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Impact of directional well inclination on the calculation of annular pressure buildup

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Abstract. This study presents a preliminary analysis investigating Annular Pressure Buildup (APB) behavior as a function of the inclination angle in directional oil wells. APB refers to the pressure increase caused by the tendency of confined fluids to expand thermally within annular spaces. This phenomenon is critical in deep reservoirs, where temperature variations compromise casing integrity due to differential pressure. Despite its relevance, the influence of wellbore inclination on APB prediction remains underexplored. In this context, the present work preliminarily investigates the impact of several well inclinations on APB behavior. The adopted methodology consists of five main stages: a) a literature review on APB computational modeling in oil wells; b) definition of a reference well scenario; c) selection of well trajectories (inclinations angles) for analysis; d) simulation of the reference well with the selected trajectories; and e) analysis and discussion of the simulation results. The findings of this study are expected to provide a more accurate understanding of the impact of well inclination on APB behavior, highlighting the limitations associated to the use of vertical well models for its predictions.

Keywords: Annular pressure build-up, thermal expansion, vertical oil wells, directional oil wells

1 Introduction

According to Barcelos [1], oil wells have been reaching increasingly greater depths. As a result, the operational conditions faced by the well are becoming more severe, including high pressures and temperatures. One of the consequences associated with this scenario is Annular Pressure Buildup (APB), a phenomenon caused by the attempt of fluids to expand within confined annuli (Barcelos [1]). This expansion results from the temperature variations to which the well is subjected during operations. APB must be predicted (or estimated) during the design stage to avoid collapse and burst failures in the casings. For this reason, several studies have focused on APB prediction.

However, most studies on annular pressure buildup focus on vertical wells, while the influence of well geometry, particularly inclination variation, remains little explored in the literature. This simplification differs from real-world practice, as few wells are truly vertical, whether due to drilling inaccuracies or logistical decisions that necessitate directional trajectories. The influence of well inclination on APB behavior has been insufficiently investigated, despite its potential impact on APB along the annulus. Nowadays, many wells follow complex paths, such as deviated or horizontal trajectories, which add thermal complexities that can affect APB behavior.

In this context, the present work aims to analyze APB behavior as a function of well inclination, through computational modeling of the phenomenon in different trajectories. By addressing this underexplored aspect, the study seeks to contribute to a better understanding of the impact of well directionality on APB prediction.

2 Methodology

The methodology adopted in this work can be divided into four main stages, as shown in Fig. 1.

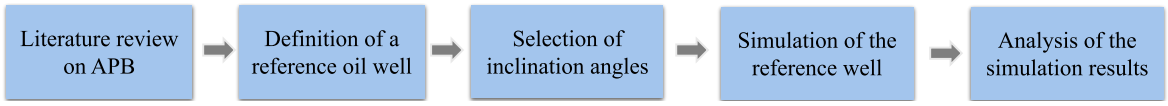


Figure 1. Methodology in this work development

In the first stage, the theoretical and mathematical framework for annular pressure buildup (APB) in oil wells is studied, drawing on established approaches in the technical literature. Subsequently, the second stage defines the reference scenario, incorporating the specific characteristics of a representative oil well. In this stage, wellbore trajectories are parameterized by varying inclination angles to represent different directional configurations. Two trajectory situations are considered: (i) constant total well length with varying inclination, and (ii) fixed final true vertical depth (TVD), ensuring convergence to the same target point. Thereafter, the third stage performs computational simulations of the defined scenarios using the StrinGnosis software, integrating the proposed model to assess APB as a function of wellbore inclination. Finally, the fourth stage analyzes and interprets the results, emphasizing the influence of inclination on APB evolution.

3 APB formulation

According to Santos et al. [2], the formulation of APB is based on the equality between the volume variation of the fluid in the annulus (ΔV_{fl}) and the volumetric variation of the annulus itself (ΔV_{an}). This relationship is expressed by the Eq. 1:

$$\Delta V_{fl} = \Delta V_{an} \tag{1}$$

ΔV_{fl} is determined using α_f and k_f. Thus, we obtain:

$$\Delta V_{fl} = V_{fl}[\alpha_f \Delta T - k_f \Delta P] \tag{2}$$

where V_{fl} represents the fluid volume, ΔT the temperature variation, and ΔP the pressure variation. This formulation is particularly useful when temperature and pressure conditions do not change significantly along the annulus, allowing α_f and k_f to be treated as constants (Santos et al. [2]). However, in real well operations, significant variations may occur, requiring more robust approaches such as those proposed by Perez [3], and Vasconcelos [4], which consider the continuous updating of fluid properties as a function of temperature and pressure. This modeling is essential in advanced APB prediction tools, such as the StrinGnosis software, which is directly based on this formulation.

4 Case study

The case analyzed in this study involves an offshore producing oil well featuring a single annular space. This annulus is filled with seawater-type fluid, with a density of 8.60 ppg. The well has a rotary table at 5 m, a water depth of 1000 m, and casings: conductor (30 in), surface (20 in), and production (10 ¾ in), in addition to the production tubing (5 in) with its top at 1005 m.

