PWD ANALYSIS IN DEEPWATER ENVIRONMENTS: CAMPOS BASIN CASE STUDIES

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Abstract. *The anticipation and remediation of potential hole problems is an ultimate goal of most real time measurement devices installed on drilling rigs. Among the several sensors available, PWD (pressure while drilling) measurements gained popularity due to its potential for problem diagnosis. The complete understanding of the physical phenomena governing downhole pressure is, however, far from being spread among the drilling teams at the rigsite.*

This article proposes to establish, in a comprehensive way, basic guidelines for PWD interpretation at deepwater environments. Focus concentrate on hole cleaning issues, which is a major source of drilling problems. Based on wellbore pressure calculation fundamentals, a sensibility analysis to the main operational parameters was carried on. Additionally, some representative field cases collected from Campos basin operations, offshore Brazil, were used to highlight the relevant phenomena.

Keywords: *PWD, pressure, drilling, fluid, ECD, rheology*

1. Introduction

Hydrocarbon exploitation in deepwater environments presents several particularities concerning hydraulics design. Due to the low sediment coverage, rock formations frequently present low competency and, consequently, hydraulics should contemplate the narrow operational window between pore and fracture pressures. Additional difficulties may be faced in situations where lower collapse is higher than pore pressures and/or upper collapse is lower than fracture pressures. Figure 1 and 2 compare operational windows in non deepwater and deepwater scenarios.

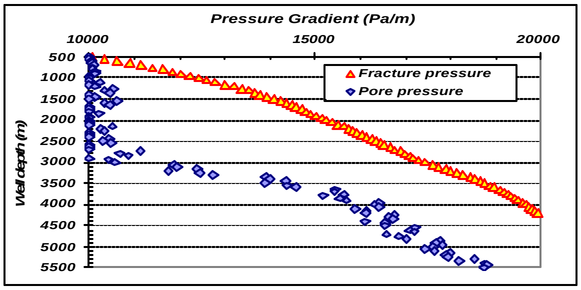

Figure 1. Typical operational window for shallow water well

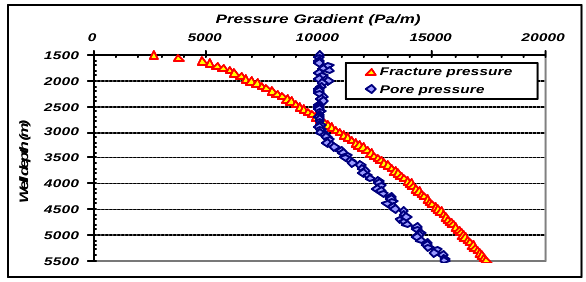

Figure 2. Narrow operational window for a deepwater well

The ability to analyze downhole annular pressures with pressure-while-drilling (PWD) data has proven to be a very efficient way to minimize and anticipate drilling problems.

PWD tools are well documented in the literature (Hutchinson, 1998 and Rojas, 1998). PWD tools run in the bottomhole assembly (BHA) measuring the annular pressure in the mud column. Figure 3 shows the tool schematics. PWD measurements are taken continuously every few seconds and stored in memory as a time file. These recorded PWD data are downloaded at surface after a trip. Real-time access to the data is also provided through a measurement-while-drilling (MWD) tool, which is programmed to periodically pulse up a pressure measurement with logging and directional data. Both the real-time and recorded data are typically merged with other surface and subsurface measurements and presented with time- or depth-based logs.

