NUMERICAL AND EXPERIMENTAL STUDY OF LAMINAR FLUIDS DISPLACEMENT

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Abstract. *The cement operation of oil and gas wells is extremely important, the successful of this operation guarantee the lifetime of the wells. The adequate operation occurs when the cement slurry distribution on wells wall is homogeneous. For this purpose, the complete displacement of the drilling mud that is in annuli space by the cement slurry is necessary. In this work, an experimental and numerical study of the displacement of two fluids through annuli concentric geometry were performed. The numerical solution of the governing conservation equations of mass and momentum is obtained with the FLUENT software, using the finite volume technique and the volume of fluid (VOF) method.The cementing operation efficiency is evaluated using the density ratio value of the fluids in the annuli outlet. The experimental and numerical results show good agreement.*

Keywords: *fluid displacement, annular flow, rheology*

1. INTRODUCTION

The cementing process in an oil well is a crucial operation that needs to be very well performed, in order to guarantee the desired well life, since the lifetime of the well is strongly influenced by the cementing operation.

As means of having a successful operation, it is of highly importance that the displacement process ends with the cement paste homogeneously distributed at the well wall. From the industrial perspective, a good displacement corresponds to the displacement of the in situ fluid perfectly, all around the annulus, with little instability at the interface and with the interface moving steadily at the mean pumping speed. Moreover, the cement paste must have the desired mechanical properties, such as adherence, compression resistance and impermeability since the cemented regions works with dual purposes. First, the cemented casing serves to uphold the wellbore, preventing collapse. Second, the cement provides a hydraulic seal on the outside of the steel tubing. A hydraulic seal is necessary in order to isolate the different fluid-bearing zones of the rock formation from one another and from the surface. Therefore, it is necessary to remove all drilling mud from the annular space between the rock formation and the casing (or the drilling column), by pushing it with the cement paste. To avoid contamination, which would affect the cement properties, one or more spacer fluids are inserted between the drilling mud and the cement paste. Failure in achieving proper zonal isolation can incur a significant economic effect in terms of loss of well productivity, and can also have adverse environmental effects, not to mention time and money consumed in a poorly cemented well.

The analysis of the replacement process of a fluid by another, with different physical properties, is characterized by the simulation of a multiphase flow. The solution of the governing equations aims to represent the evolution of the interface shape between each pair of fluids (cement/spacer fluid and spacer fluid/drilling mud) during the displacement process. This is a complex problem, specially when the fluids present non-Newtonian behavior, which is the case of drilling muds and cement slurries. Spacer fluids typically are a mixture of water and polymers, and can also present non-Newtonian behavior. The numerical simulation of flows is a powerful tool in the evaluation of different processes in the industry. Particularly in the oil industry, an experimental investigation in an oil well is an expensive task, and sometimes not operationally feasible (Haut et al., 1979).

The present investigation provides the displacement efficiency of a concentric annular flow for a scaled well. The displacement efficiency was calculated by the density ratio of the fluids injected in the well. A comparison between numerical and experimental approaches was performed.

2. EXPERIMENTAL ANALYSIS

The experimental flow approach is presented in Fig. 1. The flow section consists of a transparent vertical outer tube (OD = 34 mm) and an inner tube (ID = 16 mm), with a length of 1000 mm. The tubes are concentric.

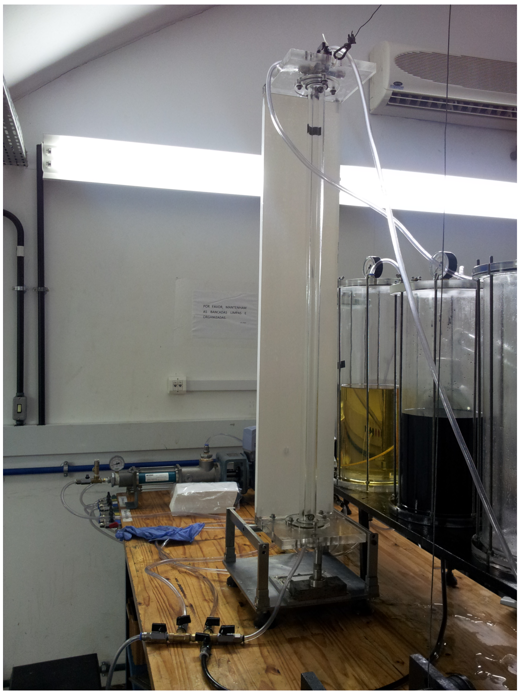

Figure 1. Experimental approach.

In the experimental procedure, the annular space is filled with the displacing fluid (oil). Next, positive displacement pump circulates the displacing fluid (water) through the annulus at constant rates. Samples of the displaced fluid are collected at outlet, the fluid density is measured and the displacing efficiency is calculated.

Tab. 1 shows the parameters of the cases studied. The flow regime is laminar and the Re number is defined according eq.1.

$$Re = \frac{\rho v D_h}{\mu} \tag{1}$$

Table 1. Cases studied.

Cases	$\dot{Q}$ $[m^3/s]$	Re	T [°C]
1	3.1 E-6	79	21
2	2.3 E-5	585	21

The fluids used in the annular displacement experiments were Newtonian. and the properties are presented in Tab.2, where ρ is the density and μ is the viscosity.

Table 2. Displacement fluids properties.

