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Efforts to Control Fluid Losses in Offshore Drilling

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Abstract

Circulation losses are one of the most critical problems while drilling for oil and gas, causing rig down-time, which heavily impacts the total cost of the operation. Difficulties in drilling and unsuccessful cementing jobs are frequent events, especially while dealing with fractured reservoirs. Preventive and corrective measures are used to mitigate the loss circulation, including the injection of coarse particulate material, gelled fluids and resins.

This study aims to investigate strategies, methodologies and technologies to minimize loss circulation problems during the wellbore constructions operated by Petrobras. In this study, 3 different experimental methodologies will be presented: Static filtration in porous medium with fractures up to 2 mm, static filtration tests in high permeability porous media and fluid flow experiments through 2 mm, 5 mm and 10 mm fractures.

Introduction

During the wellbore construction, when a positive differential pressure from the well to the formation is applied, fluid losses can occur. This phenomenon is intensified when fractured zones are drilled. This effect can be even greater during drilling operations through the interconnected fracture networks.

Fluid losses are one of the most challenging problems of well construction generating additional costs and in extreme situations, compromising the exploratory campaign and well completion.

Exploratory wells currently drilled by Petrobras in Brazil present average depths around 5500 m and in extreme situations can reach around 7000m. In this scenario, geological characteristics such as faults, natural fractures, high permeability zones and formations with vugular features are responsible for increased lost circulation events. Some exploratory wells present lost circulation events, increasing unproductive time and well construction costs. These loss events need to be combated and controlled to enable minimum well construction costs.

The usual industry approach to addressing lost circulation events has been using flakes, granular and fibers materials such as graphites, calcium carbonates, mica, nut shells and swelling polymers (Clapper[6] et al., 2011, Castro[5] et al., 2011, Arevavalo-Villagran[4] et al., 2009 and Niznik[3] et al., 2011). Mixtures of theses kind of products are available from drilling fluid service companies.

The main idea of this work is to investigate and evaluate technologies used in the oil industry with the aim of reducing and minimizing unproductive rig time during the lost circulation events during drilling operations. This paper reports test results utilizing the three different methods. These methodologies will be described in the next section.

Methodology

Experimental evaluation considered Loss Control Material (LCM) pills flowing through three different media, as detailed below:

- Static filtration considering flow through high permeability bed filled by limestone: In this type of methodology the porous bed is positioned inside an acrylic tube (column). At the bottom of acrylic column is attached a valve to control flow and the top of the acrylic column is coupled with a Nitrogen pressurization system. The LCM pill is positioned over the porous medium and a pressure differential is applied. All fluid flow through the porous medium can be visualized. Figure 1 shows a picture of the experimental apparatus.

Figure 1 – Static filtration an unconsolidated bed

- Static filtration in fractured porous media: This methodology is carried out in an HPHT filtration cell in which it is possible to apply a differential pressure up to 1300 psi. The porous media used in these studies considered fractures with apertures of 1 mm and 2 mm, as shown in the figure below.

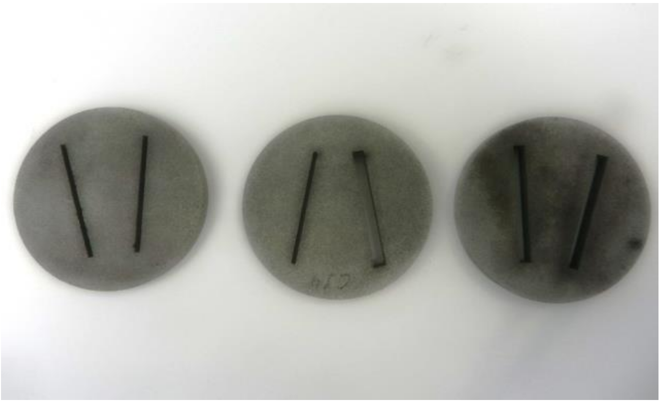

Figure 2 – Porous media of 1 and 2 mm apertures

- Fracture Flow Simulator: The equipment allows simulating fluid flow through 3 different fractures; 2, 5 and 10 mm apertures. In this apparatus it is possible to perform tests considering multiple fractures or simply a single fracture. The equipment has two sections where it is possible to simulate different Reynolds numbers in the annular, represented by 12 ¼ in (Geometry 1) and 8 ½ in (Geometry 2) sections. The equipment was manufactured in acrylic to enable flow visualization; however this fact limits the maximum operating pressure at 150 psi. Figure 3 shows the experimental setup with zoom of the fractured channels.