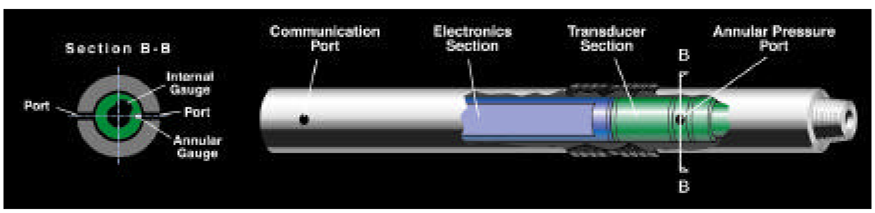

Figure 3. Tool schematics

2. Pressure Evaluation

With the mud pumps off and the drillstring stationary, the borehole annulus is at the hydrostatic pressure of the mud column, a function of the temperature and density gradients of the fluid in the annulus. This hydrostatic pressure measurement is typically converted to an equivalent mud weight and referred to as the equivalent static density (ESD).

When circulating the drillstring, the annular pressure consists of the mud column's hydrostatic pressure and a dynamic component resulting from frictional pressure losses as the fluid moves up the annulus (Equation 1). Drillstring movement also dynamically impacts the annulus pressure because of surge and swab effects. ECD is the expression of the hydrodynamic annulus pressure in common oilfield density units. Equation 2 presents the ECD evaluation.

$$P_{annular} = P_{surf} + P_{hydrostatic} + \Delta P_{friction} \qquad (1)$$

$$(ECD)_i = \frac{(P_{dynamics})_i}{g h_i} = \frac{(P_{hydrostatic})_i + (P_{annular})_i}{g h_i} \qquad (2)$$

In this scenario, the global comprehension of the phenomena governing bottomhole pressure is a must for the high cost ultra deepwater operations. Among other topics, the presence of solids in the annulus plays a major role in bottomhole pressure prediction by two different mechanisms:

- Solids traveling in the annulus transmit hydrostatic pressure which directly impact bottomhole pressure. This effect increases with water depths due to the natural solids loading at the low velocity annular flows through the riser. A common approach for predicting the impact of solids loading is to consider an average density of the fluid cuttings mixture (r_m), as follows:

$$r_m = r_f(1 - C_s) + r_s C_s \tag{3}$$

where C_s is the solids concentration (% v/v) and r_f and r_s are the fluid and cuttings density, respectively. Figure 4 illustrates the pressure increase caused by the presence of cuttings on a 10 ppg mud density for a complete range of water depths. Figure 5 shows the effect of cuttings loading on ECD at a typical deepwater well.

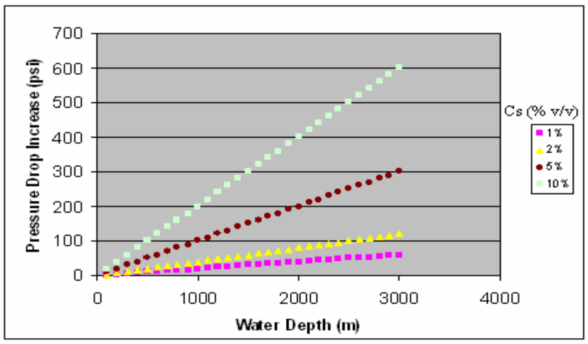

Figure 4. Impact of cuttings concentration at several water depths

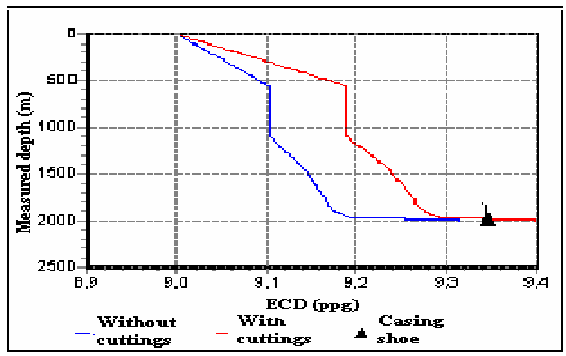

Figure 5. Influence of the presence of solids on ECD in a typical deepwater well

- Solids forming a cuttings bed in a highly inclined section may not transmit hydrostatics but will restrict flow area, besides accumulate near annulus restrictions, resulting in pressure peaks as highlighted in a typical field case illustrated in figure 6.

