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Microscale Computational Modeling of the Infiltration of Suppressors into the Porous Surface of Iron Ore Pellets

J.V.M Costa[1], M.F.Martins[1]

[1]*Multiphysics Modeling Laboratories (MM Labs), Department of Mechanical Engineering, Universidade Federal do Espírito Santo (UFES)*
Fernando Ferrari Av. 514, 29075-910, Espírito Santo, Brazil
joao.vm.costa@edu.ufes.br, marcio.martins@ufes.br

Abstract. Dust emissions during iron ore pellet handling pose a significant industrial challenge. This study presents a microscale computational model using COMSOL Multiphysics to simulate the biphasic flow of a liquid suppressant into a pellet's porous surface. A realistic geometry was obtained from X-ray microtomography , and the fluid-fluid interface was tracked using the Level Set method. The research aims to better understand the suppressant's interaction with the porous matrix to increase dust mitigation effectiveness. A parametric analysis was performed to evaluate how infiltration is affected by contact angle, droplet diameter, and impact velocity. The results demonstrate that droplet diameter is the most influential parameter, directly impacting pressure and the absorbed volume fraction. The model provides crucial insights into infiltration dynamics, serving as a scientific tool for optimizing suppressant application systems.

Keywords: Porous Media, Dust Supression, Iron Ore Pellets, Level Set Method

1 Introduction

The iron ore pelletizing process generates fine particles that can be dispersed during transport and storage, causing pollution and health risks. To mitigate these emissions, dust suppressants are applied, and their effectiveness depends on proper absorption by the pellet's porous structure. A flawed understanding of this process can lead to ineffective surface protection and waste of resources. This study, therefore, aims to computationally simulate the infiltration process to estimate properties of interest. The objective is to develop a microscale model based on a realistic geometry to analyze the flow dynamics and the impact of operational parameters, promoting a more sustainable operation in the mining industry.

2 Methodology

2.1 Geometry and Computational Mesh

The geometry of the computational domain was developed from an X-ray microtomography image of a cross-section of an iron ore pellet [1]. The image was processed and binarized to distinguish the solid phase (ore) from the porous phase (voids), generating the 2D geometry used in the simulations. An unstructured mesh was generated over this domain, and a mesh convergence study was performed to ensure that the results were independent of the discretization. The aim of this extended abstract is not to deal with the mesh independence test. The figure 2 represents the computational mesh used in the simulations.

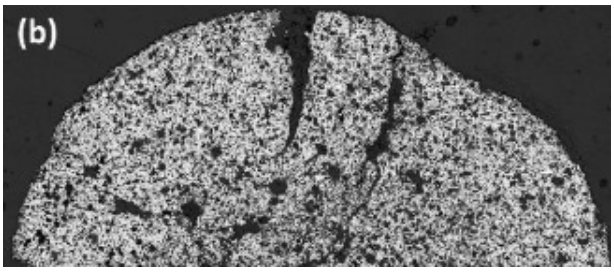


Figure 1. Pellet's X-Ray Microtomography

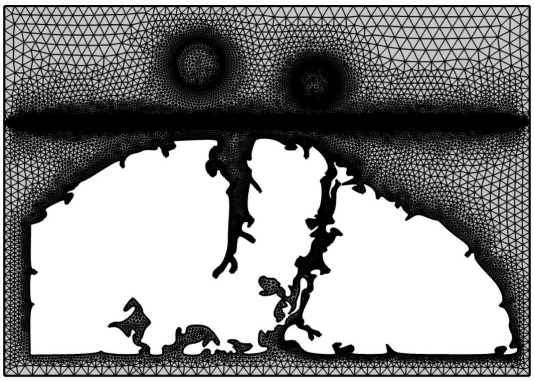


Figure 2. Mesh Used in the Simulations

2.2 Numerical Modeling

For the numerical modeling, the pores were treated as microchannels, with porous domain equations applied, considering these channels as being formed by the different types of pores within the pellet. The biphasic and incompressible flow of the suppressant (liquid) and air (gas) in the porous domain is described by the Navier-Stokes equations.

