nm) affects plants, besides causing photosynthesis. Infrared rays of longer wavelengths are not involved in the plant process. It is primarily, the visible spectrum of light that is used in photosynthesis. In the blue and red bands, the photosynthesis activity is higher, when the blue light (shorter wavelength) alone is supplied to plants, the growth is retarded, and the plant becomes hard and dark in colour. When the plants are grown under red light (longer wavelength), growth is soft and internodes are long, resulting in tall plants. Visible light of all wavelengths is readily utilized in photosynthesis.

3.2 Temperature

Temperature is a measure of level of the heat present. All crops have temperature range in which they can grow well. Below this range, the plant life processes stops due to ice formation within the tissue tying up water, and cells are possibly punctured by ice crystals. At the upper extreme, enzymes become inactive, and again process essential for life cease. Enzymes are biological reaction catalyst and are heat sensitive. All biochemical reactions in the plant are controlled by the enzymes. The rate of reactions controlled by the enzyme often doubles or triples for each rise of temperature by 10^0C, until optimum temperature is reached. Further increase in temperature begins to suppress the reaction and finally stop it.

As a general rule, greenhouse crops are grown at a day temperature, which are 3^0C to 6^0C higher than the night temperature on cloudy days and 8^0C higher on clear days. The night temperature of greenhouse crops is generally in the range of 7^0C to 21^0C. Primula, mathiola incana and calceolaria grow best at 7^0C, carnation and cineraria at 10^0C, rose at 16^0C, chrysanthemum and poinsettia at 17^0C to 18^0C and African violet at 21^0C to 22^0C.

3.3 Relative humidity

As the greenhouse is a closed space, the relative humidity of the greenhouse air will be more when compared to the ambient air, due to the moisture added by the evapotranspiration process. Some of this moisture is taken away by the air leaving from the greenhouse due to ventilation. Sensible heat inputs also lower the relative humidity of the air to some extent. In order to maintain the desirable relative humidity levels in the greenhouses, processes like humidification or dehumidification are carried out. For most crops, the acceptable range of relative humidity is between 50 to 80%. However for plant propagation work, relative humidity up to 90% may be desirable.

In summers, due to sensible heat addition in the daytime, and in winters for increasing the night time temperature of the greenhouse air, more sensible heat is added causing a reduction in the relative humidity of the air. For this purpose, evaporative cooling pads and fogging systems of humidification are employed. When the relative humidity is on the higher side, ventilators, chemical dehumidifiers and cooling coils are used for dehumidification.

3.4 Ventilation

A greenhouse is ventilated for either reducing the temperature of the greenhouse air or for replenishing carbon dioxide supply or for moderating the relative humidity of the air. Air temperatures above 35^0C are generally not suited to crops in greenhouse. It is quite possible to bring the greenhouse air temperature below this upper limit during spring and autumn seasons simply by providing adequate ventilation to the greenhouse. The ventilation in a greenhouse can either be natural or forced. In case of small greenhouses (less than 6m wide) natural ventilation can be quite effective during spring and autumn seasons. However, fan ventilation is essential to have precise control over the air temperature, humidity and carbon dioxide levels.

3.5 Carbon dioxide

Carbon is an essential plant nutrient and is present in the plant in greater quantity than any other nutrient. About 40% of the dry matter of plant is composed of carbon. Under normal conditions, carbon dioxide (CO_2) exits as a gas in the atmosphere slightly above 0.0345% or 345ppm. During the day, when photosynthesis occurs under natural light, the plants in a greenhouse draw down the level of CO_2 to below 200ppm. Under these circumstances, infiltration or ventilation increases carbon dioxide levels, when the outside air is brought in, to maintain the CO_2 at ambient levels. If the level of CO_2 is less than ambient levels, CO_2 may retard the plant growth. In cold climates, maintaining ambient levels of CO_2 by providing ventilation may be uneconomical, due to the necessity of heating the incoming air in order to maintain proper growing temperatures. In such regions, enrichment of the greenhouse with CO_2 is followed. The exact CO_2 level needed for a given crop will vary, since it must be correlated with other variables in greenhouse production such as light, temperature, nutrient levels, cultivar and degree of maturity. Most crops will respond favorably to CO_2 at 1000 to 1200 ppm.

Lecture No.4

Precise control of various parameters of greenhouse environment is necessary to optimize energy inputs and thereby maximize the economic returns. Basically, the objective of environmental control is to maximize the plant growth. The control of greenhouse environment means the control of temperature, light, air composition and nature of the root medium. A greenhouse is essentially meant to permit at least partial control of microclimate within it. Obviously greenhouses with partial environmental control are more common and economical. From the origin of greenhouse to the present there has been a steady evolution of controls. Five stages in this evolution include manual controls, thermostats, step-controllers, dedicated micro processors and computers. This chain of evolution has brought about a reduction in control labour and an improvement in the conformity of greenhouse environments to their set points. The benefits achieved from greenhouse environmental uniformity are better timing and good quality of crops, disease control and conservation of energy.

Greenhouse Cooling

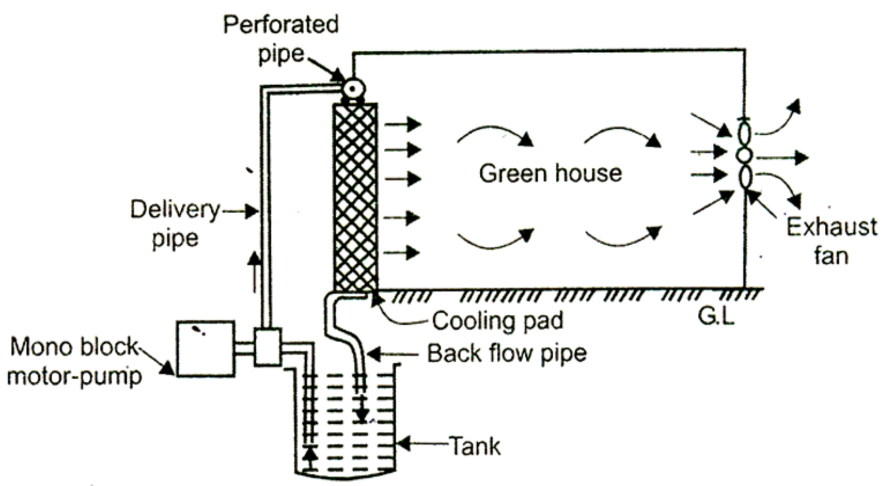
Greenhouse ventilation and cooling of greenhouse environment is essential during summer and winter as well. While summer cooling is done using evaporative cooling systems, the winter cooling uses convection tube with pressurizing fans and exhaust fans. Greenhouse cooling requires that large volume of air to be brought into the greenhouse.

4.1 Active summer cooling systems

Active summer cooling is achieved by evaporative cooling process .The evaporative cooling systems developed are to reduce the problem of excess heat in greenhouse. In this process cooling takes place when the heat required for moisture evaporation is derived from the surrounding environment causing a depression in its temperature. The two active summer cooling systems, presently in use, are ‘fan-and-pad’ and ‘fog’ systems. In the evaporative cooling process the cooling is possible only up to the wet bulb temperature of the incoming air.

4.1.1 Fan and Pad cooling system

The fan and pad evaporative cooling system has been available since 1954 and is still the most common summer cooling system in greenhouses. Along one wall of the greenhouse, water is passed through a pad that is usually placed vertically in the wall. Traditionally, the pad was composed of



Fan and Pad cooling system

excelsior (wood shreds), but today it is commonly made of a cross-fluted-cellulose material, some what similar in appearance to corrugated card board. Exhaust fans are placed on the opposite wall. Warm outside air is drawn in through the pad. The supplied water in the pad, through the process of evaporation, absorbs heat from the air passing through the pad as well as from surroundings of the pad and frame, thus causing the cooling effect. Khus-khus grass mats can also be used as cooling pads.

4.1.2 Fog cooling system

The fog evaporative cooling system, introduced in greenhouses in 1980, operates on the same cooling principle as the fan and pad cooling system but uses quite different arrangement. A high pressure pumping apparatus generates fog containing water droplets with a mean size of less than 10 microns using suitable nozzles. These droplets are sufficiently small to stay suspended in air while they are evaporating. Fog is dispersed throughout the greenhouse, cooling the air everywhere. As this system does not wet the foliage, there is less scope for disease and pest attack. The plants stay dry throughout the process. This system is equally useful for seed germination and propagation since it eliminates the need for a mist system.

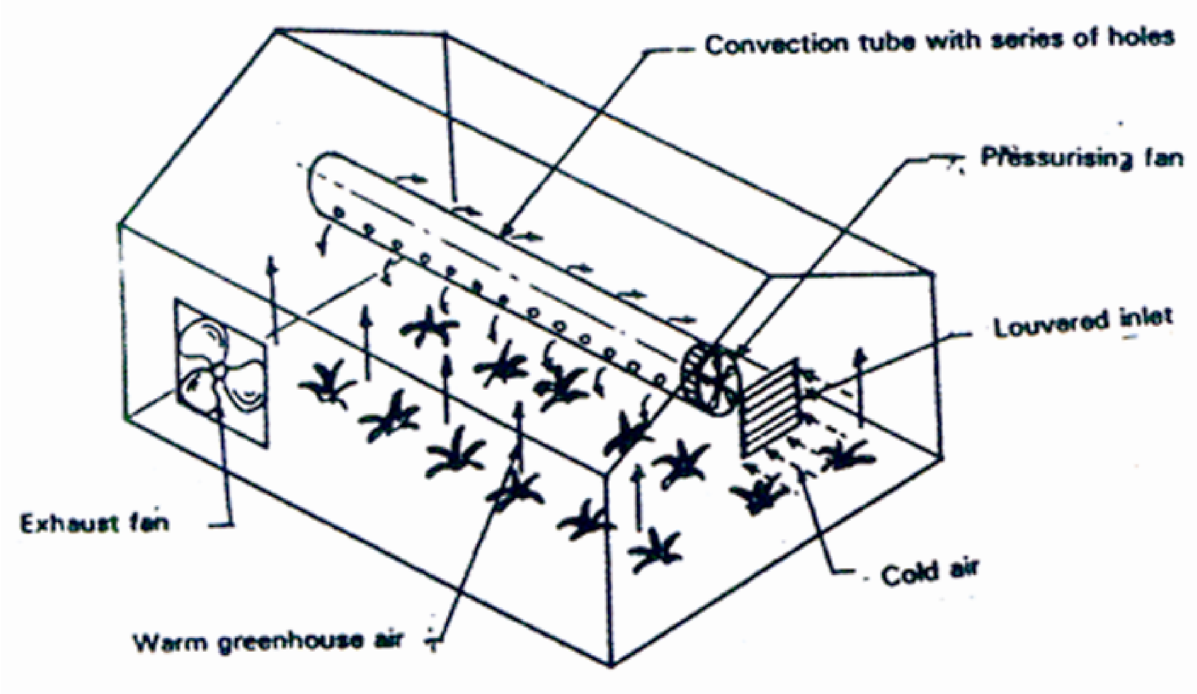
Both types of summer evaporative cooling system can reduce the greenhouse air temperature. The fan-and-pad system can lower the temperature of incoming air by about 80% of the difference between the dry and wet bulb temperatures, while the fog cooling system can lower the temperature by nearly 100% difference. This is, due to the fact that complete evaporation of the water is not taking place because of bigger droplet size in fan-and-pad; whereas in the fog cooling system, there will be complete evaporation because of the minute size of the water droplets. Thus lesser the dryness of the air, greater evaporative cooling is possible.

4.2 Active winter cooling systems

Excess heat can be a problem during the winter. In the winter, the ambient temperature will be below the desired temperature inside the greenhouse. Owing to the greenhouse effect, the entrapment of solar heat can rise the temperature to an injurious level; if the greenhouse is not ventilated. The actual process in winter cooling is tempering the excessively cold ambient air before it reaches the plant zone. Otherwise, hot and cold spots in the greenhouse will lead to uneven crop timing and quality .This mixing of low temperature ambient air with the warm inside air cools the greenhouse in the winter. Two active winter cooling systems, commonly employed, are convection tube cooling and horizontal air flow (HAF) fan cooling systems.

4.2.1 Convection tube cooling

The general components of convection tube are the louvered air inlet, a polyethylene convection tube with air distribution holes, a pressurizing fan to direct air in to the tube under pressure, and an exhaust fan to create vacuum. When the air temperature inside the greenhouse exceeds the set point, the exhaust fan starts functioning thus creating vacuum inside the greenhouse. The louver of the inlet in the gable is then opened through which cold air enters due to the vacuum. The pressurizing fan, at the end of the clear polyethylene convection tube, operates to pick up the cool air entering the louver. A proper gap is available for the air entry, as the end of the convection tube is separated from the louvered inlet by 0.3 to 0.6m and the other end of the tube is sealed. Round holes of 5 to 8 cm in diameter are provided in pairs at opposite sides of the tube spaced at 0.5 to 1m along the length of the tube.



Convection tube cooling system

Cold air under pressure in the convection tube shoots out of holes on either side of the tube in turbulent jets. In this system, the cold air mixes with the warm greenhouse air well above the plant height. The cool mixed air, being heavier, gently flows down to the floor level, and affects the complete cooling of the plant area. The pressurizing fan forcing the incoming cold air in to the convection tube must be capable of moving at least the same volume of air as that of the exhaust fan, thereby avoiding the development of cold spots in the house. When cooling is not required, the inlet louver closes and the pressurizing fan continues to circulate the air within the greenhouse. The process minimizes the temperature gradient at difference levels. The circulation of air using convection tube consumes more power than a circulation system.

4.2.2 Horizontal air flow cooling

HAF cooling system uses small horizontal fans for moving the air mass and is considered to be an alternative to convection tube for the air distribution. In this method the greenhouse may be visualized as a large box containing air and the fans located strategically moves the air in a circular pattern. This system should move air at 0.6 to 0.9 $m^3/min/m^2$ of the greenhouse floor area. Fractional horse power of fans is 31 to 62 W (1/30 to 1/15hp) with a blade diameter of 41cm are sufficient for operation. The fans should be arranged in such a way that air flows are directed along the length of the greenhouse and parallel to the ground. The fans are placed at 0.6 to 0.9m above plant height and at intervals of 15m.They are arranged such that the air flow is directed by one row of the fans along the length of the greenhouse down one side to the opposite end and then back along the other side by another row of fans (Fig.6). Greenhouses of larger widths may require more number of rows of fans along its length.