Fluids	$\rho\ [kg/m^3]$	$\mu\ [Pa.s]$
water	1000	0.001
oil	919.8	0.05

3. NUMERICAL ANALYSIS

The numerical solution of conccentric annuli flow of non-Newtonian fluids is analyzed using an axisymmetric geometry. The fluids flow vertically through an annular space. The solution assumptions are that both fluids phase are incompressible and the axisymmetric flow is laminar and transient. The boundary conditions are no-slip at walls, uniform velocity at inlet and fully developed flow at the outlet. The computational domain is created with the same dimensions of the experiment. The mesh used is uniform with 21576 elements. The governing equations presented above are discretized via the finite volume method described by Patankar (1980), using the SIMPLE algorithm (Patankar, 1980) to couple velocity and pressure. The numerical results are obtained using the commercial software FLUENT (ANSYS).

The volume of fluid method (VOF) (FLUENT User's Guide, 2010) is used to take into account the multiphase flow. The VOF method solves a set of mass conservation equations and obtains the volume fraction of each phase α_j through the domain, which should sum up unity inside each control volume. Therefore, if $\alpha_i = 0$, the cell is empty of the phase i; if $\alpha_i = 1$, the cell is full of the phase i and if $0 < \alpha_i < 1$, the volume contains the interface between the phases. The properties appearing in the transport equations ϕ are determined using an average of the property value among the n phases. In the problem studied, three phases are considered. Therefore,

$$\phi = \alpha_2\phi_2 + (1 - \alpha_2)\phi_1 \tag{2}$$

The interface between phases is obtained by the solution of continuity equation for α_i for the $n - 1$ phases:

$$\frac{\partial \alpha_i}{\partial t} + u_j \frac{\partial \alpha_i}{\partial x_j} = 0 \tag{3}$$

where x_j are the coordinates and u_j are the velocity components. The volume fraction of one of the phases is obtained with the following constraint equation:

$$(\alpha_1 + \alpha_2) = 1 \tag{4}$$

The momentum conservation equation is presented below, for incompressible fluids.

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial(\rho u_i u_k)}{\partial x_i} = -\frac{\partial P}{\partial x_k} + \frac{\partial}{\partial x_i}\left[\eta\left(\frac{\partial u_i}{\partial x_k} + \frac{\partial u_k}{\partial x_i}\right)\right] + \rho g_k \tag{5}$$

where ρ is the density, P is the pressure and g is the gravity.

4. RESULTS

Preliminary results comparing the results of experimental and numerical approaches is shown in Fig.2 and Fig.3. Fig. 2 shows the density mixture of the displaced fluids for $Re = 79$. It can be observed that the results give a sharper decrease of the density ratio, and no mixture is observed. There is a good agreement of numerical and experimental results. The same behavior can be observed for $Re = 585$.

Further analyzes are been performed to take into account the non-Newtonian fluid behavior.

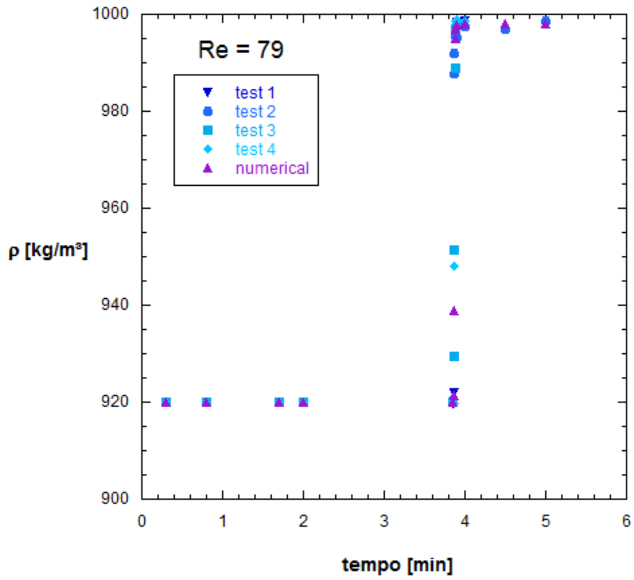

Figure 2. Density mixture of fluid displacement ($Re = 79$).

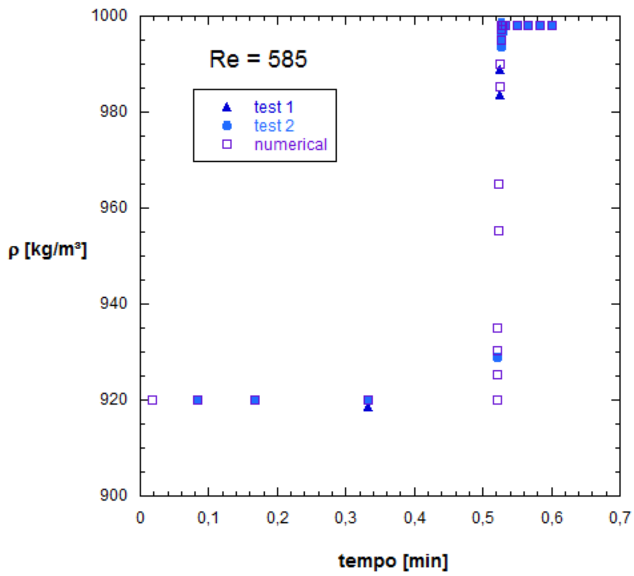

Figure 3. Density mixture of fluid displacement ($Re = 585$).

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