2.3 Level Set Method for Fluid-Fluid Interface Tracking

Fluid flow with interfaces or moving boundaries can be modeled in various ways. One method of tracking moving interfaces is through the Level Set Method. A given contour line of the globally defined function ϕ represents the interface between phases. Using the Level Set modeling approach, it is possible to move the interface between fluids within any velocity field. The figure 3 provides a representation of the mechanism and the relationship between the fluid interfaces specified in the problem formulation.

$$\frac{\partial \phi}{\partial t} + \mathbf{u} \cdot \nabla \phi = \gamma \nabla \cdot \left(\epsilon_{ls} \nabla \phi - \phi(1-\phi) \frac{\nabla \phi}{|\nabla \phi|} \right), \quad \phi = phils \tag{1}$$

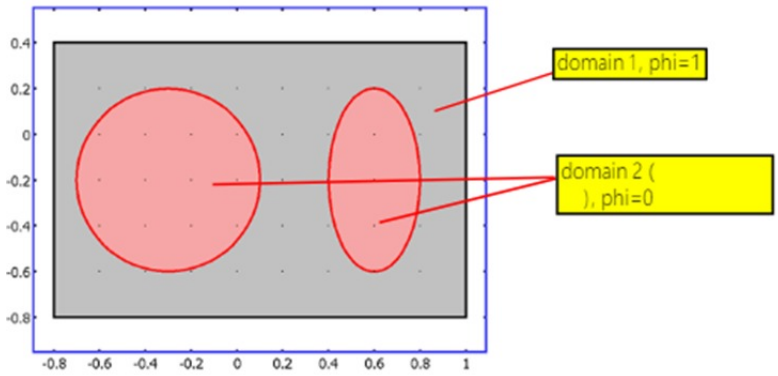


Figure 3. Level Set Method [2]

The equation 1 is used to move an interface with numerical stability. The terms on the left side of the equation adjust the movement of the interface, while those on the right ensure numerical stability. The parameter ϵ defines

the thickness of the interface and the parameter γ controls the stabilization of the level set function. The initial condition sets $\gamma = 1$, $\phi = 0$ in the air domain, and $\phi = 0$ in the liquid domain (supressor droplet) with a "no flow" condition at the boundaries, as specified in equation 2.

$$\mathbf{n} \cdot \left(\epsilon_{ls} \nabla \phi - \phi(1-\phi) \frac{\nabla \phi}{|\nabla \phi|} \right) = 0 \tag{2}$$

2.4 Parametric Variation Analysis

To investigate the suppressor infiltration process, several parameters of interest in the infiltration of suppressors into the iron ore pellet were analyzed. In the simulations performed, certain parameters were assessed and varied, such as the contact velocity of the water droplet with the pellet surface, the contact angle between the phases, and the suppressor droplet diameter.

- Impact Velocity Two tests were conducted with different impact velocities. The suppressor impact velocity influences droplet breakup upon contact and, consequently, also affects liquid absorption within the pores. The table 3 represents the velocities used in the simulations

Table 1. Velocities used in the parametric variation tests

Test	Velocity [m/s]
1	2.5
2	1

- Droplet Diameter The spray nozzle, a structure that releases the suppressor solution onto the iron pellets at different stages of the production chain, disperses the suppressor under pressures of 294,200 Pa and 980,665 Pa. The breakup of the solution into smaller droplets results in droplets of varying sizes before they reach the iron ore pellets. The simulations were conducted using two droplets of different diameters, as specified in table 2.

Table 2. Droplet diameter used in the parametric variation tests

Test	Droplet 1 [mm]	Droplet 2 [mm]
1	0.61	0.48
2	0.5	0.42

- Contact Angle Another parameter involved in this process that can affect the absorption of suppressants is the contact angle between the suppressant and the most superficial layer of the pellet, consequently affecting how the fluid will flow in the pores.

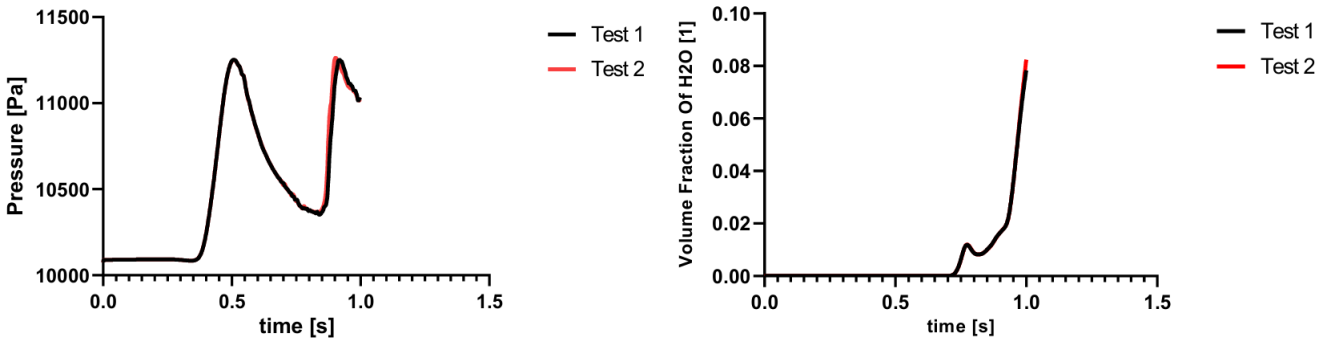
Table 3. Velocities used in the parametric variation tests

Test	Angle [rad]
1	$\pi/4$
2	$\pi/6$

3 Results and Discussion

The analysis of the suppressant infiltration process, based on the variation of the parameters mentioned above, was carried out by evaluating two quantities: the pressure within the porous microchannels and the volumetric fraction of fluid (water), as a function of the simulated physical time (2s).