Temperatures at plant height are more uniform with HAF system than with convection tube system. The HAF system makes use of the same exhaust fans, inlet louvers and controls as the convection tube system. The only difference is the use of HAF fans in place of convection tubes for the air distribution. Cold air entering through the louvers located at the higher level in the gables of the greenhouse is drawn by the air circulation created by the net work of HAF fans and to complete the cycle, proper quantity of air is let out through the exhaust fans. The combined action of louvered inlet, HAF fans and the exhaust fans distribute the cold air throughout the greenhouse.

Similarly, the convection tubes and the HAF fans can be used to distribute heat in the greenhouse. When neither cooling nor heating is required, the HAF fans or convection tube can be used to bring warm air down from the upper level of the gable and to provide uniform temperature in the plant zone. It is possible to integrate summer and winter cooling systems with heating arrangements inside a greenhouse for the complete temperature control requirements for certain days of the season.

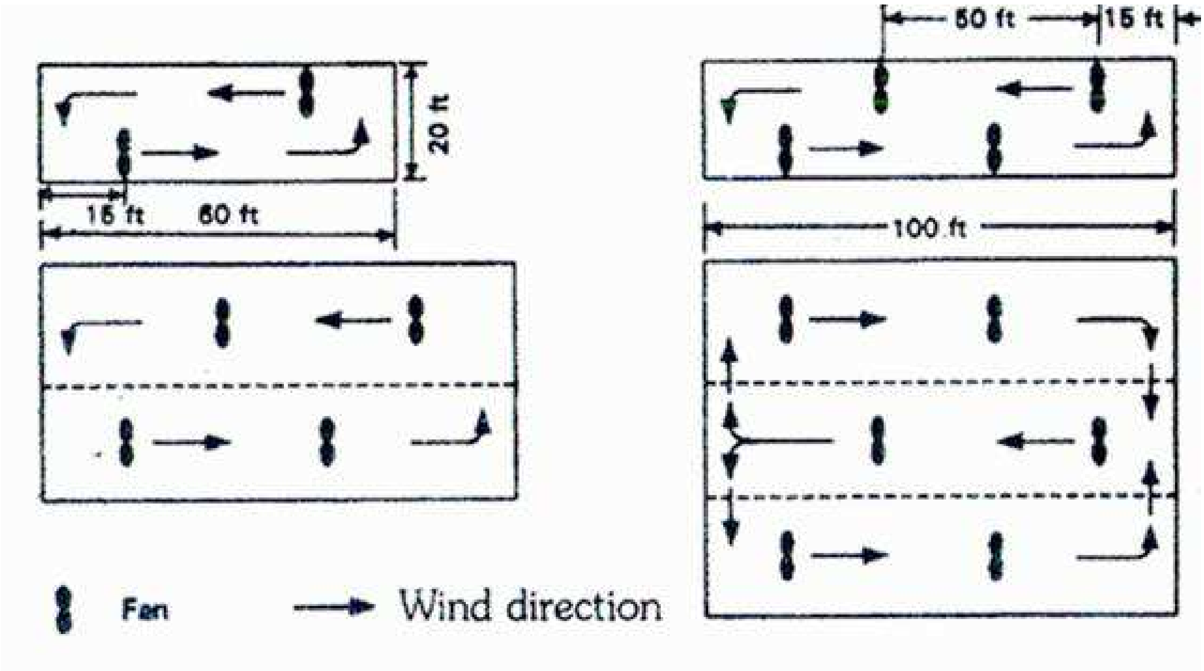


Fig.6. HAF system in different sizes of greenhouses

4.3 Greenhouse ventilation

Ventilation is the process of allowing the fresh air to enter in to the enclosed area by driving out the air with undesirable properties. In the greenhouse context, ventilation is essential for reducing temperature, replenishing CO_2 and controlling relative humidity. Ventilation requirements for greenhouses vary greatly, depending on the crop grown and the season of production. The ventilation system can be either a passive system (natural Ventilation) or an active system (forced ventilation) using fans. Usually greenhouses that are used seasonally employ natural ventilation only. The plant response to specific environment factor is related to the physiological processes and hence the latter affects the yield and quality. Hence, controlling of environment is of great importance to realize the complete benefits of CEA (Controlled Environment Agriculture). Manual maintenance of uniform environmental condition inside the greenhouse is very difficult and cumbersome. A poor maintenance results in less crop production, low quality and low income. For effective control of automatic control systems, micro processor and computer are used presently to maintain the environment.

4.3.1 Natural ventilation

In the tropics, the sides of greenhouse structures are often left open for natural ventilation. Tropical greenhouse is primarily a rain shelter, a cover of polyethylene over the crop to prevent rainfall from entering the growing area. This mitigates the problem of foliage diseases. Ventilators are located on both roof slopes adjacent to the ridge and also on both side walls of the greenhouse. The ventilators on the roof as well as those on the side wall accounts, each about 10% of the total roof area. During winter cooling phase, the south roof ventilator is opened in stages to meet cooling needs. When greater cooling is required, the north ventilator is opened in addition to the south ventilator. In summer cooling phase, the south ventilator is opened first, followed by the north ventilator. As the incoming air moves across the greenhouse, it is warmed by sunlight and by mixing with the warmer greenhouse air. With the increase in temperature, the incoming air becomes lighter and rises up and flows out through the roof ventilators. This sets up a chimney effect (Fig.7), which in turn draws in more air from the side ventilators creating a continuous cycle. This system does not adequately cool the greenhouse. On hot days, the interior walls and floor are frequently injected with water to help cooling.

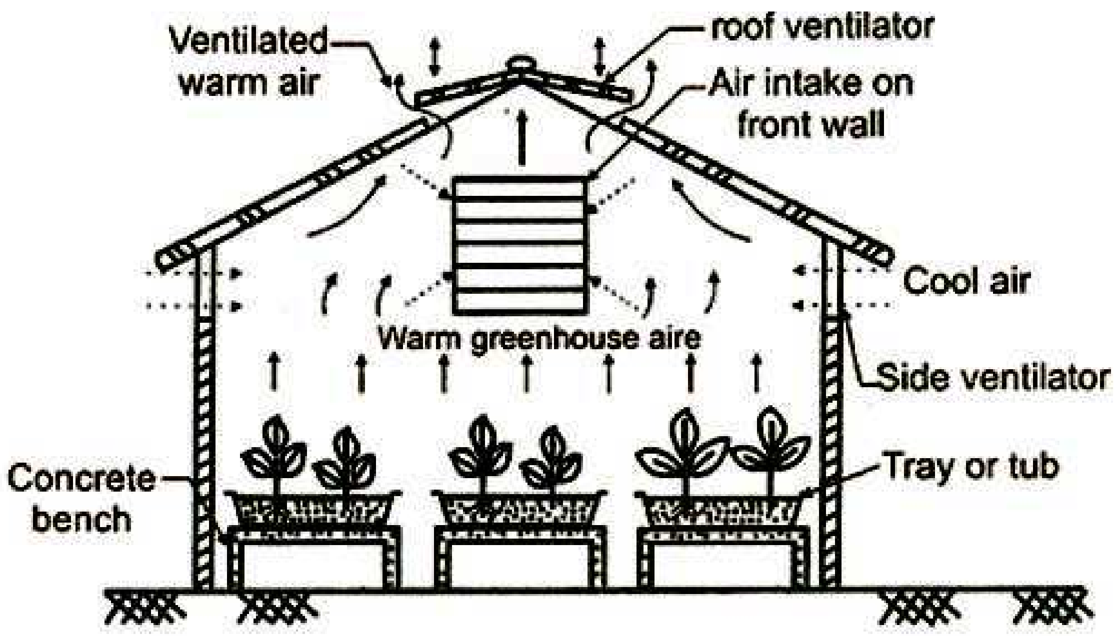
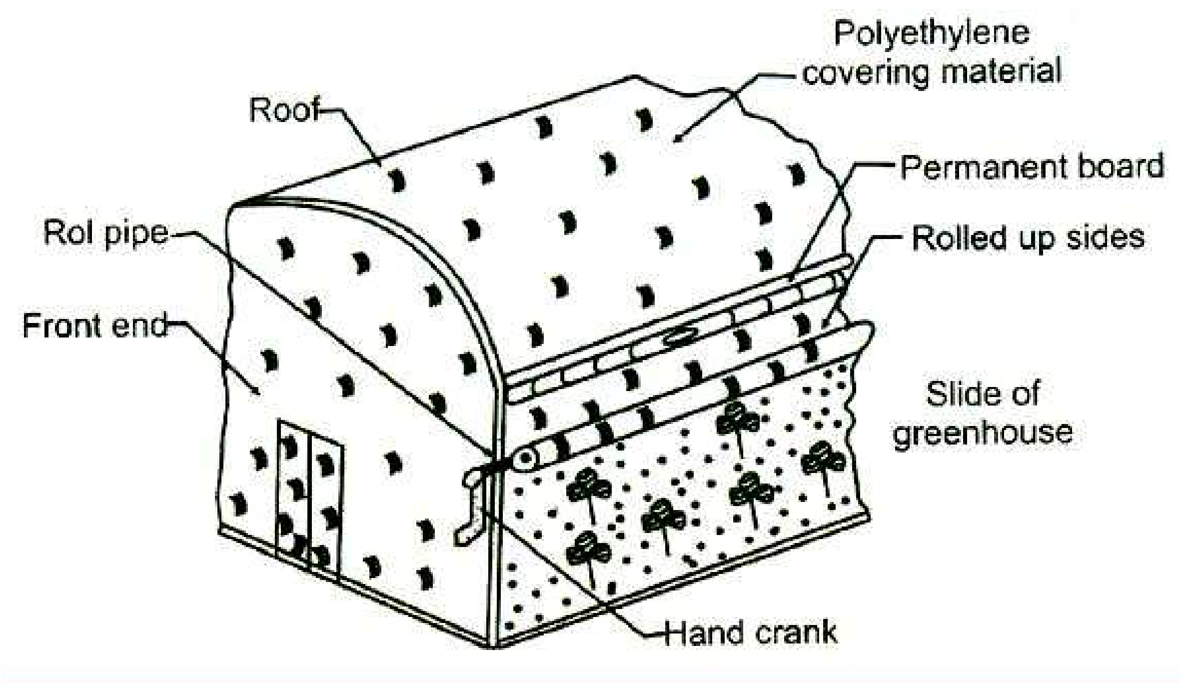


Fig.7. Chimney effect in general passive ventilation

4.3.1.1 Roll up side passive ventilation in poly houses

Roll up method of ventilation, allows the air to flow across the plants. The amount of ventilation on one side, or both sides, may be easily adjusted in response to temperature, prevailing wind and rain (Fig.8). During the periods of excessive heat, it may be necessary to roll the sides up almost to the top. Passive ventilation can also be accomplished by manually raising or parting the polyethylene sheet. The open vent areas must be covered with screens to prevent virus diseases. The holes must be large enough to permit free flow of air. Screens with small holes block air movement and cause a build up of dust. Rollup side passive ventilation on plastic greenhouses is only effective on free standing greenhouses and not on gutter connected greenhouses.



Roll up side passive ventilation

4.3.2 Forced Ventilation

In forced or active ventilation, mechanical devices such as fans are used to expel the air. This type of ventilation can achieve uniform cooling. These include summer fan-and-pad and fog cooling systems and the winter convection tube and horizontal airflow systems. For mechanical ventilation, low pressure, medium volume propeller blade fans, both directly connected and belt driven are used for greenhouse ventilation. They are placed at the end of the green house, opposite to the air intake, which is normally covered by gravity or motorized louvers. The fans vents, or louvers, should be motorized, with their action controlled by fan operation. Motorized louvers prevent the wind from opening the louvers, especially when heat is being supplied to the green house. Wall vents should be placed continuously across the end of the greenhouse to avoid hot areas in the crop zone.

Evaporative cooling in combination with the fans is called as fan-and-pad cooling system. The fans and pads are usually arranged on opposite walls of the greenhouse (Fig.8). The common types of cooling pads are made of excelsior (wood fiber), aluminum fiber, glass fiber, plastic fiber and cross-fluted cellulose material. Evaporative cooling systems are especially efficient in low humidity environments. There is growing interest in building greenhouses combining both passive (natural) and active (forced) systems of ventilation. Passive ventilation is utilized as the first stage of cooling, and the fan-pad evaporative cooling takes over when the passive system is not providing the needed cooling. At this stage, the vents for natural ventilation are closed. When both options for cooling are designed in greenhouse construction, initial costs of installation will be more. But the operational costs are minimized in the long run, since natural ventilation will, most often meet the needed ventilation requirements.

Fogging systems is an alternative to evaporative pad cooling. They depend on absolutely clean water, free of any soluble salts, in order to prevent plugging of the mist nozzles. Such cooling systems are not as common as evaporative cooling pads, but when they become more cost competitive, they will be adopted widely. Fogging systems are the second stage of cooling when passive systems are inadequate.