The injection is carried out by hot water injection, where the surface pressure and temperature are, respectively, 8000 psi and 90°C, with a water injection rate of 3000 m³/day and an injected fluid density of 8.33 ppg. Fig. 2 presents the casing schematic for the well.

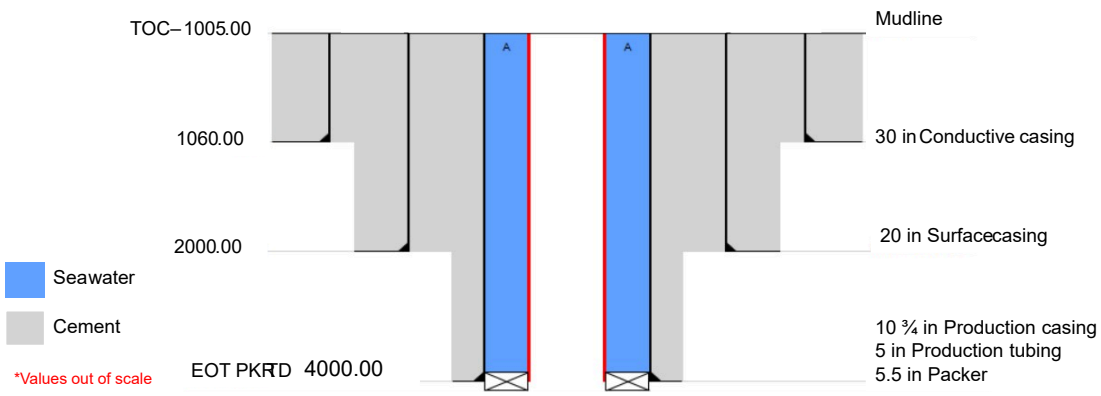


Figure 2. Representation of the studied oil well

According to Souza [5], type I directional wells are those with a simple trajectory, composed of a vertical section followed by a kickoff point (KOP) — the starting point of the angle growth section — where the inclination relative to the vertical direction is established, and finally, a tangent section, where the inclination is maintained until reaching the target (Zamprogno [6]). For the reference scenario, a KOP depth of 2000 m was adopted.

Accordingly, the case study is divided into two situations: in the first (A), the well maintains its total length constant, varying only the angle (θ) relative to the vertical section. In the second (B), the final true vertical depth (TVD) of the well is kept fixed at 4000 m, while varying the angle (θ).

To analyze the impact of inclination in both situations, different inclination angles are considered, ranging from 0° (vertical) to 60°, with increments of 10° between each analyzed case. The two situations are presented in Fig. 3.

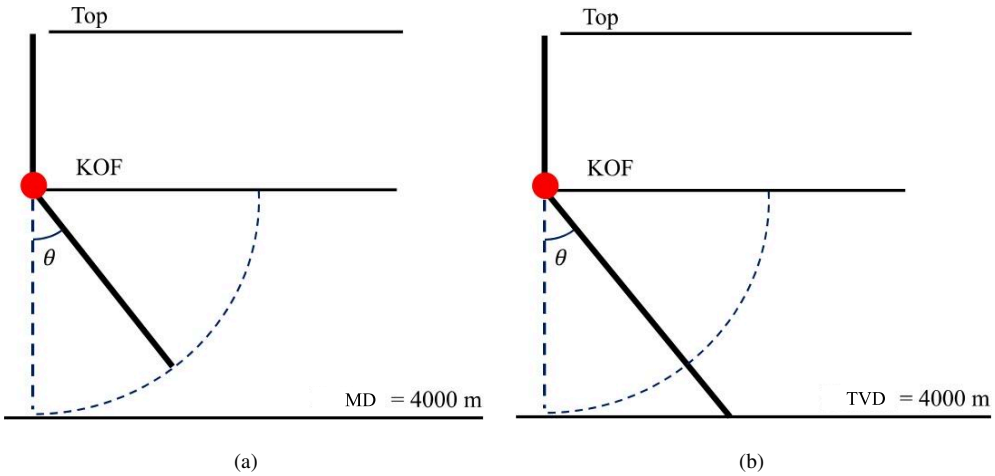
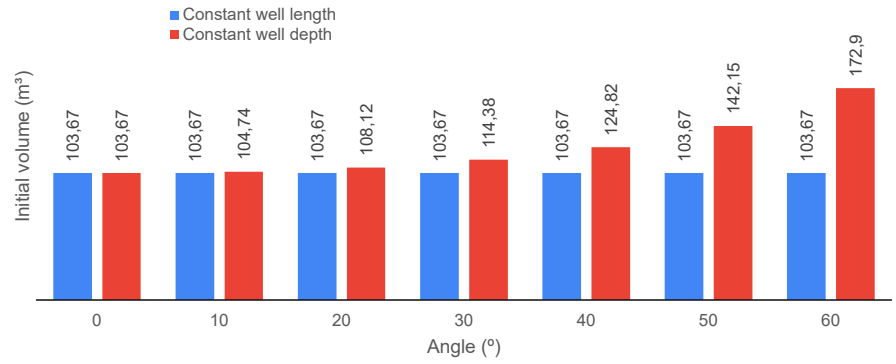