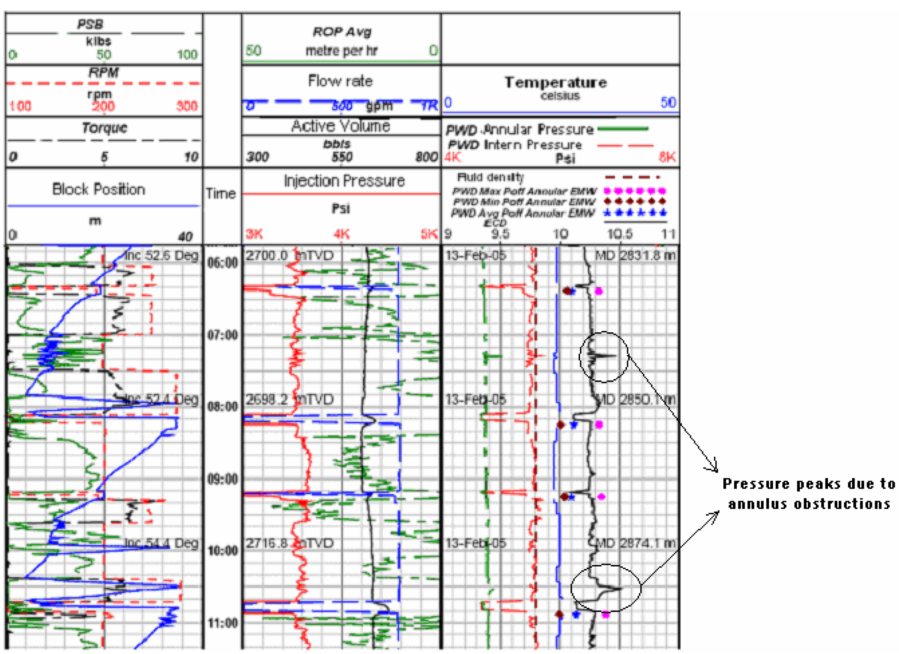

Figure 6. Pressure peaks due to annulus temporary obstruction

3. Operational Parameters and Sensibility Analysis

Several operational parameters affect solids concentration in deepwater wells, such as:

- Rate of Penetration (ROP)

ROP dramatically impacts solids concentration in different manners: in the high angle sections, there is a tendency of cuttings bed formation while at lower angles, cuttings loading will increase. In general, the increase in ROP will result at an increase of ECD in deepwater wells. Special care should be taken to keep solids concentration inside acceptable ranges and ECD inside the operational window. Figures 7 and 8 illustrate the impact of ROP in solids concentration in the inclined section and in the riser, respectively. Results are based on the solution of a mechanistic two layer model described by Santana et al, 1998. Certainly different models could capture such tendencies at different manners. A field evidence is illustrated in figure 9.