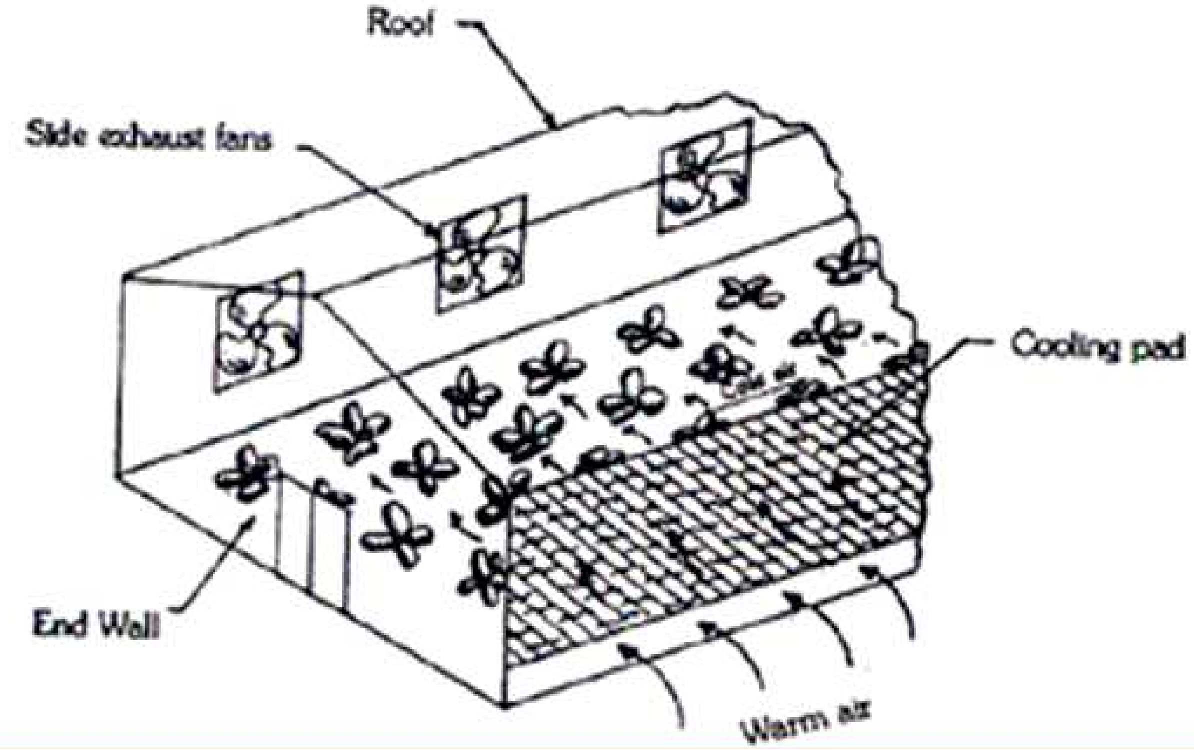
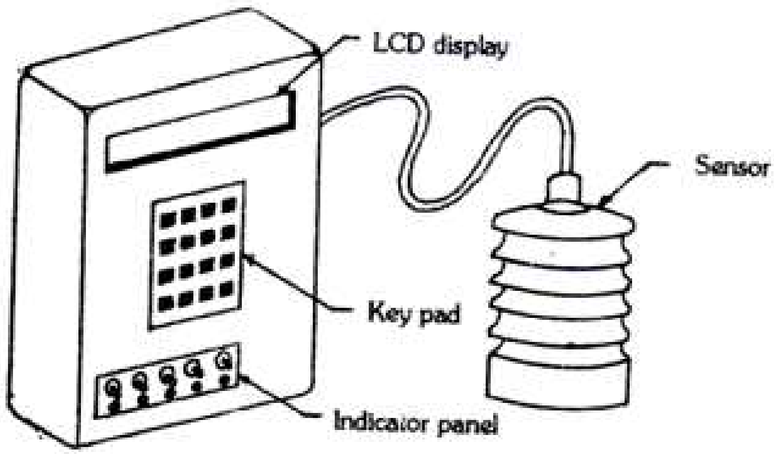


Fig.8. Fan and Pad type Active Summer Cooling System

4.3.3 Microprocessors

Dedicated microprocessors can be considered as simple computers. A typical microprocessor will have a keypad and a two or three line liquid crystal display of, sometimes, 80-character length for programming. They generally do not have a floppy disk drive. They have more output connections and can control up to 20 devices. With this number of devices, it is cheaper to use a microprocessor. They can receive signals of several types, such as, temperature, light intensity, rain and wind speed. They permit integration of the diverse range of devices, which is not possible with thermostats. The accuracy of the microprocessor for temperature control is quite good. Unlike a thermostat, which is limited to a bimetallic strip or metallic tube for temperature sensing and its mechanical displacement for activation, the microprocessor often uses a thermistor. The bimetallic strip sensor has less reproducibility and a greater range

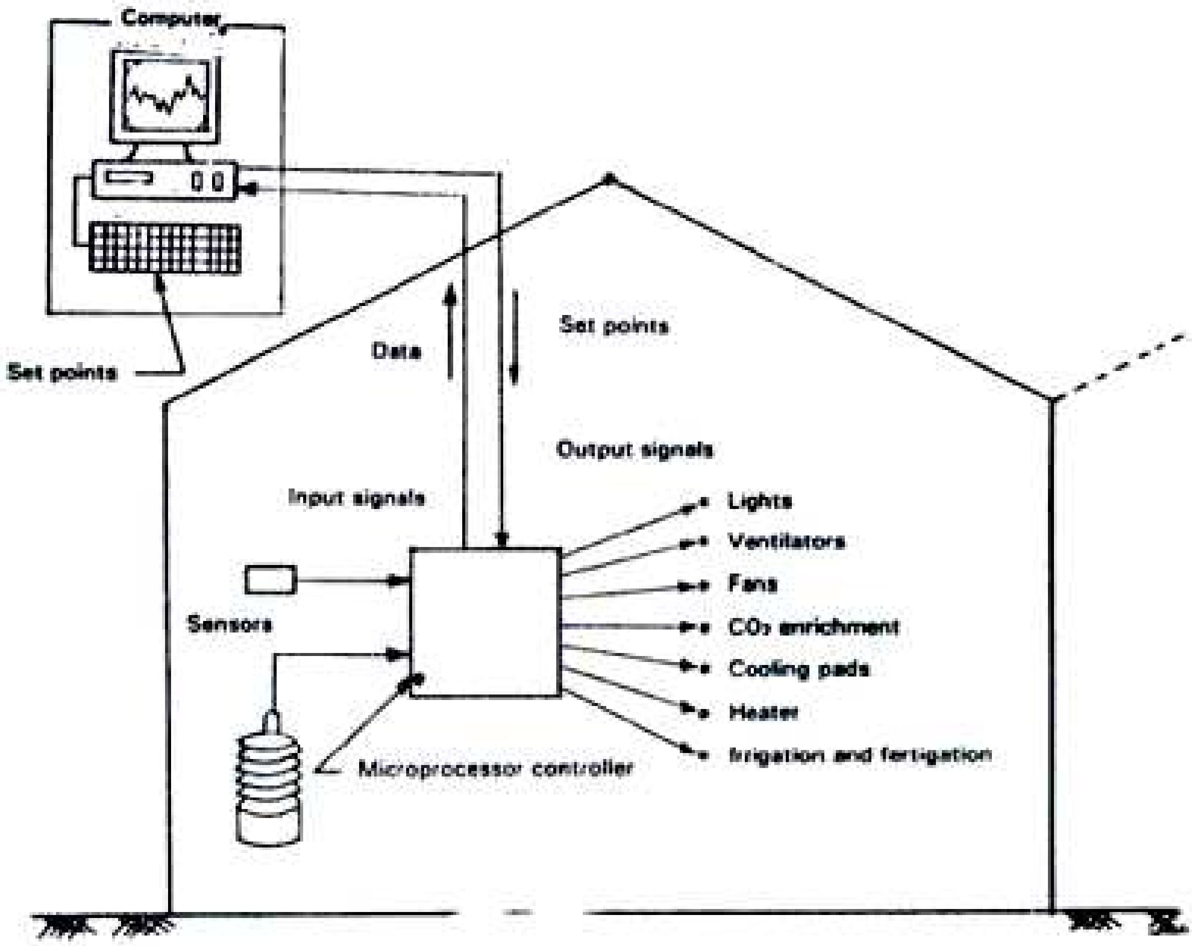


Microprocessor for controlling greenhouse environment

between the ON and OFF steps. Microprocessors can be made to operate various devices, for instance, a microprocessor can operate the ventilators based on the information from the sensor for the wind direction and speed. Similarly a rain sensor can also activate the ventilators to prevent the moisture sensitive crop from getting wet. A microprocessor can be set to activate the CO_2 generator when the light intensity exceeds a given set point, a minimum level for photosynthesis.

4.3.4 Computers

Now-a-days, computer control systems are common in greenhouse installation throughout Europe, Japan and the United States. Computer systems can provide fully integrated control of temperature, humidity, irrigation and fertilization, CO_2, light and shade levels for virtually any size growing facility. Precise control over a growing operation enables growers to realize saving of 15 to 50% in energy, water, chemical and pesticide applications. Computer controls normally help to achieve greater plant consistency, on-schedule production, higher overall plant quality and environmental purity.



Computerized control systems in greenhouse

A computer can control hundreds of devices within a green house (devices like vents, heaters, fans, hot water mixing valves, irrigation valves, curtains and lights etc.) by utilizing dozens of input parameters, such as outside and inside temperatures, humidity, outside wind direction and velocity, CO_2 levels and even the time of the day or night. Computer systems receive signals from all sensors, evaluate all conditions and send appropriate commands every minute to each piece of equipment in the greenhouse range thus maintaining ideal conditions in each of the various independent greenhouse zones defined by the grower (Fig.9). Computers collect and record data provided by greenhouse production managers. Such a data acquisition system will enable the grower to gain a comprehensive knowledge of all factors affecting the quality and timeliness of the product. A computer produces graphs of past and current environmental conditions both inside and outside the greenhouse complex. Using a data printout option, growers can produce reports and summaries of environmental conditions such as temperature, humidity and the CO_2 status for the given day, or over a longer period of time for current or later use.

As more environmental factors in the greenhouse are controlled, there comes a stage when individual controls cannot be coordinated to prevent system overlap. An example is the greenhouse thermostat calling for heating while the exhaust fans are still running. With proper software program, which uses the environmental parameters as input from different sensors, can effectively coordinate all the equipment without overlap and precisely control all parameters affecting plant development as desired. Despite the attraction of the computer systems, it should be remembered that the success of any production system is totally dependent on the grower's knowledge of the system and the crop management. Computers can only assist by adding precision to the overall greenhouse production practice, and they are only as effective as the software they run and the effectiveness of the operator. The advantages and disadvantages of computerized control system are as follows:

Advantages

1. The computer always knows what all systems are doing and, if programmed properly, can coordinate these systems without overlap to provide the optimum environment.

2. The computer can record the environmental data, which can be displayed to show current conditions or stored and processed ones to provide a history of the cropping period, and if desired it may also be displayed in table or graph form.

3. A high-speed computer with networking facility can control several remotely located greenhouses, by placing the computer in a central area and the results can be monitored frequently by the management.

4. With proper programming and sensing systems, the computer can anticipate weather changes and make adjustments in heating and ventilation systems, thus saving the energy.

5. The computer can be programmed to sound an alarm if conditions become unacceptable to and to detect sensor and equipment failure.

Disadvantages

1. High initial cost investment.
2. Requires qualified operators.
3. High maintenance, care and precautions are required.
4. Not economical for small scale and seasonal production.

Lecture No.5

Planning of Greenhouse Facility

A greenhouse, has basically the purpose of providing and maintaining a growing environment that will result in optimum production at maximum yield. The agriculture in the controlled environment is possible in all the regions irrespective of climate and weather.

As an enclosing structure for growing plants, greenhouse must admit the visible light portion of solar radiation for the plant photosynthesis and, therefore, must be transparent. At the same time, to protect the plants, a greenhouse must be ventilated or cooled during the day because of the heat load from the radiation. The structure must also be heated or insulated during cold nights. A greenhouse acts as a barrier between the plant production areas and the external or the general environment.

5.1 Site selection and orientation

A greenhouse is designed to withstand local wind, snow and crop loads for a specific cropping activity. In this way, the structure becomes location and crop specific. The building site should be as level as possible to reduce the cost of grading, and the site should be well aerated and should receive good solar radiation. Provision of a drainage system is always advisable. It is also advisable to select a site with a natural windbreak. In regions where snow is expected, trees should be 30.5 m away in order to keep drifts back from the greenhouses. To prevent shadows on the crop, trees located on the east, south, or west sides should be at a distance of 2.5 times their height.

5.2 Structural design

The most important function of the greenhouse structure and its covering is the protection of the crop against hostile weather conditions (low and high temperatures, snow, hail, rain and wind), diseases and pests. It is important to develop greenhouses with a maximum intensity of natural light inside. The structural parts that can cast shadows in the greenhouse should be minimized.

The different structural designs of greenhouse based on the types of frames are available. A straight side wall and an arched roof (a type) is possibly the most common shape for a greenhouse, but the gable roof (b type) is also widely used**.** Both structures can be free standing or gutter connected with the arch roof greenhouse. The arch roof and hoop style (c type) greenhouses are most often constructed of galvanized iron pipe. If tall growing crops are to be grown in a greenhouse or when benches are used, it is best to use a straight side wall structure (d type) rather than a hoop style house, this ensures the best operational use of the greenhouse. A hoop type greenhouse is suitable for low growing crops, such as lettuce, or for nursery stock which are housed throughout the winter in greenhouses located in extremely cold regions. A gothic arch frame structure (e type) can be designed to provide adequate side wall height without loss of strength to the structure (Fig.10).

Loads in designing the greenhouse structures include the weight of the structure itself and, if supported by the structure, loads of the equipment for the heating and ventilation and water lines. The load may also include the weight of crops, if they are trailed to a support system carried by the greenhouse frame; and also loads from wind and snow. Greenhouse structures should be designed to resist a 130 km/h wind velocity. The actual load depends on wind angle, greenhouse shape and size, and the presence or absence of openings and wind breaks.

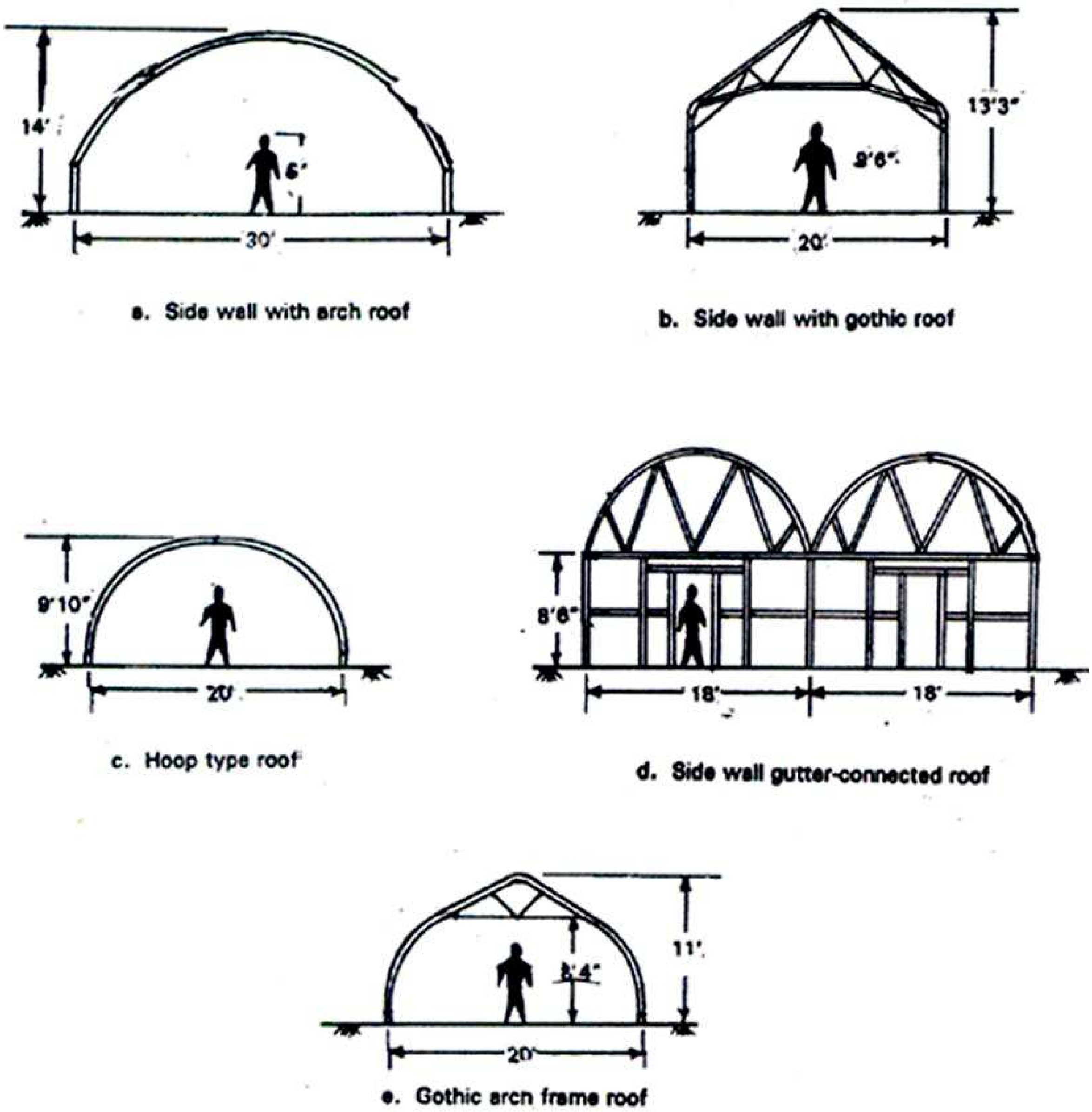


Fig.10. Structural designs of different greenhouse frameworks

The ultimate design of a greenhouse depends on the following aspects:

(i) The overall structural design and the properties of the individual structural components.
(ii) The specific mechanical and physical properties which determine the structural behaviour of the covering materials.
(iii) The specific sensitivity of the crop to light and temperature to be grown in the greenhouse.
(iv) The specific requirements relevant to the physical properties of the covering material.
(v) The agronomic requirements of the crop.