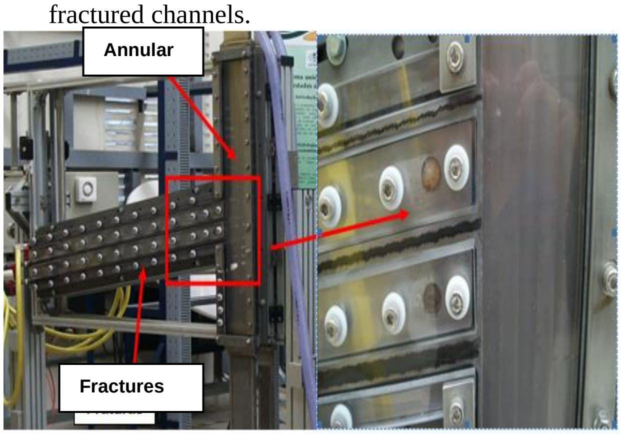

Figure 3 – Fracture flow simulator with 2, 5 and 10 mm aperture

- The LCM pills tested were:

1. Pill A: This fluid is a blend of borate mineral and polymers designed for suspension, fluid loss control and cross linking technology. When activated with time and temperature, the fluid develops a rigid cross-linked gel structure that effectively prevents loss of fluid to the formation.

2. Pill B: It is a high solid, high fluid loss blend squeeze product designed to plug loss circulation zones with large fractures. This fluid is designed to be used in water and oil based drilling fluids producing very thick filtercake. This LCM pill contains an expandable polymer that remains swollen after displacement at the loss zone. Normal quantities required for fresh water pills are 50-80 ppb.

3. Pill C: This type of fluid can be made by drilling fluid (Pill C1) or paraffin (Pill C2). This LCM pill is obtained by increasing the rheology when subjected to temperatures above 150 F.

4. Pill D: This fluid can be easily prepared in water. The material is basically composed of hydrogels and other particulate materials (fibers, cellulose, etc.). The materials expand when in contact with water to form hydrogels with excellent shear strengths.

Loss Circulation Pill - A

Static filtration in fractured porous media

Tests were carried out in a filtration cell where it was possible to combine a limestone bed with fractured porous media. On the bottom of the filtration cell was positioned a fractured porous media with 2 mm aperture. The LCM pill was placed on top of the filtration cell and the system subjected to a differential pressure of 600 psi for 12 hours.

During the filtration test it was possible to observe a very small filtrate volume and at the end of the test it was observed a consistent plug sealing the porous medium, as can be seen in Figure 4.

Figure 4 – Static filtration in fractured porous media – Fluid A

Compatibility tests

Compatibility tests were performed adding different fractions of drilling fluid into fluid A. The results obtained with this kind of LCM pill show that the maximum contamination value is 10% v/v in drilling fluid. Volumetric contamination higher than 10% v/v drastically decreases the mechanical resistance of the LCM pill. The figure below illustrates pictures of the system with different levels of contamination.

