Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME/CFDSC/CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

NUMBER

Impact of Three-Dimensional Effects on Yield-Stress Fluid Injection in Eccentric Pipes

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Abstract

Injecting a yield-stress fluid into a lower-density Newtonian fluid finds application in many industries, including the oil and gas. The plugging phase of oil and gas wells often involves injecting a heavy yield-stress fluid (cement slurry), through a an injector into a lighter Newtonian fluid (water) that fills a larger pipe. The purpose of the propose is to prevent the migration of fluids along the well. Ideally, the injector is placed concentric with the larger pipe. In practice, however, some eccentricity is unavoidable.

In previous work, Ghazal et al [1] used a two-dimensional model of the process to show that when the injector is not concentric, the injected fluid diverts into the annular space between the injector and the larger pipe. In practice, however, the flow domain is three dimensional. To examine the influence of this simplification and increase the accuracy of the numerical predictions, we develop numerical simulations to investigate the effect of eccentricity in a three dimensional flow domain.

In contrast with the two-dimensional predictions, the new model predicts that when the injector is concentric, a displacement flow develops as a finger below the injector. This is followed by the appearance of disturbances at the fluids' interface which lead to the disruption of the displacement flow. The growth of the interfacial disturbance leads to the formation of a vortex street that enhances mixing below the injector and a density-stratified layer thus develops, leading to diverting the injected fluid into the annulus. When the injector is not concentric, the initial displacement flow is not observed. Instead, a mixing region forms below the injector as soon as injection starts and the density-stratified layer develops sooner beneath the injector. We found that the length of the density-stratified layer is independent of eccentricity value. This contrasts with the predictions based on the two-dimensional models, which suggested no mixing beneath the injector.

Overall, we demonstrate that while a mechanistic understanding can be developed using two-dimensional simulations, investigating the three-dimensional dynamics is essential for constructing high-fidelity predictive models relevant to practical industrial applications.

Keywords-component

Yield Stress Fluid, Eccentric Pipe Flow, Displacement Dynamics

[1] Ghazal, A., & Karimfazli, I. (2022). On the hydrodynamics of off-bottom plug placement: Effects of geometry in a 2D model problem. Journal of Petroleum Science and Engineering, 212, 110153.