5.3 Covering materials

The various factors; to be considered while selecting the greenhouse covering material; are light transmission, weight, resistance to impact, and durability to outdoor weathering and thermal stability over wide range of temperatures. Before selecting the covering material, two important points should be taken into consideration: the purpose for which greenhouse facility is intended and service life of material. In temperate regions where high temperatures are required, the covering material with high light transmission and far IR absorption must be selected. Also the loss of heat by conduction should be minimum.

Another important aspect in selection of covering material is the service life of the material

Covering material	Life span
1. Glass and acrylic sheet	20 years
2. Polycarbonate and fiberglass-reinforced polyester sheet	5-12 years
3. Polyethylene	2-6 months
4. Polyethylene stabilized for UV rays	2-3 years

The ideal greenhouse selective covering material should have the following properties:

(i) It should transmit the visible light portion of the solar radiation which is utilized by plants for photosynthesis.

(ii) It should absorb the small amount of UV in the radiation and convert a portion of it to fluoresce into visible light, useful for plants.

(iii) It should reflect or absorb IR radiation which are not useful to plants and which causes greenhouse interiors to overheat.

(iv) Should be of minimum cost.

(v) Should have usable life of 10 to 20 years.

Such a covering material will obviously improve CEA performance, reducing solar heat load, increasing light levels and crop yields.

Lecture No.6

Greenhouse Construction Materials

The materials that are commonly used to build frames for greenhouse are (i) Wood, (ii) Bamboo, (iii) Steel, (iv) Galvanized iron pipe, (v) Aluminum and (vi) Reinforced cement concrete (RCC). The selection of above materials is based on their specific physical properties, requirements of design strength, life expectancy and cost of construction materials.

6.1 Wood

Wood and bamboo are generally used for low cost polyhouses. In low cost polyhouses, the wood is used for making frames consisting of side posts and columns, over which the polythene sheet is fixed. The commonly used woods are pine and casuarina, which are strong and less expensive. In pipe-framed polyhouses, wooden battens can be used in the end frames for fixing the covering material. In tropical areas, bamboo is often used to form the gable roof of a greenhouse structure. Wood must be painted white to improve light conditions within the greenhouse. Care should be taken to select a paint that will prevent the growth of mold. Wood must also be treated for protection against decay. Special treatment should be given to the wood that may come into contact with the soil. Chromated copper arsenate and ammonical copper arsenate are water based preservatives that are safe to use where plants are grown. Even natural decay resistance woods, such as redwood or cypress should be treated, in desert or tropical regions, but they are expensive.

6.2 Galvanized Iron (GI), Aluminium, Steel and Reinforced Cement Concrete (RCC)

GI pipes, tubular steel and angle iron are generally used for side posts, columns and purlins in greenhouse structure, as wood is becoming scarce and more expensive. In galvanising operation, the surface of iron or steel is coated with a thin layer of zinc to protect it against corrosion. The commonly followed processes to protect against corrosion are:

(i) Hot dip galvanising (hot process) process: The cleaned member is dipped in molten zinc, which produces a skin of zinc alloy to the steel.

(ii) Electro-galvanising (cold process) process: The cleaned member is zinc plated similar to other forms of electro-plating.

The galvanising process makes the iron rust proof, and eliminates the problem of rusting of structural members. Aluminum and hot dipped GI are comparatively maintenance free. In tropical areas, double dipping of steel is required, as single dip galvanising process does not give a complete cover of even thickness to the steel. Aluminum and steel must be protected by painting with bitumen tar**,** to protect these materials from corrosion, while these materials come in direct contact with the ground. Now-a-days, the greenhouse construction is of metal type, which is more permanent. RCC is generally limited to foundations and low walls. In permanent bigger greenhouses, floors and benches for growing the crops are made of concrete.

6.3 Glass

Glass has been traditional glazing material all over the world. Widely used glasses for greenhouse are: (i) single drawn or (ii) float glass, (iii) hammered and (iv) tempered glass. Single drawn or float glass has the uniform thickness of 3 to 4 mm. Hammered and tempered glass has a thickness of 4 mm. Single drawn glass is made in the traditional way by simply pulling the molten glass either by hand or by mechanical equipment. Float glass is made in modern way by allowing the molten glass to float on the molten tin. Coating with metal oxide with a low emissivity is used for saving of energy with adequate light transmittance. Hammered glass is a cast glass with one face (exterior) smooth and the other one (interior) rough. It is designed to enhance light diffusion. This glass is not transparent, but translucent. Tempered glass is the glass, which is quickly cooled after manufacture, adopting a procedure similar to that used for steel. This kind of processing gives higher impact resistance to the glass, which is generally caused by hail. Glass used as a covering material of greenhouses, is expected to be subjected to rather severe wind loading, snow and hail loading conditions. The strength mainly depends on the length/width ratio of the panel and on the thickness of the panel, but the most widely used thickness is 4 mm.

6.4 Polyethylene Film

Polyethylene is principally used today for two reasons- (i) Plastic film greenhouses with permanent metal frames cost less than glass greenhouses and (ii) Plastic film greenhouses are popular because the cost of heating them is approximately 40% lower compared to single-layer glass or fiberglass-reinforced plastic greenhouses. The disadvantages are **: t**hese covering materials are short lived compared to glass and plastic panels. UV light from the sun causes the plastic to darken, thereby lowering transmission of light, also making it brittle, which leads to its breakage due to wind. A thermal screen is installed inside a glass greenhouse that will lower the heat requirement to approximately that of a double-layer plastic film greenhouse, but this increases the cost of the glass greenhouse. Polyethylene film was developed in the late 1930s in England and spread around the middle of this century. Commonly used plastic for greenhouse coverings are thermoplastics. Basic characteristics of thermoplastics are: (i) thermoplastics consists of long chain molecules, soften with heating and harden with cooling and this process is reversible and (ii) thermoplastics constitute a group of material that are attractive to the designer for two main reasons: (a) Thermoplastics have specific physical properties- stiffness, robustness and resilience to resist loads and deformations imposed during normal use and (b) They can readily be processed using efficient mass production techniques, which result in low labour charges.

Polyethylene used for greenhouse covering year round has UV-inhibitor in it. Otherwise it lasts for only one heating season. UV-inhibited plastic cover may last for a period of 4 to 5 years. UV-grade polyethylene is available in widths up to 15.2 m (50 ft) in flat sheets and up to 7.6 m (25 ft) in tubes. Standard lengths include 30.5, 33.5, 45.7, 61.0 and 67.0 m (100, 110, 150, 200 and 220 ft). Some companies provide custom lengths upto a maximum of 91.5 m (300 ft).

Condensation on polyethylene film is a big problem. Condensation causes disease development, development of water logged condition and oxygen deficiency inside the greenhouse. Condensation reduces light intensity within the greenhouse. To avoid this problem, anti-fog surfactant, which discourages condensation, is built into the film or panel.

Warm objects, such as plants, the greenhouse frame and soil radiate IR energy to colder bodies (sky) at night, which result in loss of heat in greenhouse. Since polyethylene is a poor barrier to radiant heat, it is formulated with IR-blocking chemicals into it during manufacture, so as to stop about half of the radiant heat loss. On cold and clear nights, as much as 25% of the total heat loss of a greenhouse can be prevented in this way and on cloudy nights only 15% is prevented.

UV-stabilized polyethylene, on an average, transmits about 87% of photosynthetically active radiation (PAR) into the greenhouse. IR absorbing polyethylene, reduces radiant heat loss, transmits about 82% of photosynthetically active radiation (PAR) into the greenhouse. The amount of light passing through two layers of a greenhouse covering is approximately the square of the decimal fraction of the amount passing through one layer. Eg. When 87% passes through one layer of UV-inhibited polyethylene, only 76% (0.87 x 0.87) passes through two layers. Similarly, when 82% passes through one layer of IR-absorbing polyethylene, only 67% (0.82 x 0.82) passes through two layers.

6.5 Polyvinyl Chloride Film (PVC films)

PVC films are UV light resistant vinyl films of 0.2 and 0.3 mm thickness (8 and 12 mil thickness; 1 mil = 1/1000 in) and are guaranteed for 4 and 5 years respectively. The cost of 0.3 mm (12 mil) vinyl film is three times that of 0.15 mm (6 mil) polyethylene. Vinyl film is produced in rolls upto 1.27 m (50 in) wide. Vinyl films tend to hold a static electrical charge, which attracts and holds dust. This in turn reduces light transmittance unless the dust is washed off. Vinyl films are seldom used in the United States. In Japan, 95% of greenhouses are covered with plastic film, out of which 90% are covered with vinyl film.

6.6 Polyester Film

Polyester films offer long life and are strong. Films of 0.13 mm (5 mil) thickness are used for roofs and will last for 4 years, whereas 0.08 mm (3 mil) films are used on vertical walls and have a life expectancy of 7 years. Although the cost of polyester is higher than that of polyethylene, it was offset by the extra life expectancy. Other advantages include light transmittance equal to that of glass and freedom from static electrical charges, which collect dust. Polyester is still used frequently, in heat retention screens because of its high capacity to block radiant energy.

6.7 Tefzel T^2 Film

The most recent addition of greenhouse film plastic covering is Tefzel T^2 film (ethylene tetrafluoroethylene). Earlier, this film was used as the transparent covering on solar collectors. Anticipated life expectancy is 20 years or more. The light transmission is 95% and is greater than that of any other greenhouse covering material. A double layer has a light transmission of 90% (0.95 x 0.95). Tefzel T^2 film is more transparent to IR radiation than other film plastics. Hence, less heat is trapped inside the greenhouse during hot weather. As a result, less cooling energy is required. Disadvantage is that, the film is available only in 1.27 m (50 in) wide rolls. This requires clamping rails on the greenhouse for every 1.2 m (4 ft). If reasonable width strips become available, the price is not a problem, because a double layer covering will still cost less than a polycarbonate panel covering with its aluminum extrusions, and will last longer, and will have much higher light intensity inside the greenhouse.

6.8 Polyvinyl Chloride Rigid-Panel

Initially, PVC rigid panels showed promise as an inexpensive covering material (almost 40% of cost of long lasting fiberglass reinforced plastics), having the life expectancy of 5 years, when polyethylene lasted one year. After commercial application, these panels indicated that the life expectancy was much shorter, less than 2 years. This was undesirable (unacceptable) factor, because the cost of PVC panels was 4 to 5 times that of polyethylene film and they required much more time to install. Now-a-days, PVC rigid panels are not in use.

6.9 Fiberglass-Reinforced Plastic (FRP) Rigid Panel

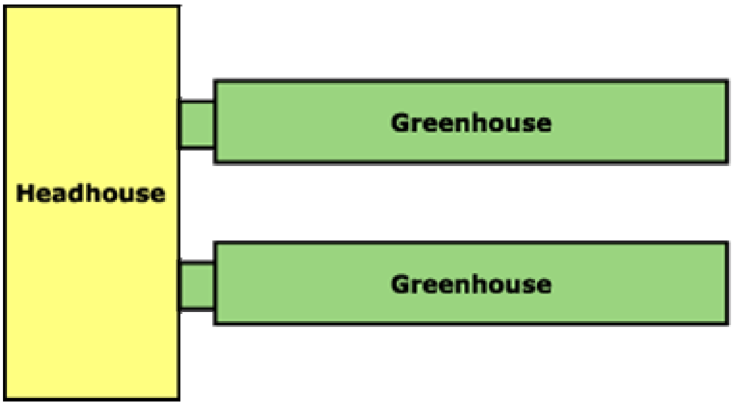
FRP was more popular as a greenhouse covering material in the recent past. Advantage of FRP is that it is more resistant to breakage by factors, such as hail or vandals. Sunlight passing through FRP is scattered by the fibers in the panels, as a result the light intensity is rather uniform throughout the greenhouse in comparison with a glass covering. Disadvantages with these are the panels subjected to etching and pitting by dust abrasion and chemical pollution. Based on the grade, the usable life period of FRP panel varies. Some grades give 5 to 10 years, while better grades can last up to 20 years. FRP panels are flexible enough to conform to the shape of quonset greenhouses, which make FRP a very versatile covering material. FRP can be applied to the inexpensive frames of plastic film greenhouses or to the more elaborate frames of glass type greenhouses. The price of FRP greenhouse lies between that of a plastic film greenhouse and that of a glass greenhouse. But the cost is compensated by the elimination of the need for replacement of film plastic in every year or alternate years. Corrugated panels were used because of their greater strength. Flat panels are used occasionally for the end and side walls, where the load is not great. It is available in 1.3 m width, length up to 7.3 m and in a variety of colours. The total quantity of light transmitted through clear FRP is approximately equivalent to that transmitted through glass, but diminishes in relation to its colour. For greenhouse crops in general, only clear FRP permits a satisfactory level of light transmission (88 to 90%). Coloured FRP has found a limited use in greenhouses intended for growing houseplants that require low light intensity and in display greenhouses for holding plants during the sales period. FRP has advantage over glass is that, it cools easily. FRP greenhouses require fewer structural members since sash bars are not needed.