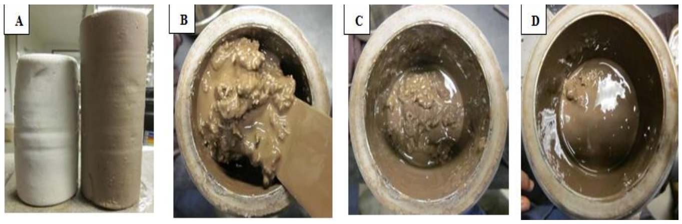

Figure 5 – (A): 0% v/v and 10% v/v;(B): 25% v/v; (C):50% v/v e (D):75% v/v

Loss Circulation Pill - B

Static filtration test in high permeability limestone bed

The acrylic tube was filled with a coarse limestone bed (~400 Darcy, Waldmann[1], 2010) and porous media saturated with paraffin. The LCM pill was placed on the porous medium and subjected to differential pressure of 100 psi. Fluid dehydration and impermeable filtercake build up was observed (Figure 6). The filtercake did not penetrate the limestone bed and this behavior generated doubts about the efficiency of this pill formulation in plugging fractures. As only an external filter cake is formed, any drill string or drill bit movement could remove it and restart loss circulation. Therefore additional tests were performed considering other methodologies.

Figure 6 – Static filtration test in high permeability limestone bed

Static filtration in fractured porous media

The experiments were performed in HPHT filtration cells utilizing a sintered steel porous media with fractures of 2 mm aperture, as shown in Figure 2. The fluid was positioned against the porous medium and subjected to a differential pressure of 200 psi.

The valve positioned after filtration fractured porous medium was removed, because this valve can cause extra friction losses and may cloud evaluation of the results.

After approximately 4 minutes, an initial filtrate volume of approximately 12 ml was observed and fractures were closed. The differential pressure was increased up to 800 psi and no additional fluid loss was observed.

Fracture Flow Simulator tests

With this equipment it is possible to run tests on fractures of 2 mm, 5 mm and 10 mm aperture. The equipment has two different annular flow sections in which it is possible to simulate the same Reynolds number observed during the drilling operation. Annular sections represented by this equipment are:

- Geometry 1; represents annular between a 12¼" section and 5" drillstring.
- Geometry 2; represents annular between a 8½" section and 5" drillstring.

The tests were performed considering the six configurations. Tests carried out in both annular sections considering flow through fractures with 2 mm aperture were successful. In both annulars the flow rate through fracture channels was stopped. Tests performed in geometry 1 with flow through fractures of 5 mm showed very good results. However, tests carried out in fractures with 10 mm aperture, in both annulars, did not achieve good results, as the flow through the fractured channel was not stopped, as can be seen in Figure 7 below.

Figure 7 – Flow through fractures 2, 5 and 10 mm apertures – Geometry 1

Figures 8 and 9, respectively, illustrate the flow rate and pumping pressure during fluid flow through the fractures in geometry 1 and 2. The black curve shows the annular flow rate and the red curve represents the pumping pressure.

Initially, the flow rate was stabilized around 2 m^3/h and then the valve located at the end of the fracture chanel was opened. In this moment it is possible to observe an abrupt reduction in the annular flow rate, represented by the first down step in Figure 8. Flow rate stabilization to the initial level (2m^3/h) represents the exact moment in which fractures with 2 mm (first down step) and 5 mm (second down step) are filled in geometry 1. Figure 9 shows the 2 mm fracture bridging in geometry 2. The results show an erratic behavior, due to the high flow rates obtained in this geometry, but it is possible to initially observe the flow rate decrease and after that, the flow rate returns at the initial values.

