Proceeding Series of the Brazilian Society of Computational and Applied Mathematics, v. 11, n. 1, 2025.

Trabalho apresentado no XLIII CNMAC, Centro de Convenções do Armação Resort - Porto de Galinhas - PE, 2024

A Two-dimensional Modeling Approach of the Settling of Weighting Solids in Non-Newtonian Drilling Fluids

Victor H. R. Morais[1] Kamila S. Oliveira[2] Luís A. Calçada [3] Cláudia M. Scheid[4]
Fluid Flow Laboratory - LEF/DEQ/IT/UFRRJ, Seropédica, RJ
Renan S. Teixeira[5]
Dept. of Mathematics - DEMAT/UFRRJ, Seropédica, RJ

During the preparation of oil wells, drilling fluids are employed for various purposes, such as lubricating the drill, removal of cuttings, and controlling the well's hydrostatic pressure. Pressure control is achieved by increasing the density of these fluids with particulate minerals, like barite. In the cementing stage, the fluid is confined in the annular regions between the casing layers and the rock. The confined fluid undergoes temperature variations, leading to pressure increases in the annular region, known as Annular Pressure Build-Up (APB), which can compromise the integrity of the casings, as stated by [1]. One APB mitigation strategy consists of leaving an unlined region within the annulus, known as open shoe, so the fluid can flow into the formation if there is an excessive pressure increase. However, the solids within the confined fluid may settle and cover this region entirely.

In this context, this study aims to enhance the one-dimensional model previously developed by [1] to predict the settling dynamics of weighting materials within annular regions. This will enable the consideration of complex geometries in future research, such as annular diameter contractions and deviated wells. A bench scale case was considered and the results were reassured by the one-dimensional model, in turn validated with experimental data by [1].

The phenomenological model implemented is governed by the 2D continuity equation (1) and momentum equations. Following the same considerations as [1] on pressure gradient ($\frac{\mathrm{d}P_s}{\mathrm{d}\varepsilon_s}$), dynamic parcel of stress tensor, resistive force and adopting a different medium permeability (K) equation, this leads to Equations (2) and (3), which describe the velocity field in the horizontal ($v_{s,x}$) and vertical direction ($v_{s,y}$), respectively.

$$\frac{\partial \varepsilon_s}{\partial t} + \frac{\partial(\varepsilon_s v_{s,x})}{\partial x} + \frac{\partial(\varepsilon_s v_{s,y})}{\partial y} = 0 \tag{1}$$

$$v_{s,x}(v_{s,x}^2 + v_{s,y}^2)^{\frac{1}{2}(n-1)} = \frac{K}{M(1-\varepsilon_s)^{1-n}} \left[\frac{d_p}{\Psi(\phi)}\right]^{n-1} \left(\frac{\rho_{susp}}{\rho_{susp} - \rho_s \varepsilon_{s0}}\right) \left[\varepsilon_s(\rho_s - \rho_l) g_x - \frac{\mathrm{d}P_s}{\mathrm{d}\varepsilon_s}\frac{\partial \varepsilon_s}{\partial x}\right] \tag{2}$$

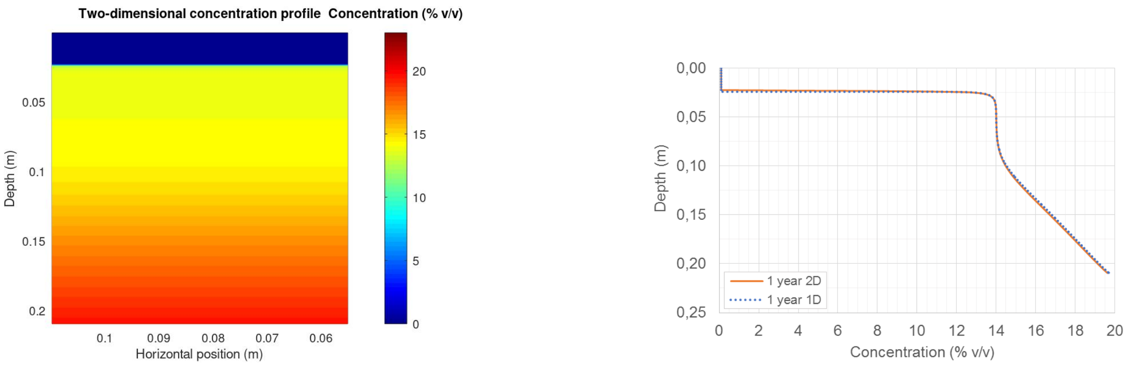
$$v_{s,y}(v_{s,x}^2 + v_{s,y}^2)^{\frac{1}{2}(n-1)} = \frac{K}{M(1-\varepsilon_s)^{1-n}} \left[\frac{d_p}{\Psi(\phi)}\right]^{n-1} \left(\frac{\rho_{susp}}{\rho_{susp} - \rho_s \varepsilon_{s0}}\right) \left[\varepsilon_s(\rho_s - \rho_l) g_y - \frac{\mathrm{d}P_s}{\mathrm{d}\varepsilon_s}\frac{\partial \varepsilon_s}{\partial y}\right] \tag{3}$$

where ε_s is the volumetric concentration of solids, d_p is the solid diameter, ρ_s, ρ_l and ρ_{susp} are the densities of the solid, liquid and suspension phases, in this order, g is the gravity, $\Psi(\phi)$ is the

[1]victormoraisufrrj@gmail.com
[2]kamila.oliveira@ufrrj.br
[3]calcada@ufrrj.br
[4]scheid@ufrrj.br
[5]rsteixeira@ufrrj.br

particle form and M and n are the fluid consistency and behavior indexes, respectively. The Finite Volume Method was employed to numerically solve the mathematical model. The unsteady term was discretized using the forward Euler scheme, and the upwind method was utilized for spacial derivatives.

The domain was divided in 90000 volumes and has dimensions of 0.21 m in depth, with an internal radius of 0.055 m and an external radius of 0.11 m. 0.38 and 1.25 $Pa.s^n$ were used for the n and M rheological properties, respectively, a CFL number of 0.005 was adopted as the stability criterion and a 14% volumetric concentration was used as the initial condition. The one-dimensional simulator validated the results obtained by the two-dimensional model through graphical analysis, Figures 1a and 1b, and average deviation percentages. The average deviation percentages for 6 months, 1, 2 and 5 years were 0.25 %, 0.39 %, 0.58 %, and 0.39%, respectively.



(a) (b)

Figure 1: Volumetric concentration of solids for 1 year simulation time is depicted in Fig. 1a. Comparison for 1 year simulation time between two and one-dimensional models for a horizontal fixed position in Fig. 1b. Source: Author, 2024.

As can be seen in Figure 1a, the typical settling zones have been captured accurately, which the top region represents the clarified zone (blue region) where the concentration tends to zero, and right below rises the constant concentration region close to the initial condition (yellow region), and a thickening zone at the bottom where solids will accumulate (red region). Figure 1b portrays a good fit between the results for the two approaches.The small average deviation percentages suggest a reasonable agreement between the two- and one-dimensional approaches, which makes the 2D code reliable for future complex geometrical implementations.

Aknowledgements

The authors thank the funding of Petrobras (Projeto SAP 4600669323) and UFRRJ's support for the development of this work.

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