6.10 Acrylic and Polycarbonate Rigid-Panel

These panels have been available for about 15 years for greenhouse use. The panels have been used for glazing the side and end walls of plastic film greenhouses and for retrofitting old glass greenhouse. Acrylic panels are highly inflammable, where as polycarbonate panels are non-flammable. Acrylic panels are popular due to their higher light transmission and longer life. Acrylic panels are available in thickness of 16 and 18 mm, and have 83% of PAR light transmission. Acrylic panels cannot be bent, but the thinner panels can be bent to fit curved-roof greenhouses. These panels are also available with a coating to prevent condensation drip. Polycarbonate panels are preferred for commercial greenhouses due to lower price, flame resistance and greater resistance to hail damage. Polycarbonate panels are available in thickness of 4,6, 8, 10 and 16 mm. These panels are also available with a coating to prevent condensation drip and also with an acrylic coating for extra protection from UV light.

Lecture No.7

The term greenhouse refers to a structure covered with a transparent material for the purpose of admitting natural light for plant growth. Two or more greenhouses in one location are referred to as a greenhouse range. A building associated with the greenhouses that is used for storage or for operations in support of growing of plants, is referred to as a service building or head house.



7.1 Design Criteria of Construction

For locating the greenhouse, a piece of land larger than the grower's immediate need should be acquired. The ultimate size of the greenhouse range should be estimated. Area should then be added to this estimated figure to accommodate service buildings, storage, access drives and a parking lot. The floor area of service buildings required for small firms is about 13% of the greenhouse floor area, and it decreases with the increase in size of the firm. On an average, service buildings occupy 10% of the growing area. The service building is centrally located in a nearly square design of the firm, which minimizes distance of movement of plants and materials. Doors between the service buildings and the greenhouse should be wide enough to facilitate full use of the corridor width. Doors at least 3.1 m wide and 2.7 m high are common. It is good to have the greenhouse gutter at least 3.7 m above the floor to accommodate automation and thermal blanket and still leave the room for future innovations.

7.2 Construction of Glass Greenhouses

Glass greenhouses have an advantage of greater interior light intensity over plastic panel and film plastic covered greenhouses. Glass greenhouses tend to have a higher air infiltration rate, which leads to lower interior humidity, which is advantageous for disease prevention. On the other hand, glass greenhouses have a higher initial cost than double-layer film plastic greenhouses. While comparing the price of a glass greenhouse to a film plastic greenhouse, one needs to take into account the initial purchase price of each as well as the cost of re-covering the film plastic greenhouse every three to four years.

Several types of glass greenhouses are designed to meet specific needs. A lean-to-type design is used when a greenhouse is placed against the side of an existing building. This design makes the best use of sunlight and minimizes the requirements for roof supports. It is found mostly in the retail industry. An even-span greenhouse is one in which the two roof slopes are of equal pitch and width. By comparison, an un-even-span greenhouse has roofs of unequal width, which makes the structure adaptable to the side of a hill. This style is seldom used today because such greenhouses are not adaptable to automation. Finally, a ridge-and-furrow design uses, two or more A- frame greenhouses connected to one another along the length of the eave. The sidewall is eliminated between greenhouses, which results in a structure with a single large interior. Basically, three types of frames are used in glass greenhouses, which are wood frames (6.1 m in width), pipe frames (12.2 m in width) and truss frames (15.2 m in width). Latest glass greenhouses are primarily of the truss frame type. Truss frame greenhouses are best suited for prefabrication.

All-metal greenhouses proved cheaper to maintain since they required no painting. At present, virtually all glass greenhouse construction is of the metal type. The structural members of the glass greenhouse cast shadows that reduce plant growth during the dark months of the year. Aluminum sash bars are stronger than wooden ones; hence wider panels of glass can be used with aluminum bars. The reduction in materials and the reflectance of aluminum have given these metal greenhouses a great advantage over wooden greenhouses in terms of higher interior light intensity.

Glass greenhouse construction of today can be categorized as low profile or high profile. The low profile greenhouse is most popular in the Netherlands and is known as the Venlo greenhouse. The low profile greenhouse uses single panels of glass extended from eave to ridge. The low profile greenhouse slightly reduces exposed surface area, thereby reducing the heating cost, but more expensive to cool. The high profile greenhouses require more than single panel to cover from eave to ridge. A problem with this design is the unsealed junction between pieces of glass in the inner layer. Moisture and dust may enter between the layers and reduce light transmission.

7.3 Construction of Pipe Framed Greenhouses

The choice of construction of pipe framed greenhouses often favours low initial investment and relatively long life. Galvanized mild steel pipe as a structural member in association with wide width UV- stabilized low density polyethylene (LDPE) film is a common option of greenhouse designers.

7.3.1 Material requirement

The structural members of greenhouse are:

(a) Hoops

(b) Foundation

(c) Lateral supports

(d) Polygrip assembly

(e) End frame

The following materials are required for a greenhouse having 4m x 20m floor area:

(i) GI pipe class A (25 mm diameter, 85 cm long, 30 m total length)

(ii) GI pipe class B (15 mm diameter, 6.0 m long, 21 Nos.)

(iii) GI sheet (20 gauge, size 90 x 24 cm, 4 sheets)

(iv) MS flat (25 x 3 mm size, 4 m length)

(v) Lateral support to end frames (10 mm diameter rod, 10 m length)

(vi) Cement concrete (1: 3: 6 mix, 1.0 m^3)

(vii) UV- stabilized LDPE film (single layer 800 gauge, 5.4 m^2/kg, 154 m^2)

(viii) Polygrip (channel 2000 x 3.5 x 4 cm, 2 Nos.; Angle 2000 x 2 x 2 cm, 2 Nos.; both made from the procured 20 gauge GI sheet, key 6 mm diameter, 56 mm length)

(ix) Wooden end frames (5 x 5 cm wood, 0.15 m^3)

(x) Nuts and bolts 9.6 mm diameter, 35 mm long, 70 sets)

(xi) Miscellaneous items like nails, hinges and latches as per requirement

7.3.2 Procedure of erection

(1) A 4m by 20m rectangular area is marked on the site, preferably orienting the longer dimension in east-west direction. This rectangle will act as the floor plan of the greenhouse (Fig.11).

(2) Mark four points on the four corners of the rectangle.

(3) Start from one corner point and move along the length of marked rectangle, marking a point every 1.25 m distance until reaching the other corner (16 bays; 17 points). The same procedure is repeated on the other side of the rectangle.

(4) Dig 10 cm diameter holes upto 70 cm depth on all marked points with the help of bucket auger (or) a crowbar. This way a total of 34 holes on both the parallel sides of the greenhouse floor are obtained.

(5) Polygrip sections formed according to the drawing into two 20m length.

(6) Fix the prefabricated polygrip channels to the foundation pipes on 1.25 m spacing with the help of 6 mm diameter bolts.

(7) Set these assemblies on temporary supports between the holes with the foundation pipes hanging vertically in the holes.

(8) Pour cement concrete mix of 1: 3: 6 around foundation pipes in such a way that the lower 15 cm to 20 cm ends are covered in concrete. The concrete is compacted around the foundation pipes with the help of the crowbar and is allowed to cure for 2-3 days.

(9) After curing, fill the soil around the foundation pipes to the ground level and compact it well.

(10) Position end frames on the two ends. Mark the position of legs and dug holes for fixing of legs. Now install both the end frames.

(11) Put the ringside of lateral support members on adjacent foundation pipe to the corner, and other side is hooked to the end frame.

(12) Put all the hoops in the foundation pipes in such a way that straight portion of hoop is inserted into the foundation and rests on the bolt used for fixing of polygrip channel.

(13) Take a 20 m long ridge line by spacing 15 mm diameter pipes together. Put the 20m long pipe at the ridge line of the hoops.

(14) Use cross connectors on the ridge line pipe, in such a way that one half of it remains on the one side of the hoop and the other half on the other side.

(15) Put two bolts of 6 mm diameter in the holes provided in the ends of cross-connector. Tie a few of them with the help of nuts.

(16) Repeat the same procedure for joining all the hoops with ridge line pipe.

(17) While forming cross-connectors, the distance between the cross-connectors or hoops should be maintained 1.25 m center to center. This poly grip mechanism will provide a firm grip of the ridge line pipe and hoops at right angles without allowing for slippage.

(18) Spread polyethylene film over the structure from one end to the other end without wrinkles and keeping the edges together.

(19) Place polyethylene film between the polygrip channel and right angle strip and secure them under pressure with the help of iron rods. The film is stretched gently and fixed on the other parallel side by polygrip. This way the polyethylene is secured on both the longer sides.

(20) On the other two remaining ends, polyethylene is nailed to the end frames using wooden battens and nails.

(21) The remaining portion of the end frames is covered with polyethylene film, which is secured with wooden battens and nails.

(22) Mechanical ventilation, heating and cooling equipment is installed on the frames as per the crop requirement.

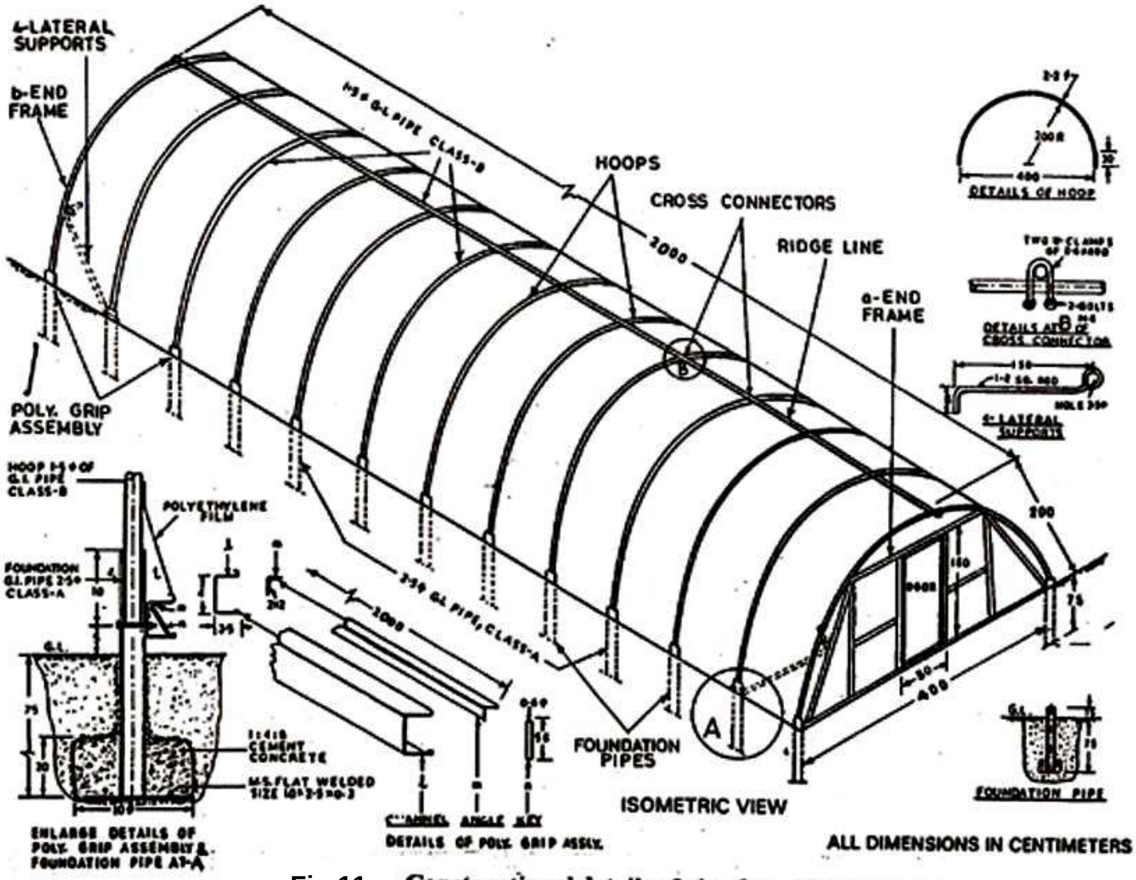
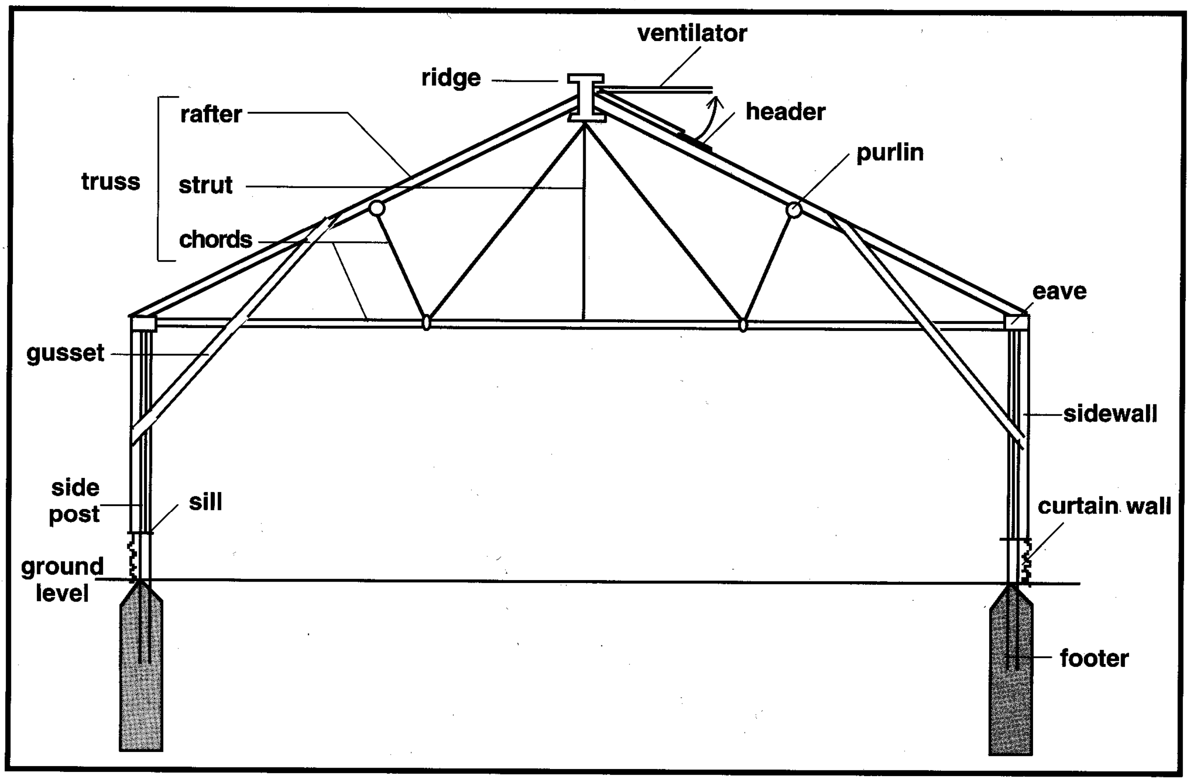


Fig.11: **Constructional details of pipe framed greenhouse**

Figure End view diagram of even-span greenhouse construction



Lecture No.8

8.1 Greenhouse Heating

The northern parts of our country experience cold winters, where heating system need to be employed in the greenhouses along with cooling systems for summer. Whereas the southern region greenhouses need only cooling systems since the winter cold effect is not that severe. Greenhouse heating is required in cold weather conditions, if the entrapped heat is not sufficient during the nights. The heat is always lost from the greenhouse when the surroundings are relatively cooler. Heat must be supplied to a greenhouse at the same rate with which it is lost in order to maintain a desired temperature: Heat losses can occur in three different modes of heat transfer, namely conduction, convection, and radiation. Maintenance of desired higher temperature, compared with the surroundings needs heating systems and heat distribution systems. For the purpose of greenhouse heating, apart from conventional systems, solar energy can also be used and the heat can be stored using water and rock storage. Different heat conservation practices are available to effectively utilize the heat energy.