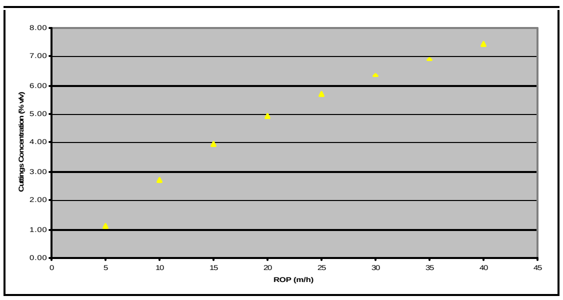

Figure 7. Effect of ROP in cuttings concentration in a deviated well

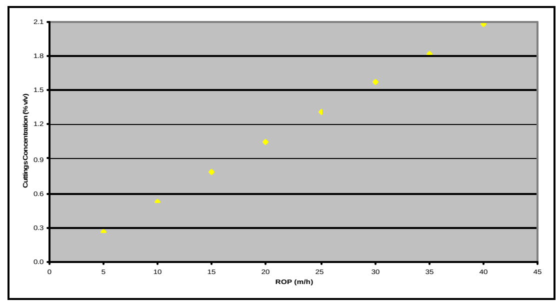

Figure 8. Effect of ROP in cuttings concentration in the riser

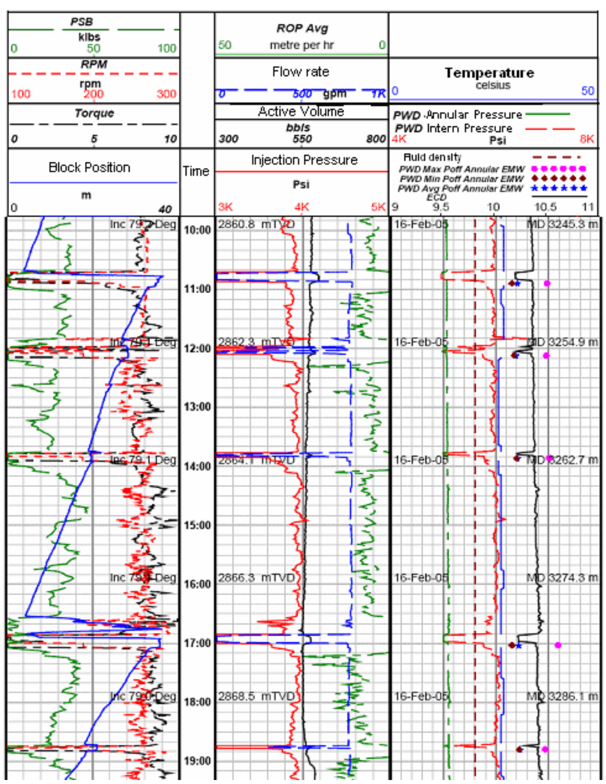

Figure 9. Field example of high ROP increasing the ECD

- Well depth:

The increase in the well measured depth directly affects the frictional terms and consequently increases ECD. This factor may be not relevant for clean large diameter holes where annular friction losses are negligible. For smaller diameter phases (9 ½", 8 ½" and smaller) friction losses start to play an important role on total bottomhole pressures. Figure 10 (Martins et al., 2004) represents a discussion on the hydraulic limits for long horizontal section wells in deepwater environments. The Configuration #1 is constituted by an 8 ½" open hole 6 $^{5}/_{8}$" drillpipe. Such wells may constitute economical drives for the exploitation of offshore heavy oil fields (Vicente et al, 2003).

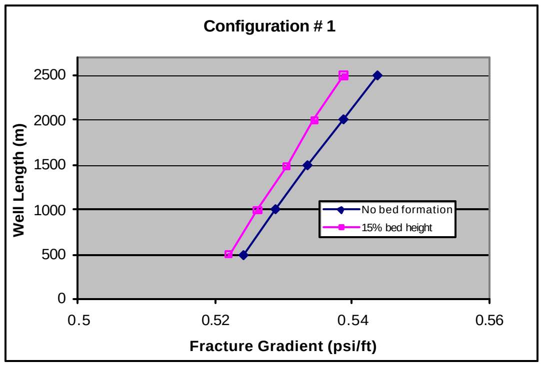

Figure 10. Impact of the well length in fracture gradient

- Pipe rotation:

Low or zero pipe rotations stimulate bed formation and, consequently, a hole cleaning problem may not be reflected by ECD measurements. On the other hand, high pipe rotations enhance solids re-suspension which immediately affects ECD. Figure 11 shows typical PWD responses to pipe rotation and the discussed aspects. Figure 12 shows the impact of rotation on solids concentration based on the empirical model proposed by Sanchez et al, 1999.