Figure 3. Schematic representation of the two analyzed directional well situations: (a) keeping the total well length constant; (b) keeping the final depth constant

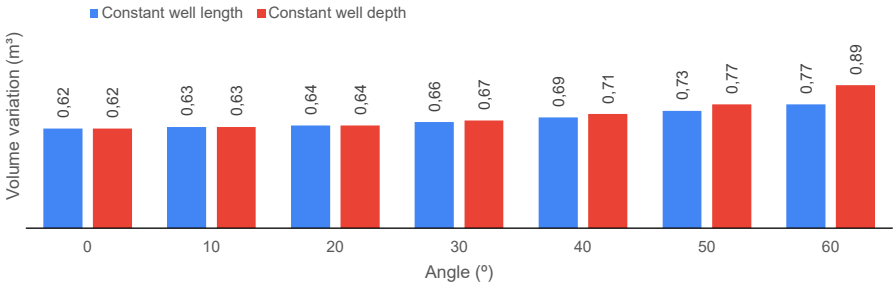
All simulations of wells with different inclination angles and scenarios are performed using the StrinGnosis software. The results are presented in the following section.

5 Results and discussion

Considering both analyzed situations, it is possible to assess the impact of well inclination on APB behavior. The data related to the initial volume of fluid confined in the annuli, shown in Fig. 4(a), indicate that in situation B (constant TVD), the total volume progressively increases with the inclination angle. This is because, to maintain the same true vertical depth in more inclined wells, the total well trajectory must be longer, resulting in a larger volume. In situation A (constant length), the initial volume remains unchanged, regardless of the angle, as expected.



(a)



(b)

Figure 4. Production casing results: (a) initial volume of the scenarios; (b) volume variation after injection

Fig. 4(b) shows increasing volume variation with inclination in both situations. However, from 30° onward, the rate of volume variation in scenario B is greater than that in scenario A, indicating that the well's directionality directly influences the magnitude of the fluid's thermal expansion. This difference is attributed to the temperature field present in each scenario; when the well inclination angle is small, the difference in volume variation is almost imperceptible, but as θ increases, the results show a more significant difference.

The APB values obtained (Fig. 5) reveal distinct behaviors between the two analyzed scenarios. When the well length is kept constant, APB progressively increases with each increment in the angle, indicating that inclination alters the temperature fields and, consequently, intensifies the pressure generated by the confined fluid. However, when TVD is kept constant, the opposite behavior occurs: as the angle increases, APB values tend to decrease.

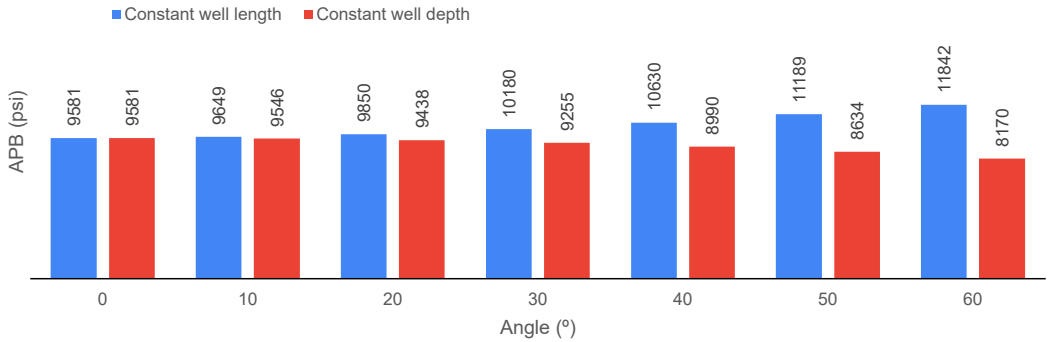


Figure 5. Resulting APB values

This divergence between the scenarios highlights that the well's length and inclination exert an influence on temperature field, and, consequently, on annular pressure buildup. Therefore, considering only the TVD in APB

modeling may lead to estimates that differ from actual field conditions, reinforcing the importance of accounting for the well's directionality in annular pressure analyses.

6 Conclusions

This study investigated the behavior of annular pressure buildup (APB) in directional oil wells, with emphasis on the effect of wellbore trajectory inclination. Two reference scenarios are evaluated using the StrinGnosis software: (i) a constant total well length, and (ii) a constant true vertical depth (TVD). For the case study, the results indicate that the well's inclination has a influence on APB behavior. In the constant-length situation, APB increased with inclination, while in the constant-TVD scenario, APB tended to decrease as the angle increased. This divergence between the situations reinforces that considering only the well's final depth is insufficient for an accurate prediction of the phenomenon, since the trajectory directly affects the confined fluid volume, the temperature field, and, consequently, the pressure generated during thermal expansion. Therefore, the results indicate that wellbore inclination is a significant parameter in APB modeling and must be explicitly considered in the design phase and the structural integrity assessment of directional wells.

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