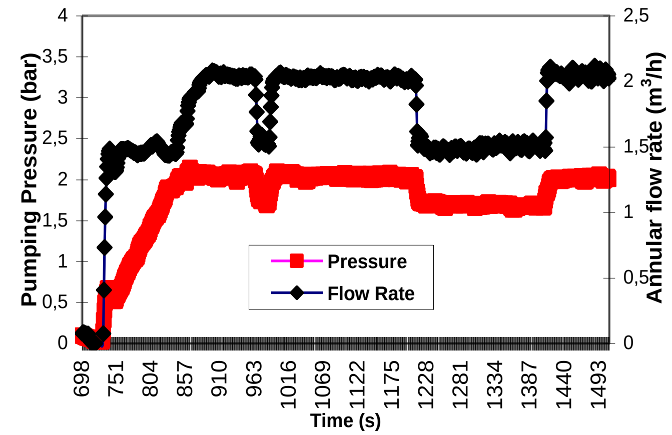

Figure 8 – Pumping pressure and annular flow rate x time – Geometry 1

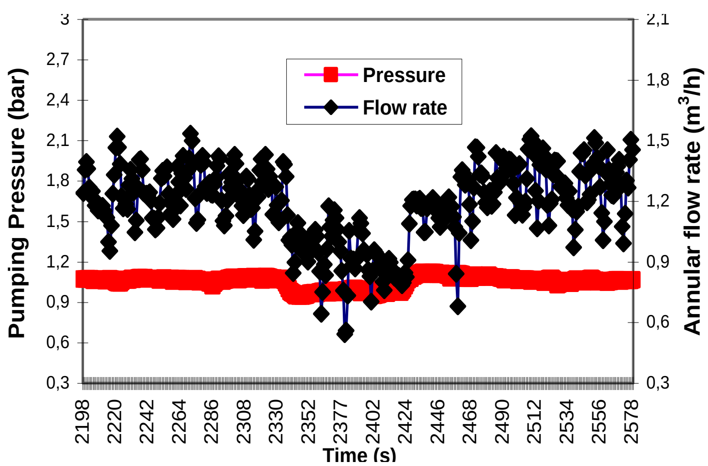

Figure 9 – Pumping pressure and Flow rate x time – Geometry 1

Loss Circulation Pill - C

Static filtration in fractured porous media

Tests performed with Pill C, due to its manner of operation, were executed in a filtration cell where it was possible to combine a limestone porous bed with fractured media. Two different pills formulations were considered:

- Pill C1; prepared with the drilling fluid;
- Pill C2; prepared in n-paraffin.

Experiments were performed in HPHT filtration cells utilizing a sintered steel porous media with a 2 mm fracture aperture. The fluid was placed in position and subjected to a differential pressure of 200 psi while increasing the temperature to 150ºF.

Pill C1 - Prepared with the drilling fluid

Results obtained with this pill were very successful. Results show that an initial spurt loss obtained during the test (20 ml) was stabilized after 3 minutes. In this same test the differential pressure was increased to 400 psi and any extra fluid loss was observed. Figure 10 shows the filter cake observed at the conclusion of the static filtration test.

Figure 10 – Filter cake generated by Pill C1

Pill C2 - Prepared in n-paraffin

In this scenario the fluid was prepared considering only the n-paraffin as the base fluid. Results obtained with this fluid were unsuccessful. Once the fluid flow through the porous fractured disks at a high flow rate was achieved, no fracture sealing was observed.

Loss Circulation Pill D

Static filtration test in high permeability limestone bed

The product was positioned on the porous medium and subjected to a differential pressure of 100 psi, as shown in Figure 11. Static filtration tests in the high permeability bed with Pill D showed a very small filtrate volume (~4 ml) with a thick and impermeable filter cake stopping the fluid flow through the limestone bed.

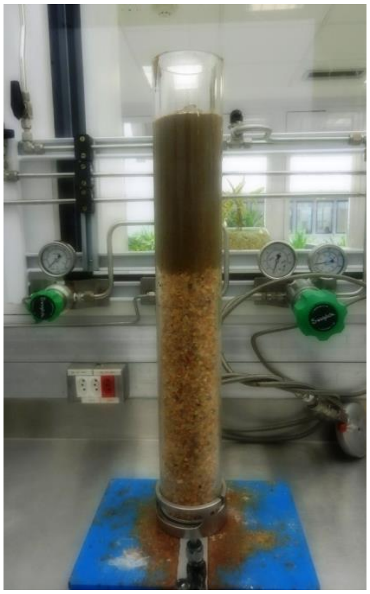

Figure 11 – Static filtration test on limestone bed – Pill D

Static filtration in fractured porous media

The fluid was positioned against the porous medium and subjected to differential pressure of 200 psi. Results obtained with this pill showed a spurt loss equal to 33 ml and the fractures were totally sealed after about 5 minutes. Differential pressure was further elevated up to 400 psi and no further fluid flow through the fractured porous media was observed. Figure 12 shows Pill D sealing fractured porous media after filtration test.