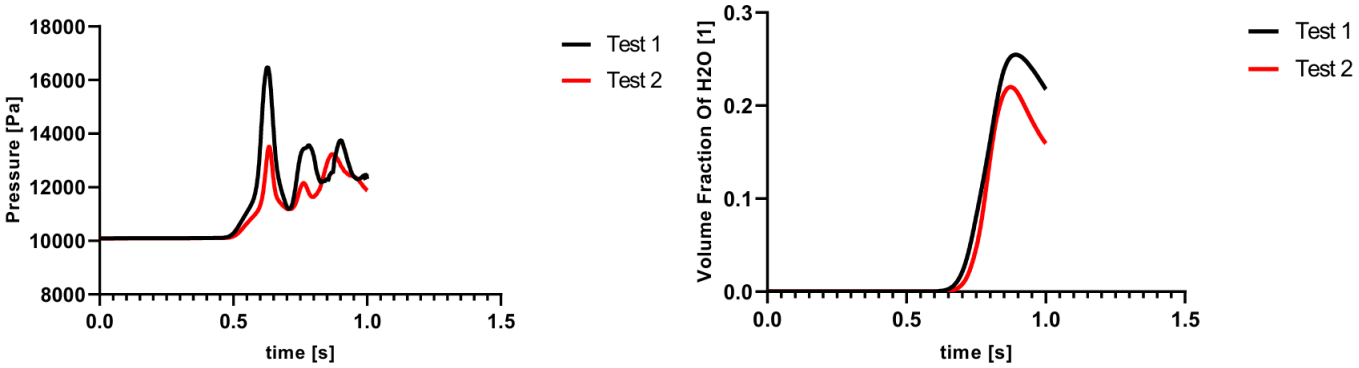
The contact angle of the suppressant droplets on the surface of the iron ore pellet did not significantly affect the analyzed parameters, as shown in the figure 4.



(a) (b)

Figure 4. Pressure and Volume Fraction in Contact Angle Variation Tests

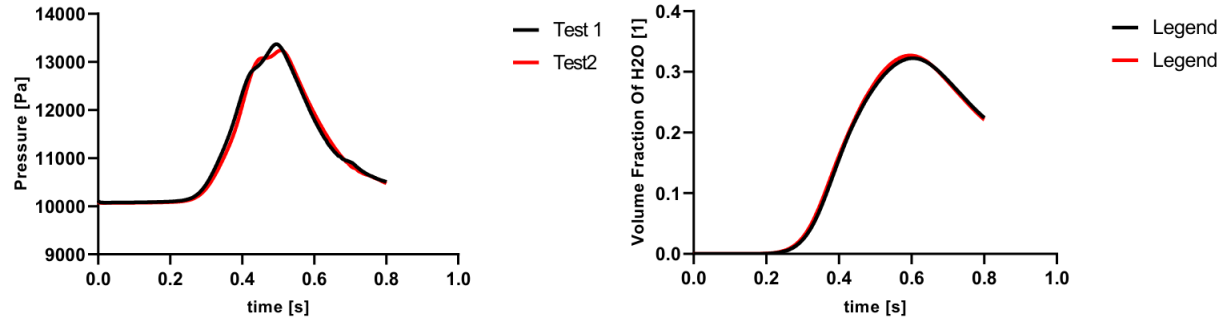
By varying the diameters of the suppressant droplets coming into contact with the iron ore pellet, it was observed in figure 5 that there was a noticeable variation in the air dynamic pressure within the channels, indicating that the flow behavior differed for distinct droplet diameters. The same trend is evident in the water volume fraction.



(a) (b)

Figure 5. Pressure and Volume Fraction in Droplet Diameter Variation Tests.

Upon analyzing the graphs, it is evident that the contact velocity of the suppressant on the pellet also did not result in significant differences in the analyzed parameters. This may be attributed to fluid spreading upon impact with the material surface.



(a) (b)

Figure 6. Pressure and Volume Fraction in Velocity Variation Tests

4 Conclusions

The investigation into the absorption of mineral dust suppressants is of significant importance for both industrial and environmental applications. This work was conducted to understand key variables influencing this process and how the phenomenon changes according to their variation. The research seeks to offer insights into these dynamics and to assess the flow within the porous media of iron ore pellets.

References

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