8.1.1 Modes of heat loss

The heating systems, in a continuous process, should supply the heat just enough to compensate which is lost. Most heat is lost by conduction through the covering materials of the greenhouse. Different materials; such as aluminum sash bars, glass, polyethylene, and cement partition walls, vary in conduction according to the rate at which each conducts heat from the warm interior to the colder exterior. A good conductor of heat looses more heat in a shorter time than a bad conductor and vice versa. There are only limited ways of insulating the covering material without blocking the light transmission. A dead air space between two coverings appears to be the best system. A saving of 40% of the heat requirement can be achieved when a second covering in applied. For example greenhouse covered with one layer of polyethylene loses, 6.8 W of heat through each square meter of covering every hour when the outside temperature is 1^0C lower than the inside. When second layer of polyethylene is added, only 3.97 W/m^2 is lost (40% reduction).

A second mode of heat loss is that of convection (air infiltration). Spaces between panes of glass or FRP and ventilators and doors permit the passage of warm air outward and cold air inward. A general assumption holds that the volume of air held in a greenhouse can be lost as often as once every 60 minutes in a double layer film plastic or polycarbonate panel greenhouse, every 40 minutes in a FRP or a new glass greenhouse, every 30 minutes in an old well maintained glass greenhouse, and every 15 minutes in an old poorly maintained glass greenhouse. About 10% of total heat loss from a structurally tight glass greenhouse occurs through infiltration loss.

A third mode of heat loss from a greenhouse is that of radiation. Warm objects emit radiant energy, which passes through air to colder objects without warming the air significantly. The colder objects become warmer. Glass, vinyl plastic, FRP, and water are relatively opaque to radiant energy, whereas polyethylene is not. Polyethylene, greenhouses can lose considerable amounts of heat through radiation to colder objects outside, unless a film of moisture forms on the polyethylene to provide a barrier.

8.1.2 Heating systems

The heating system must provide heat to the greenhouse at the same rate at which it is lost by conduction, infiltration (convection), and radiation. There are three popular types of heating systems for greenhouses. The most common and least expensive is the unit heater system. In this system, warm air is blown from unit heaters that have self contained fireboxes. These heaters consist of three functional parts. Fuel is combusted in a firebox to provide heat. The heat is initially contained in the exhaust, which rises through the inside of a set of thin walled metal tubes on it way to the exhaust stack. The warm exhaust transfers heat to the cooler metal walls of the tubes. Much of the heat is removed from the exhaust by the time it reaches the stack through which it leaves the greenhouse. A fan in the back of the unit heater draws in greenhouse air, passing it over the exterior side of the tubes and then out from the heater to the greenhouse environment again. The cool air passing over hot metal tubes is warmed and the air is circulated.

A second type of system is central heating system, which consists of a central boiler that produces steam or hot water, plus a radiating mechanism in the greenhouse to dissipate the heat. A central heating system can be more efficient than unit heaters, especially in large greenhouse ranges. In this system, two or more large boilers are in a single location. Heat is transported in the form of hot water or steam through pipe mains to the growing area, and several arrangements of heating pipes in greenhouse are possible (Fig.12.1). The heat is exchanged from the hot water in a pipe coil on the perimeter walls plus an overhead pipe coil located across the greenhouse or an in-bed pipe coil located in the plant zone. Some greenhouses have a third pipe coil embedded in a concrete floor. A set of unit heaters can be used in the place of the overhead pipe coil, obtaining heat from hot water or steam from the central boiler.

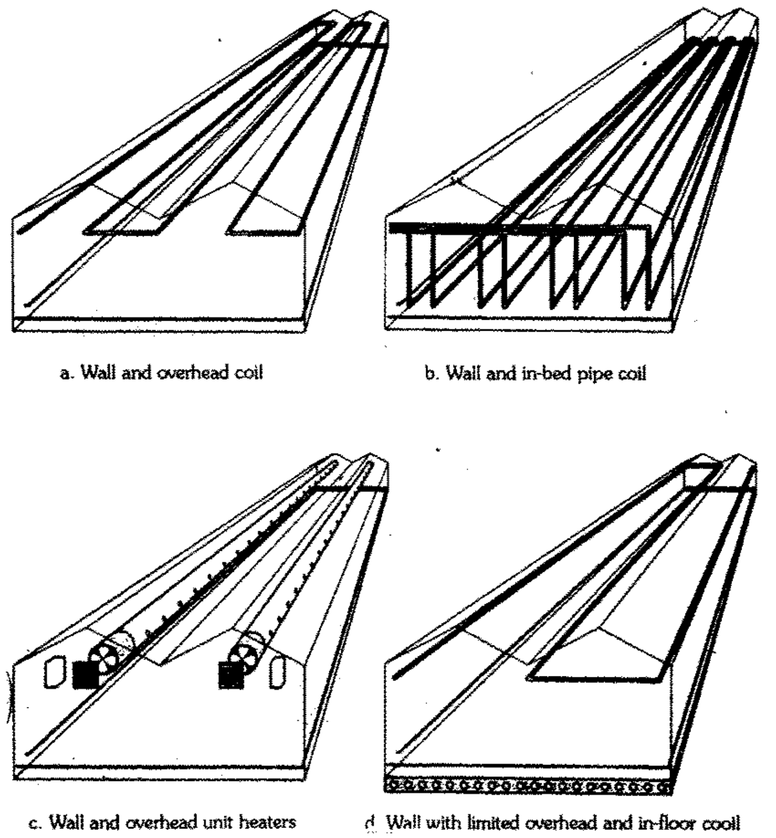


Fig. 12.1 Arrangement of heating pipe coils using steam or hot water in greenhouse

The third type of system is radiation heating system. In this system, gas is burned within pipes suspended overhead in the greenhouse. The warm pipes supply (radiate) heat to the plants. Low intensity infrared radiant heaters can save 30% or more, of fuel compared to conventional heaters. Several of these heaters are installed in tandem in the greenhouse. Lower air temperatures are possible since only the plants and root substrate are heated directly by this mode of heating.

The fourth possible type of system is the solar heating system, but it is still too expensive to be a viable option. Solar heating systems are found in hobby greenhouses and small commercial firms. Both water and rock energy storage systems are used in combination with solar energy. The high cost of solar heating systems discourages any significant use by the greenhouse industries.

8.1.3 Heat distribution systems

Heat is distributed from the unit heaters by one of two common methods. In the convection tube method, warm air from unit heaters is distributed through a transparent polyethylene tube running through the length of the greenhouse. Heat escapes from the tube through holes on either side of the tube in small jet streams, which rapidly mix with the surrounding air and set up a circulation pattern to minimize temperature gradients.

The second method of heat distribution is horizontal airflow. In this system, the greenhouse may be visualized as a large box containing air, and it uses small horizontal fans for moving the air mass. The fans are located above plant height and are spaced about 15 m (50 ft) apart in two rows. Their arrangement is such that, the heat originating at one corner of the greenhouse is directed from one side of the greenhouse to the opposite end and then back along the other side of the greenhouse. Proper arrangement of fans is necessary for effective distribution in horizontal airflow system for various greenhouse sizes. Both of these distribution systems can also be used for general circulation of air and for introducing cold outside air during winter cooling.

8.1.4 Solar heating system

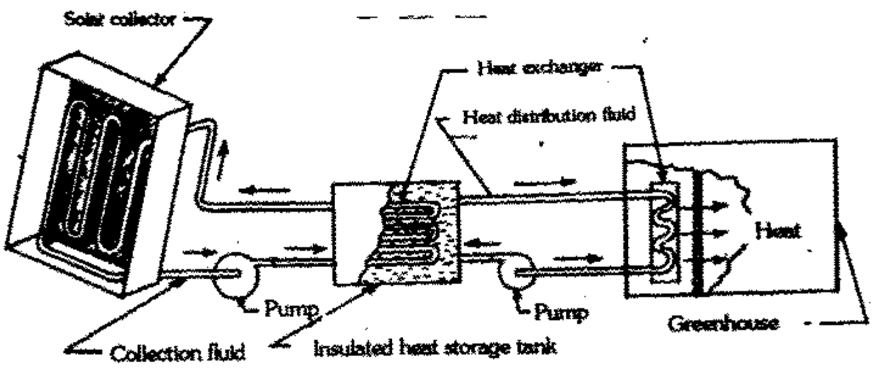


Fig. 12.2 A typical solar heating system for greenhouse

Solar heating is often used as a partial or total alternative to fossil fuel heating systems. Few solar heating systems exist in greenhouses today. The general components of solar heating system (Fig.12.2) are collector, heat storage facility, exchanger to transfer the solar derived heat to the greenhouse air, backup heater to take over when solar heating does not suffice and set of controls.

Various solar heat collectors are in existence, but the flat plate collector has received greatest attention. This consists of a flat black plate (rigid plastic, film plastic, sheet metal, or board) for absorbing solar energy. The plate is covered on the sun side by two or more transparent glass or plastic layers and on the backside by insulation. The enclosing layers serve to hold the collected heat within the collector. Water or air is passed through the copper tubes placed over the black plate and absorb the entrapped heat and carry it to the storage facility. A greenhouse itself can be considered as a solar collector. Some of its collected heat is stored in the soil, plants, greenhouse frame, floor, and so on. The remaining heat is excessive for plant growth and is therefore vented to the outside. The excess vented heat could just as well be directed to a rock bed for storage and subsequent use during a period of heating. Collection of heat by flat-plate collectors is most efficient when the collector is positioned perpendicular to the sun at solar noon. Based on the locations, the heat derived can provide 20 to 50% of the heat requirement.

8.1.5 Water and rock storage

Water and rocks are the two most common materials for the storage of heat in the greenhouse. One kg of water can hold 4.23 kJ of heat for each 1^0C rise in temperature. Rocks can store about 0.83 kJ for each 1^0C. To store equivalent amounts of heat, a rock bed would have to be three times as large as a water tank. A water storage system is well adapted to a water collector and a greenhouse heating system which consists of a pipe coil or a unit heater which contains a water coil. Heated water from the collector is pumped to the storage tank during the day. As and when heat is required, warm water is pumped form the storage tank to a hot water or steam boiler or into the hot water coil within a unit heater. Although the solar heated water will be cooler than the thermostat setting on the boiler, heat can be saved, since the temperature of this water need be raised as high as to reach the output temperature of water or steam from the boiler. A temperature rise of 17^oC above the ambient condition is expected during the daytime in solar storage units. Each kilogram of water can supply 71.1 kJ (30 BTU/lb) of heat, and each kilogram of rock can supply14.2 kJ (6 BTU/lb) of heat, as it cools by 17^oC.

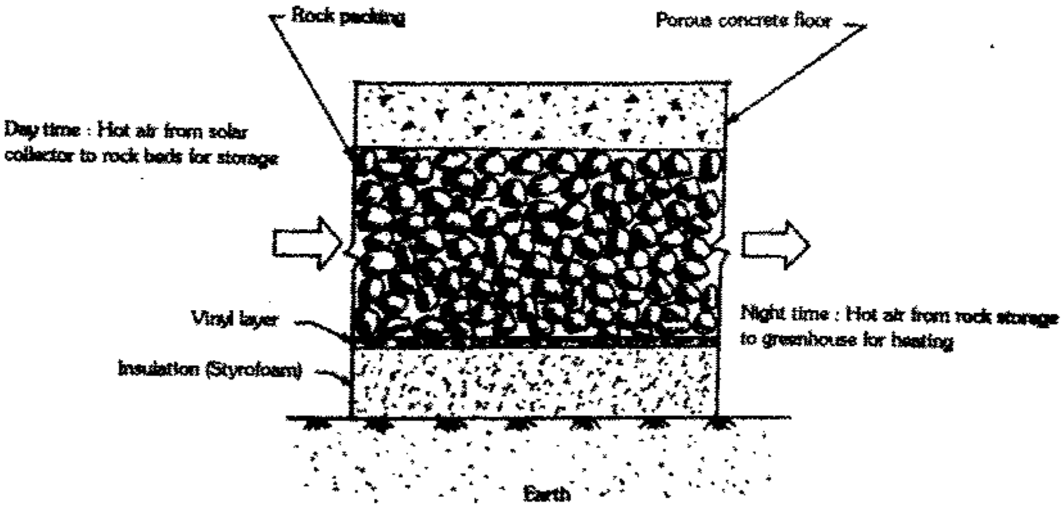


Fig. 12.3 Cross section of a typical rock storage unit

A rock storage bed can be aptly used with an air-collector and forced air heating system. In this case, heated air form the collector, along with air excessively heated inside the greenhouse during the day, is forced through a bed of rocks (Fig.12.3). The rocks absorb much of the heat. The rock bed may be located beneath the floor of the greenhouse or outside the greenhouse, and it should be well insulated against heat loss. During the night, when heat is required in the greenhouse, cool air from inside the greenhouse is forced through the rocks, where it is warmed and then passed back into the greenhouse. A clear polyethylene tube with holes along either side serves well to distribute the warm air uniformly along the length of the greenhouse. Conventional convection tubes can be used for distributing solar heated air. The water or rock storage unit occupies a large amount of space and a considerable amount of insulation is provided if the unit is placed outside. Placing it inside the greenhouse offers an advantage in that escaping heat is beneficial during heating periods, but it is detrimental when heating is not required. Rock beds can pose a problem in that they must remain relatively dry. Water evaporating from these beds will remove considerable heat.

