DEVELOPMENT OF A COMPUTATIONAL TOOL TO AVOID AND REMEDIATE DRILLING PROBLEMS BY REAL TIME PWD DATA INTERPRETATION

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Abstract. *Drilling offshore oilwells is a very expensive and complex job, in which all the efforts must be spent to keep the annular pressure between a minimum pressure (pore pressure) and a maximum pressure (frac pressure) – the operational window limits. Several factors impact the bottom hole annular pressures, such as: deficient hole cleaning, gel breaking when circulation is resumed, drillstring movement (surge and swab), trips, pill displacement, undesired formation fluids influxes, etc. The correct interpretation of PWD (Pressure While Drilling) data is a very powerful tool to identify and prevent these phenomena. The main goal of this project is the development of a computational tool to monitor pressure (and mudlogging) data in real time to identify the causes of abnormal pressures variations, helping the operators to take decisions rapidly. Beside that, the tool allows the user to handle PWD data in a flexible architecture. This flexibility allows the incorporation of new methods of event identification as they are developed. The main proposal of the development of the software is to provide a tool to help the operators to take important decisions rapidly, optimizing drilling job (reducing time and operational costs) as well to get a better comprehension of the transient physical phenomena impacting bottom hole pressures.*

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

1. INTRODUCTION

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 (Aragão *et al* and Teixeira *et al*). The complete understanding of the physical phenomena governing downhole pressure is, however, far from being spread among the drilling teams at the rigsite. Figure 1 shows a typical PWD log. PETROBRAS is developing a computational tool to interpret PWD and mudlogging real time data while drilling. The tool (called PWDa - Pressure While Drilling Analyzer) should identify undesirable phenomena such as deficient hole cleaning, gel breaking when circulation is resumed, drillstring movement (surge and swab), pills (small volumes of more viscous or less viscous fluids) displacement, undesirable formation fluids influxes (kicks), etc and alerts the operators. Nowadays, an expert monitors the operational parameters (bottomhole pressure and other surface sensors data) and tries to identify and/or anticipate problems. Thus, the identification of potential problems is a very subjective process and can vary depending on the expert interpretation. The proposal of this work is to provide a tool to help the operators to take important decisions rapidly in an objective way, optimizing drilling job (reducing time and operational costs).

The tool should receive real time PWD (ECD, ESD, internal column pressure and temperature) and mudlogging (pump pressure, rate of penetration, flow rate, drillstring rotation, torque, drag, bit and hole depth, etc) data during drilling job and predict ECD (equivalent circulation density), pump pressure and solids concentration (Gerhard *et al*). PWD data and real pump pressure are compared to the predict parameters. Differences between real and predicted ECD curves (along the time) as well between real and predicted pump pressure curves indicate some unexpected phenomenon is happening. The different tendencies of real and predicted curves are interpreted to identify potential problems. Once a problem is identified, the software proposes preventive and/or corrective actions to be taken.