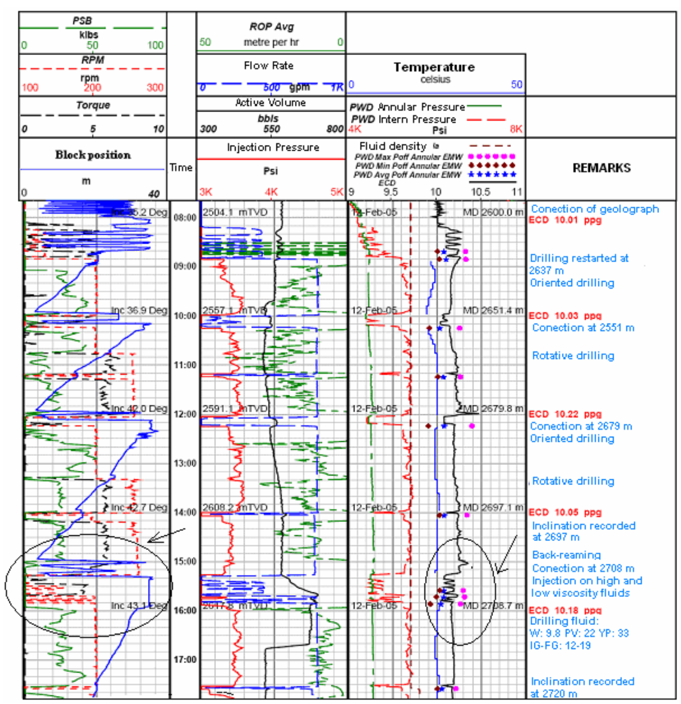

Figure 11. Effect of pipe rotation in ECD

- Flow rate

Increase in flow rate will immediately enhance hole cleaning and, consequently, reduce solids concentration. Friction losses are, on the other hand, directly proportional to flow rate. ECD may increase or decrease depending on the importance of both aspects. Figure 13 shows a curve where a minimum of ECD is observed for a given flow rate. Whether this minimum will occur or not inside the operational range will depend on each specific well design. Figure 14 illustrate the case that increasing the flow rate cause a increasing in ECD.

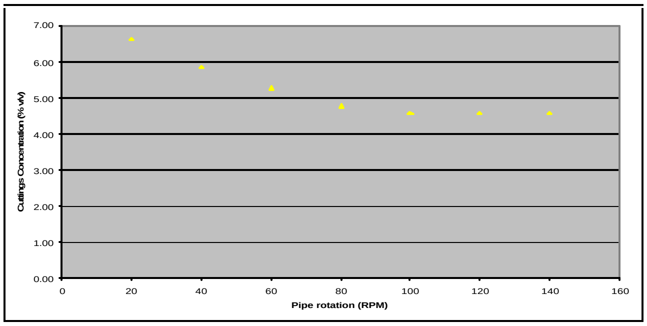

Figure 12. Impact of pipe rotation on cuttings concentration

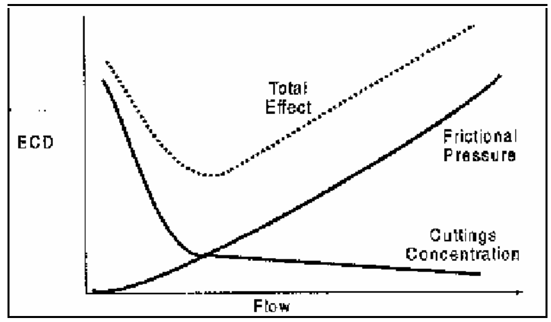

Figure 13. Impact of the flow rate in ECD regarding hole cleaning and pressure drop effects