8.1.6 Heat conservation practices

Energy can be saved significantly if a grower implements the following suggestions of the American Council for Agricultural Science and Technology (CAST, 1975):

1. Tighten-up the house, closing all possible openings.
2. Use polyethylene or fiberglass on the inside of gable ends.
3. Maintain the steam or hot water system regularly to stop leaks.
4. Use reflector materials behind heating pipes to reflect heat into the greenhouse.
5. Maintain the boiler at peak efficiency.
6. Insulate hot water and steam supply and return piping, and inspect at intervals, replacing the insulation when needed.
7. Maintain the automatic valves in the heating system. and
8. Check the thermostats regularly for proper operation.

The following are the other improved practices for energy conservation:

1. Covering a greenhouse with a double layer of polyethylene to reduce the loss of heat energy.
2. Placing a removable sheet of polyethylene over the crop and a row cover over each plant row in order to reduce heat loss from the greenhouse during night.
3. Application of opaque sheets as curtains during night.
4. Application of at least one layer of movable thermal screen.
5. Installation of polyethylene tubing which, when installed, seals the growing area from the roof surface area.
6. Improved curtain materials, with greater reflective property, conserve more energy.

8.2 Economics of Greenhouse Production

Regardless of the type, protected agricultural systems are extremely expensive. The equipment and production cost may be more than compensated by the significantly higher productivity of protected agricultural systems as compared with open field agriculture. The costs and returns of protected agriculture vary greatly, depending on the system used, the location and the crop grown. By design, all protected agricultural systems of cropping are intensive in use of land, labour, and capital. Greenhouse agriculture is the most intensive system of all. The intensity of land use is greatly dependent upon the system of protected agriculture. Year-round greenhouse crop production is therefore much more intensive than seasonal use of mulches and row covers. Coinciding with intensity are yields, which are normally far greater per ha from year round than from seasonal systems. The normal benefit of higher yields of CEA over the open field agriculture depends on the system used and the region of production.

8.2.1 Capital requirements

The capital requirements differ greatly among the various systems of protected agriculture. Mulching is least expensive while greenhouses require the most capital per unit of land. Total cost involved in the production is the sum of fixed cost and operating cost (Fig.20.1). The fixed capital costs include land, fixed and mobile equipment, and structures like grading, packing and office. Fixed costs also include taxes and maintenance. The fixed capital costs for greenhouses clearly exceed those of other systems of protected agriculture, but vary in expense according to type of structure, and environmental control and growing systems. Operating or variable costs include labour, fuel, utilities, farm chemicals and packaging materials. The operating or variable costs and fixed costs are annual expenditures and these can be substantial. Annual costs may correlate to some extent with capital investment. The flow diagram of capital requirements of production is shown in figure.

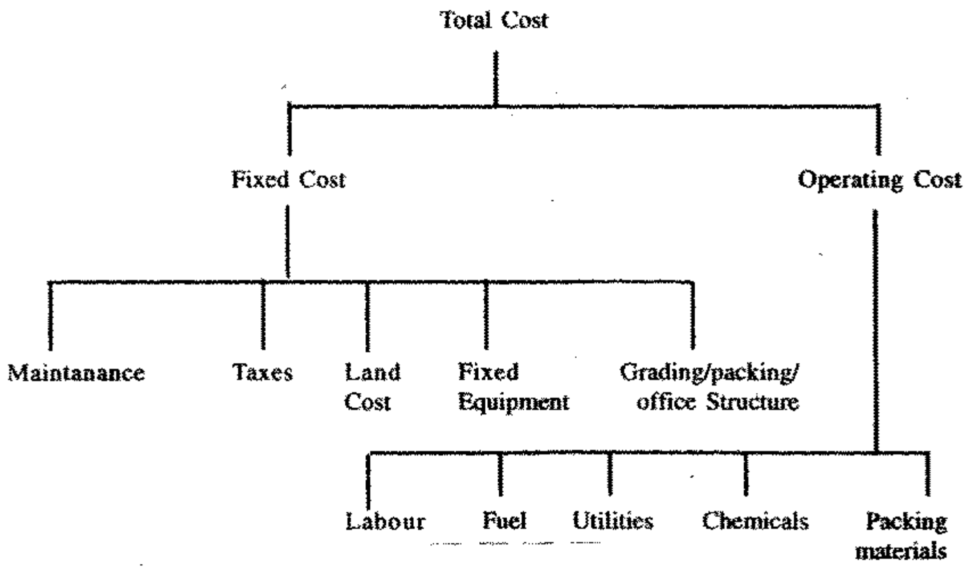


Fig. 20.1 Flow diagram of capital requirements of production

In estimating the capital requirements, the farmer must include the cost of the entire system as well as the mulch. While greenhouse production systems may be far more expensive than open field systems of equal land area, open field systems of protected agriculture are normally more expensive in field area than in greenhouse production. Greenhouses are expensive, especially if the environment is controlled by the use of heaters, fan and pad cooling systems and computer controls.

8.2.2 Economics of production

Production economics considers the various components of fixed and variable costs, compares them with the income and evaluates the net return, on unit area basis. On an average basis, wages account for approximately 85% of the total variable cost. Wages are the greatest expenditure in greenhouse production, followed by amortization costs and then energy costs, and energy expenditure, when heating is necessary. About two-fifths of the expenses are fixed costs and about three-fifths are variable costs. Depreciation and interest on investment account for most of the fixed costs.

8.2.3 Conditions influencing returns

A number of variables which may not show up in the yearly financial balance sheet influence the returns to greenhouse operators, such as economics of scale, physical facilities, cropping patterns and government incentives. The size of any system of protected agriculture will depend on the market objectives of the farmer. Most protected agricultural endeavors are family operated. Often the products are retailed directly to the consumer through a road side market at the farm site. In the developed world, greenhouse operations tend to be a size that can be operated by one family (0.4 to 0.8 ha).A unit of 0.4 ha can be operated by two to three labourers, with additional help at periods of peak activity. The labour wages can usually be provided by the owner and his family. Moreover, the owner will pay close attention to management, which is the most important factor. Labour costs may rise significantly if it is necessary to recruit labour from outside the family. Greenhouse owners who hire a highly qualified manager may have to operate a larger greenhouse than family size greenhouses in order to offset the additional salary paid.

The greenhouse system economy can be improved with increased size when:

1. There is a unique opportunity to mechanize certain operations.
2. Labour can be more efficiently utilized.
3. Low cost capital is available.
4. There are economics in the purchase of packaging materials and in marketing.
5. Some special management skills are available.

The physical facilities and location of the greenhouse influence the economics. Another variable that influences the profits from the greenhouse is intensity of production, which is determined by the type of structure. Using plastic mulches, high tunnel and the structures with complete environmental control system facilitates year round production and early harvest, thus enabling the grower to realize higher profits. Year-round production offers year round employment to the labourers. It is found that the environmentally controlled greenhouse produced only one-third more revenue than the high tunnel structure. With the improved transportation facilities, the new areas of production in combination with the following factors contribute to lower the costs.

1. High sun light intensity undiminished by air pollution.
2. Mild winter temperatures.
3. Infrequent violent weather conditions.
4. Low humidity during the summer for cooling.
5. Availability of water with low salinity levels.

Cropping pattern will have bearing on the greenhouse structure. A high –tunnel structure or any structure not fitted with environmental controlled equipment for heating and cooling will be used only on a seasonal basis. It is common to switch over from greenhouse vegetable production to flower production, especially in structures with more elaborate environmental control systems. Growers throughout the world are currently experimenting with alternative crops, such as herbs. As eating habits change, with times and as the consumers are becoming increasingly conscious of diet and the nutritional value of fruits and vegetables, growers must continually look for alternatives to existing cropping patterns. Government policies also influence the financial returns from the crops. Government may provide grants or low interest loans, subsidies towards construction costs, fuels, and use of plastics, drip irrigation systems, mulches, row covers and covering materials. Such incentives from the Government encourage the growers and stimulate the greenhouse industry.

8.3 Greenhouse Utilization in Off-Season

Drying is traditional method for preserving the food. It also helps in easy transport since the dried food becomes lighter because of moisture evaporation. Drying of seed prevents germination and growth of fungi and bacteria. The traditional practice of drying agricultural produce in the developing countries is sun drying, which is seasonal, intermittent, slow, and unhygienic. To overcome the problems of sun drying, mechanical drying is introduced with the following advantages: (i) fast drying, (ii) large volumes of produce can be handled (iii) drying parameters can be controlled and quality of the produce can be maintained. The energy demand of conventional mechanical dryers is met by electricity, fossil fuels, and firewood; and these sources are becoming scarce. Solar energy can be an alternative source for drying of food and solar dryers are employed for the purpose. The use of the greenhouse as a dryer is the latest development. The drying capabilities of the greenhouse can be utilized for curing tobacco leaves, while guarding the harvest from rain damage.

8.3.1 Drying of agricultural produce

In an efficiently managed greenhouse CEA, there will not be any time gap between crops. However, for some other management reasons, if crops are not grown in a particular period, the greenhouse can be utilized as a solar dryer. A small amount of 15 to 30% of the incoming solar radiation is reflected back from the surface of the greenhouse, with the remainder is transmitted into the interior. Most of this transmitted radiation is absorbed by plants, soil and other internal surfaces, the rest being reflected. The usage of greenhouse for the purpose of the drying is of recent origin. Papadikas et al., (1981) investigated the usage of greenhouse type solar dryer for drying grapes. Khollieve et al., (1982) developed a greenhouse type fruit dryer cum hot house to be used as a dryer in summer and as a hot house in winter. They were successful in advocating the year round utilization of the greenhouse facility and thus reducing the operation cost per unit output. In general, the produce is spread as thin layers in trays covering the greenhouse area. The trays can be fabricated with sheet metal and wire mesh. Trays should be arranged horizontally on existing growing benches or frames. For better operation and results, proper ventilation should be provided by either forced or natural ventilation, to remove the moisture liberating from the produce and to control the air temperature inside the greenhouse. The natural ventilation can be enhanced by using a black LDPE chimney connected to the greenhouse.

8.3.2 Curing of tobacco

Tobacco is an important foreign exchange earning commercial crop of India, which provides employment opportunities to lakhs of people. Curing of tobacco is a delicate and vital process in producing good quality leaves. Tobacco curing essentially refers to drying of the harvested fresh tobacco leaves under controlled temperature, humidity and ventilation in order to initiate the essential bio-chemical processes. The success of curing also depends on the condition of the harvested leaves and their degree of maturity. The usual curing methods are flue, air, pit, fire and sun curing. The open field sun curing is the cheapest method of curing. The drying capabilities of greenhouse can be successfully utilized for curing the tobacco. Different stages of tobacco curing require specific environmental conditions for the best product, which can be maintained easily in a greenhouse.

The harvested tobacco leaves are made into bunches of few leaves by knots and arranged serially to form a string with free ends left for fixing it. Scaffoldings should be erected inside the greenhouse and the string of leaves is tied to them, for the tobacco curing process. To increase the capacity, the strings are tied with judicious gap between them and also put in tiers. As curing progresses, the leaves loose moisture and the string will become lighter and the initial sag in the strings can be corrected. For maintaining uniform product quality, the strings can be cycled among the tiers in a specified sequence. Humidity and temperature control by proper ventilation and frequent inspection is important in tobacco curing operations.

Lecture No.9

Greenhouse Irrigation Systems

A well-designed irrigation system will supply the precise amount of water needed each day throughout the year. The quantity of water needed would depend on the growing area, the crop, weather conditions, the time of year and whether the heating or ventilation system is operating. Water needs are also dependent on the type of soil or soil mix and the size and type of the container or bed. Watering in the green house most frequently accounts for loss in crop quality. Though the operation appears to be the simple, proper decision should be taken on how, when and what quantity to be given to the plants after continuous inspection and assessment .Since under watering (less frequent) and over watering (more frequent) will be injurious to the crops, the rules of watering should be strictly adhered to. Several irrigation water application systems, such as hand writing, perimeter watering, overhead sprinklers, boom watering and drip irrigation are currently in use.

9.1 Rules of Watering

The following are the three important rules of application of irrigation.

Rule 1: Use a well drained substrate with good structure.

If the root substrate is not well drained and aerated, proper watering cannot be achieved. Hence substrates with ample moisture retention along with good aeration are indispensable for proper growth of the plants. The desired combination of coarse texture and highly stable structure can be obtained from the formulated substrates and not from field soil alone.

Rule 2: Water thoroughly each time.

Partial watering of the substrates should be avoided; the supplied water should flow from the bottom in case of containers, and the root zone is wetted thoroughly in case of beds. As a rule, 10 to 15% excess of water is supplied. In general, the water requirement for soil based substrates is at a rate of 20 l/m2 of bench, 0.3 to 0.35 litres per 16.5 cm (6.5 in) diameter pot.

Rule 3: Water just before initial moisture stress occurs.

Since over watering reduces the aeration and root development, water should be applied just before the plant enters the early symptoms of water stress. The foliar symptoms, such as texture, colour and turbidity can be used to determine the moisture stresses, but they vary with crops. For crops that do not show any symptoms, colour, feel and weight of the substrates are used for assessment.

9.2 Hand Watering

The most traditional method of irrigation is hand watering and in present days is uneconomical. Growers can afford hand watering only where a crop is still at a high density, such as in seed beds, or when they are watered at a few selected pots or areas that have dried sooner than others. In all cases, the labour saved will pay for the automatic system in less than one year. It soon will become apparent that this cost is too high. In addition to this deterrent to hand watering, there is great risk of applying too little water or of waiting too long between waterings. Hand watering requires considerable time and is very boring. It is usually performed by inexperienced employees, who may be tempted to speed up the job or put it off to another time. Automatic watering is rapid and easy and is performed by the grower himself. Where hand watering is practiced, a water breaker should be used on the end of the hose. Such a device breaks the force of the water, permitting a higher flow rate without washing the root substrate out of the bench or pot. It also lessens the risk of disrupting the structure of the substrate surface.

9.3 Perimeter Watering

Perimeter watering system can be used for crop production in benches or beds. A typical system consists of a plastic pipe around the perimeter of a bench with nozzles that spray water over the substrate surface below the foliage (Fig.14.1).