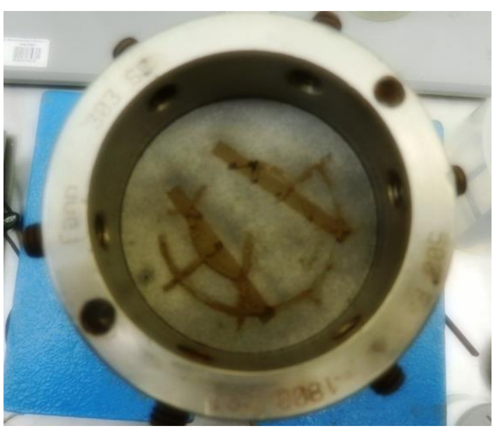

Figure 12 – Static filtration in fractured porous media – Pill D

Fracture Flow Simulator tests

Tests with Pill D were performed in geometries 1 and 2 considering fractures with 5 and 10 mm apertures. Figure 13 illustrates the flow rate and pressure profile obtained during the fluid flow in both geometries. The black curve shows the annular flow rate and the red curve represents the pumping pressure. The left side of the gray line (vertical) represents data obtained considering geometry 1 and right side are results obtained considering geometry 2.

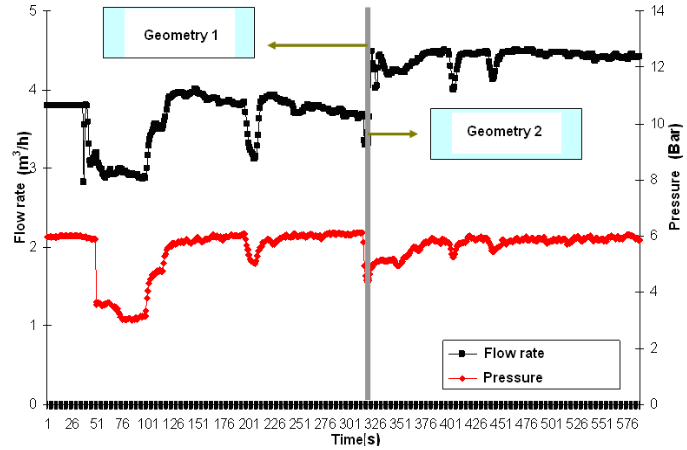

Figure 13 – Pressure and Flow rate profile at the Fracture Flow Simulator tests – Pill D

The initial flow rate was stabilized at 3.8 m3/h. After the flow stabilized, the 10 mm fracture was opened and it is possible to observe an abrupt reduction at the annular flow rate to 2.8 m3/h. When the flow rate returns to the initial level (3.8 m3/h), this moment represented the fracture sealing in geometry 1. The same behavior is observed when tests are carried out with a 5 mm fracture aperture. The only difference observed between the 5 and 10 mm fractures is the length of time to seal. Results obtained with geometry 2 were also very successful.

Final Remarks

- Experimental methodologies presented in this paper proved to be useful to evaluate different types of pills to control and minimize loss circulation events.
- The fracture flow simulator provides a different experimental methodology in which it is possible to conduct fluid loss tests. This methodology provides more reliable results once fractures with 2, 5 and 10 mm aperture, 1.5 m depth and tortuosity are considered.
- Test results show extremely promising product formulations for field applications.
- Tests carried out with pill A, showed a contamination tolerance of 10% by volume.
- Pill C is an extremely interesting option for drilling jobs. This product, when prepared in drilling fluid, could be utilized for critical and severe losses. However, the same material prepared in n-paraffin did not present good results.
- Results obtained with Pills B and C were very good. However, Pill C results were better than those of Pill B, as they showed a better capability of sealing fractures in larges apertures.

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