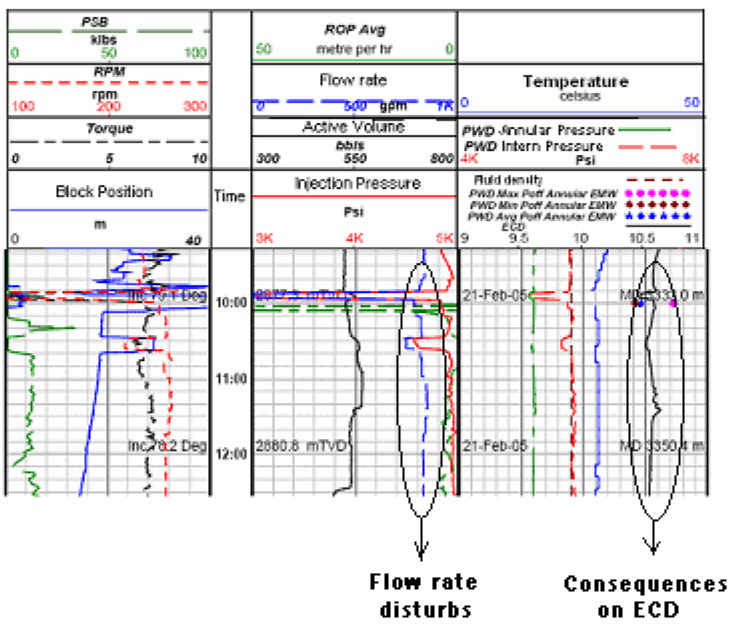

Figure 14. Field evidence of flow rate impact on ECD

- Rheology

The role of rheology on downhole pressure is complex and affects several events including hole cleaning, friction losses and pressure peaks after circulation stops. In dynamic conditions, highly pseudoplastic behavior is desired: high viscosities at low shear rates prevents cuttings sedimentation while low viscosities at high shear rates enhances cuttings bed re-suspension and minimizes friction losses. Figures 15 and 16 illustrate the effects of fluid rheology on cuttings concentration and ECDs for a typical deepwater well.

Fann V35A readings decrease from fluid A to fluid C. In static conditions, gelification plays important roles in deepwater environments: the positive aspects include solids suspension in the well and in the riser annuli and the negative aspects include the generation of pressure peaks after circulation stops as highlighted in Figure 17.