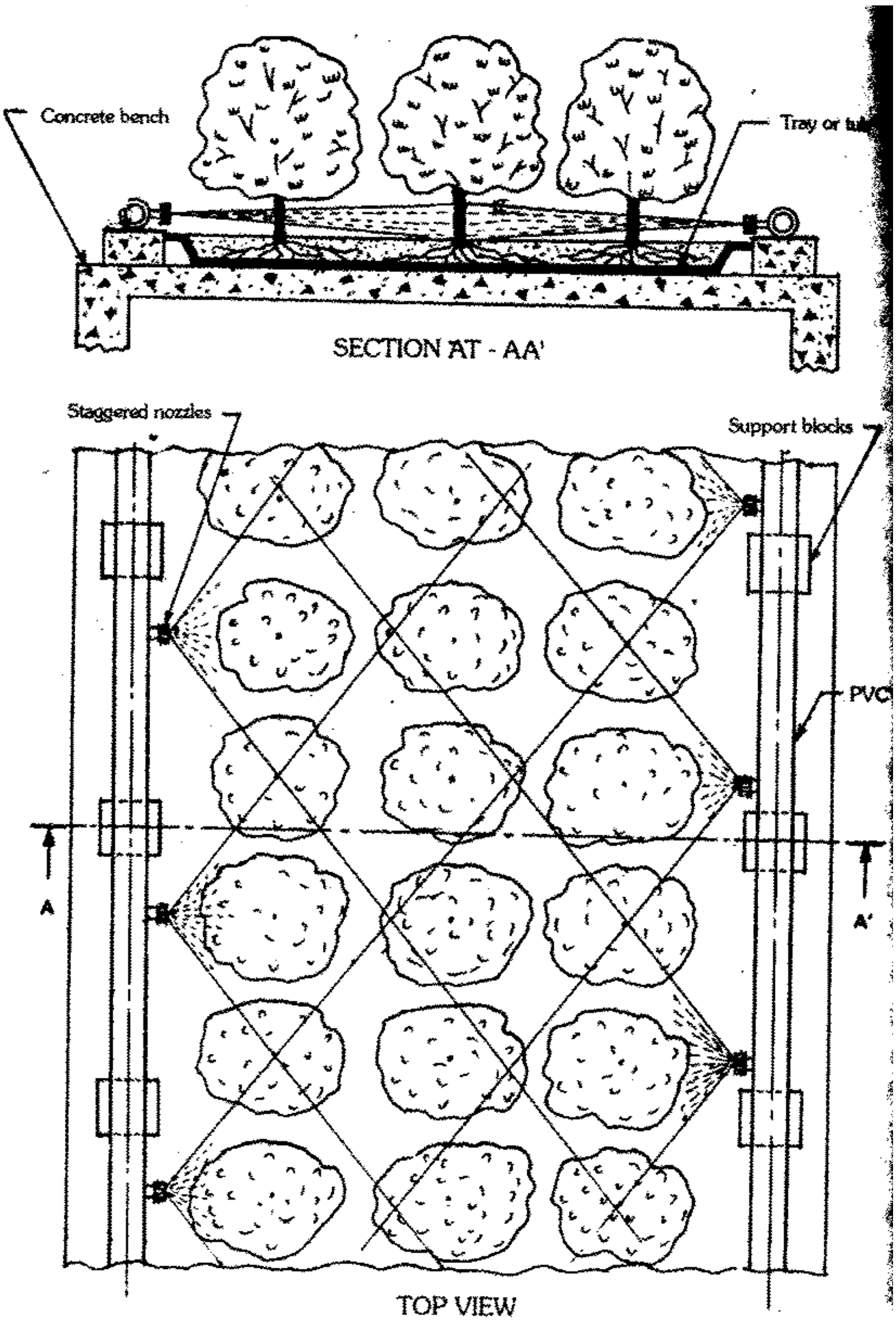


Fig. 14.1 Schematic diagram of perimeter watering system

Either polyethylene or PVC pipe can be used. While PVC pipe has the advantage of being very stationery, polyethylene pipe tends to roll if it is not anchored firmly to the side of the bench. This causes nozzles to rise or fall from proper orientation to the substrate surface. Nozzles are made of nylon or a hard plastic and are available to put out a spray arc of 180°, 90° or 45°. Regardless of the types of nozzles used, they are staggered across the benches so that each nozzle projects out between two other nozzles on the opposite side. Perimeter watering systems with 180°

nozzles require one water valve for benches up to 30.5 m (100 ft) in length. For benches over 30.5 m (100 ft) and upto 60.1 m (200 ft), a water should be installed on either side, one to serve each half of the bench. This system applies 1.25 l/min/m of pipe. Where 180° and 90° or 45° nozzles are alternated, the length of a bench serviced by one water valve should not exceed 23 m (75 ft).

9.4 Overhead Sprinklers

While the foliage on the majority of crops should be kept dry for disease control purposes, a few crops do tolerate wet foliage. These few crops can most easily and cheaply be irrigated from overhead. Bedding plants, azalea liners, and some green plants are crops commonly watered from overhead (Fig.14.2). A pipe is installed along the middle of a bed. Riser pipes are installed periodically to a height well above the final height of the crop (Fig.14.2). A total height of 0.6 m (2 ft) is sufficient for bedding plants flats and 1.8 m for fresh flowers. A nozzle is installed at the top of each riser. Nozzles vary from those that throw a 360° pattern continuously to types that rotate around a 360° circle. Trays are sometimes placed under pots to collect water that would otherwise fall on the ground between pots and wasted. Each tray is square and meets the adjacent tray. In this way nearly all water is intercepted. Each tray has a depression to accommodate the pot and is then angled upward from the pot toward the tray perimeter. The trays also have drain holes, which allow drainage of excess water and store certain quantity, which is subsequently absorbed by the substrate.

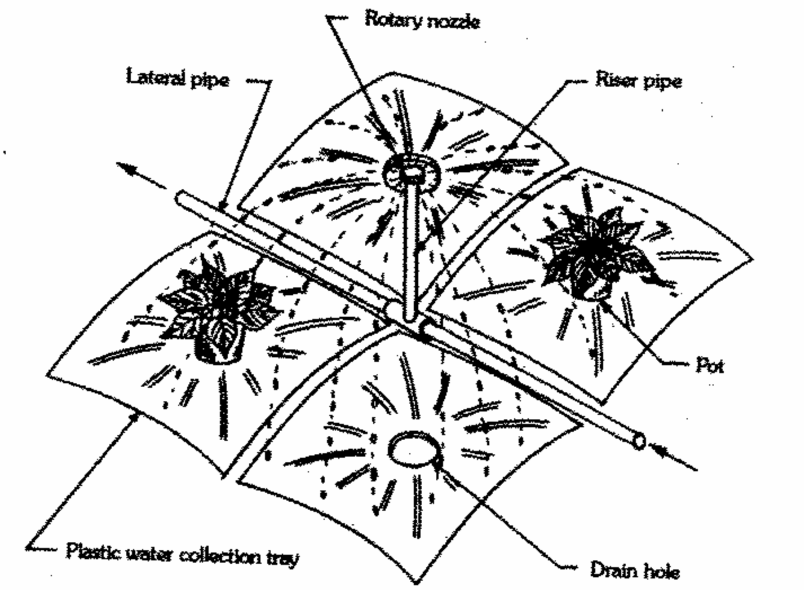


Fig.14.2 Schematic diagram of overhead sprinkler watering system

9.5 Boom Watering

Boom watering can function either as open or a closed system, and is used often for the production of seedlings grown in plug trays. Plug trays are plastic trays that have width and length dimensions of approximately 30 × 61 cm (12 x 24 in), a depth of 13 to 38 mm (0.5 to 1.5 in), and contain about 100 to 800 cells. Each seedling is grown in its own individual cell. Precision of watering is extremely important during the 2 to 8 week production time of plug seedlings.

A boom watering system generally consists of a water pipe boom that extends from one side of a greenhouse bay to the other. The pipe is fitted with nozzles that can spray either water or fertilizer solution down onto the crop. The boom is attached at its center point to a carriage that rides along rails, often suspended above the centre walk of the greenhouse bay. In this way, the boom can pass from one end of the bay to the other. The boom is propelled by an electric motor. The quantity of water delivered per unit area of plants is adjusted by the speed at which the boom travels.

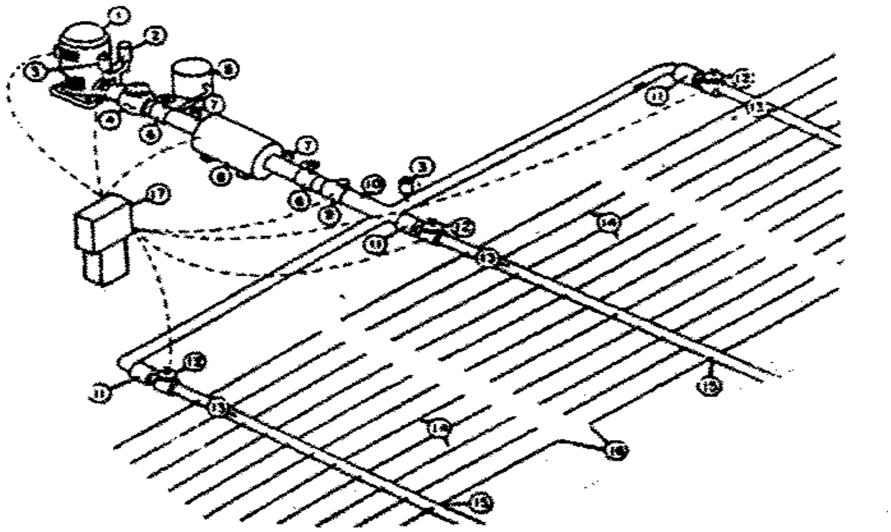
9.6 Drip Irrigation

Drip irrigation, often referred to as trickle irrigation, consists of laying plastic tubes of small diameter on the surface or subsurface of the field or greenhouse beside or beneath the plants. Water is delivered to the plants at frequent intervals through small holes or emitters located along the tube. Drip irrigation systems are commonly used in combination with protected agriculture, as an integral and essential part of the comprehensive design. When using plastic mulches, row covers, or greenhouses, drip irrigation is the only means of applying uniform water and fertilizer to the plants. Drip irrigation provides maximum control over environmental variability; it assures optimum production with minimal use of water, while conserving soil and fertilizer nutrients; and controls water, fertilizer, labour and machinery costs. Drip irrigation is the best means of water conservation. In general, the application efficiency is 90 to 95%, compared with sprinkler at 70% and furrow irrigation at 60 to 80%, depending on soil type, level of field and how water is applied to the furrows. Drip irrigation is not only recommended for protected agriculture but also for open field crop production, especially in arid and semi-arid regions of the world.

Drip irrigation is replacing surface irrigation where water is scares or expensive, when the soil is too porous or too impervious for gravity irrigation, land leveling is impossible or very costly, water quality is poor, the climate is too windy for sprinkler irrigation, and where trained irrigation labour is not available or is expensive. In drip irrigation weed growth is reduced, since irrigation water is applied directly to the plant row and not to the entire field as with sprinkler, furrow, or flood irrigation. Placing the water in the plant row increases the fertilizer efficiency since it is injected into the irrigation water and applied directly to the root zone. Plant foliage diseases may be reduced since the foliage is not wetted during irrigation.

One of the disadvantages of drip irrigation is the initial cost of equipment per acre, which may be higher than other systems of irrigation. However, these costs must be evaluated through comparison with the expense of land preparation and maintenance often required by surface irrigation. Basic equipment for irrigation consists of a pump, a main line, delivery pipes, manifold, and drip tape laterals or emitters as shown in figure 14.3 & 15.

The head, between the pump and the pipeline network, usually consists of control valves, couplings, filters, time clocks, fertilizer injectors, pressure regulators, flow meters, and gauges. Since the water passes through very small outlets in emitters, it is an absolute necessity that it should be screened, filtered, or both, before it is distributed in the pipe system. The initial field positioning and layout of a drip system is influenced by the topography of the land and the cost of various system configurations. Design considerations should also include the relationship between the various system components and the farm equipments required to plant, cultivate, maintain and harvest the crop.



1. Pump
2. Pressure relief valve
3. Air Vents (at all high points)
4. Check valve
5. Filter injector/tank
6. Mainline valve or gate
7. Pressure gauges
8. Filter
10. Mainline
11. Submain; secondary filter
12. Field control valves
13. Submains
14. Drip tape laterals
15. Lateral hook up
16. Drain / flush valves
17. System controller

Fig. 14.3 A typical layout of drip irrigation system

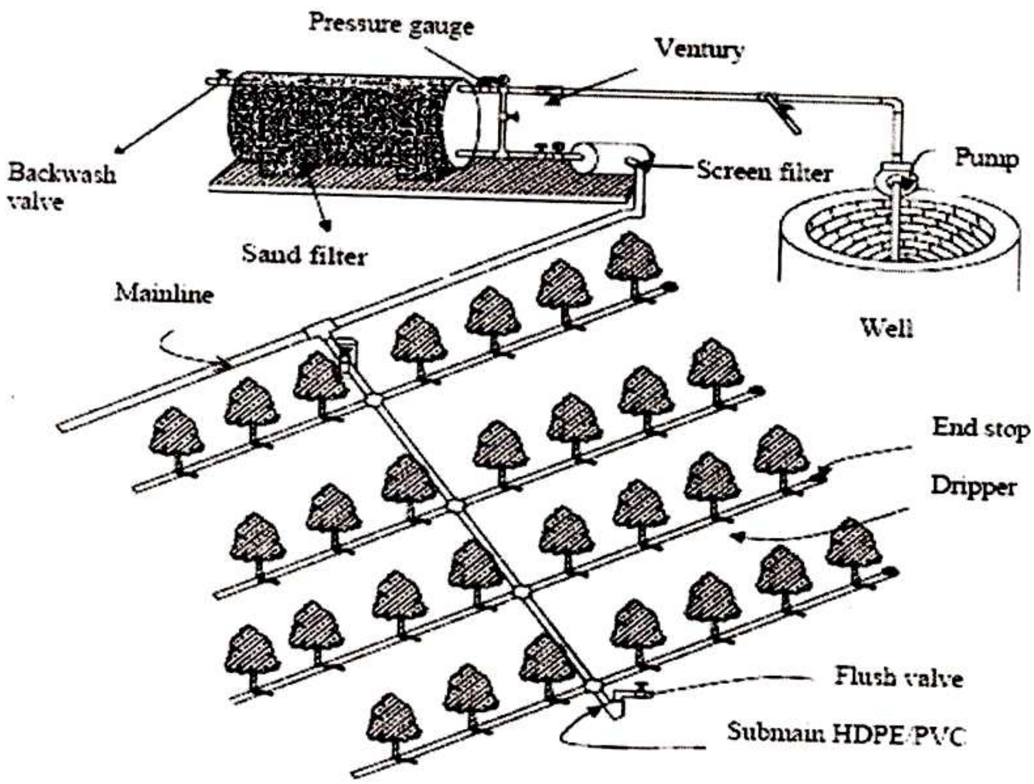


Fig.15. Diagram of drip irrigation system for greenhouse