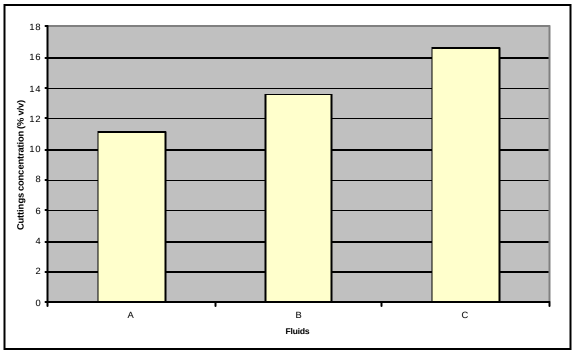

Figure 15. Effect of fluid rheology on cuttings concentration

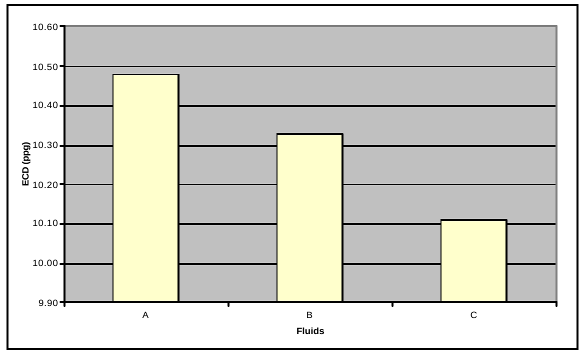

Figure 16. Effect of fluid rheology on ECD

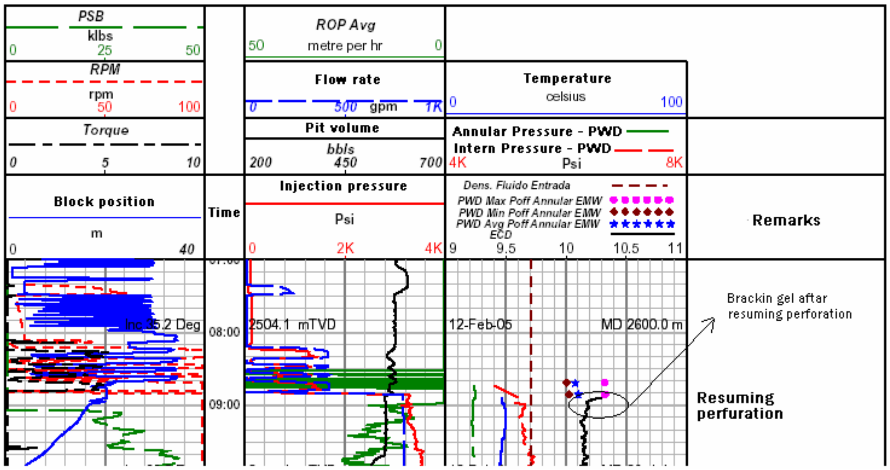

Figure 17. Effect of gel formation in ECD

Evaluating rheological properties, which represent the fluid behavior in deepwater wells, is a critical topic. Dynamic viscosities obtained by oilfield rheometers represent properly the friction loss processes but fail to capture sedimentation phenomena. Low shear rate viscosity measurements are available for lab use but the reliability of their results is not achieved in floating vessels. Table 1 highlights the difference in evaluating yield stresses using the conventional field device and lab low shear rheometers for two typical fluids used in deepwater applications (Monteiro et al., 2005). Although gelification tendencies can be estimated in oilfield rheometers, important additional information can be gathered with different rheological experiments including the small amplitude oscillatory tests (Figure 18) and the creep-recovery experiments (Figure 19), among others. In all cases evaluating properties at the low seafloor temperatures is a must.

Table 1. Yield stresses values evaluated by different equipments

Rheological model	Fluids	Oilfield viscometer	Low shear rate rheometer
Bingham	Synthetic based fluid	8.41 Pa	8.523 Pa
	Polymeric based fluid	9.40 Pa	4.300 Pa
Herschel-Bulkley	Synthetic based fluid	5.99 Pa	7.669 Pa
	Polymeric based fluid	6.13 Pa	2.961 Pa

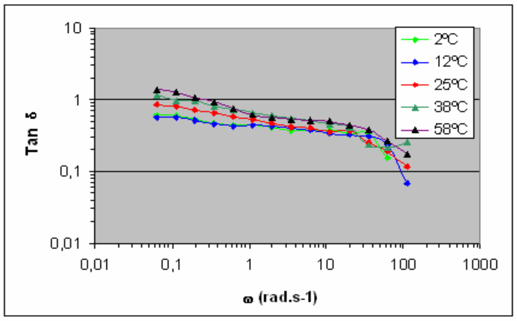

Figure 18. Small amplitude oscillatory tests

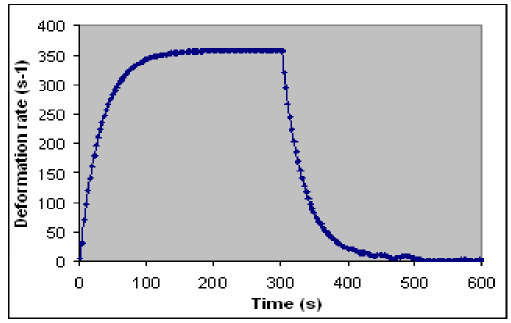

Figure 19. Creep recovery test

4. Final Remarks

- The present article represents an initial effort in understanding the phenomena which govern downhole pressures in the presence of drilled cuttings;
- The sensibility analysis consider the isolated effects of each operational parameter provide relevant support for well design;
- Real time pressure interpretation however should consider the synergistic effects of the several parameters;
- Modeling the transient phenomena affect the whole process is a necessary step to quantify the effect of each operational parameter;
- Besides hole cleaning, several other drilling problems can be detected by PWD analysis such as wellbore stability, fluid gelification, kick detection, breathing/ ballooning, hydrates and etc.
- In order to accomplish the ultimate goal of building a PWD analysis and interpretation tool, a R&D project was started with participation of several Brazilian institutions involved in the area of thermal sciences.

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