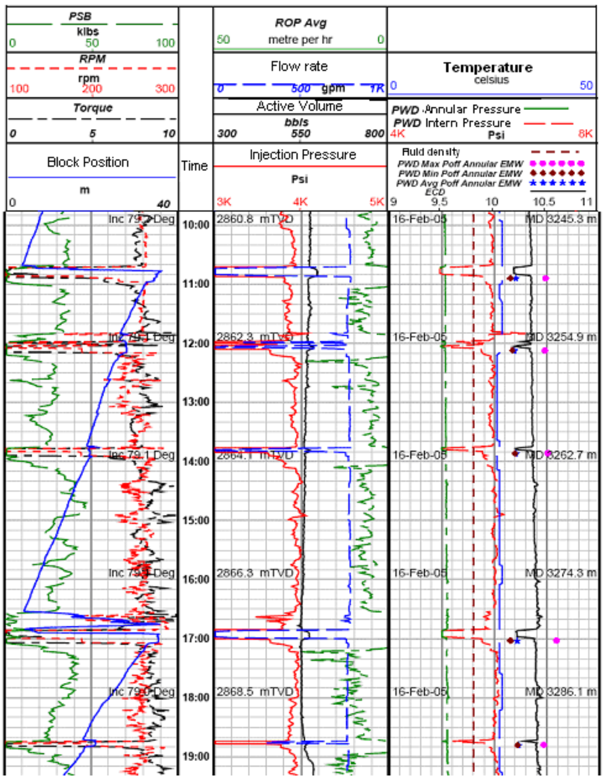

Figure 1. Example of a typical PWD log.

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2. BOTTOMHOLE PRESSURE PREDICTION

The global comprehension of the phenomena governing bottomhole pressure is a must for a correct PWD data interpretation. Bottomhole annular pressure (P_{BH}) is a sum of hydrostatic pressure (P_H) and friction loss in the annular space (ΔP_a) as described in equation 1. Note that friction loss inside drillstring and bit contribute to increase pump pressure, but not annular pressures.

$$P_{BH} = P_h + \Delta P_a \tag{1}$$

Among other topics, the presence of solids in the annulus plays a major role in bottomhole pressure prediction by two different mechanisms:

1) Solids traveling in vertical portions of the annulus transmit hydrostatic pressure which directly impact bottomhole pressure. This effect increases with water depths due to the drilled solids loading at the low velocity annular flows through the riser (that has a bigger external diameter). A common approach for predicting the impact of solids loading is to consider an average density of the fluid cuttings mixture (ρ_m), as follows:

$$\rho_m = \rho_i (1 - C_s) + \rho_s C_s \tag{4}$$

where C_s is the solids concentration (% v/v) and ρ_l and ρ_s are the fluid and cuttings density. The mixture density will impact both the hydrostatic and the friction loss terms (especially in turbulent flows regime).

2) Solids forming a cuttings bed in a highly inclined section may not transmit hydrostatics but will restrict flow area, increasing friction loss.

Annular bottomhole pressure is usually expressed as an Equivalent Circulating Density (ECD), i.e. the density of a fluid, which in static conditions (no circulating – no friction loss), would generate a hydrostatic pressure equal to the dynamic pressure (hydrostatic + friction loss).

$$ECD = \rho_{mix} + \frac{\Delta P_{annular}}{gh} \tag{5}$$

ECD should be higher than fluid density due to solids presence effect and friction loss.

3. METHODOLOGY FOR PWD DATA ANALYSIS

The software receives surface and sub-surface sensors information and interprets the data acquired. Among the several operational parameters available the most important are:

- Bottom-hole annular pressure
- Bottom-hole annular temperature
- Pump pressure
- Flow rate
- Drillstring rotation
- Rate of Penetration (ROP)
- Torque
- Drag
- Hole depth
- Bit depth

Based on ROP, flow rate and other parameters, the program estimates the solids concentration profile, dynamic pressure profile and pump pressure. The predicted ECD (Equivalent Circulation Density) is obtained from the predicted annular bottom-hole pressure. The software constructs pump pressure, ECD and average solids concentration curves along the time and the predicted curves are compared with the real ones. Different behaviors between the curves can indicate the occurrence of a non expected phenomenon and the program tries to identify it, warning the operators and suggesting corrective or preventives actions.

An example of unexpected behavior is when the real pump pressure and ECD curves present a tendency to increase while the predict pump pressure and ECD are constant. There are many possible causes for this behavior such as inefficient solids removal, annular obstruction, drilling fluid degradation, etc, but each one has its specific symptoms. For example, if the wellbore walls collapse, besides the increment of pump pressure and ECD, there may be an increment in torque and drag values. On the other hand, a gas influx may cause a reduction in ECD and an increment in bottomhole temperature. The software tries to identify one unique cause among the several possible by analyzing the other operational parameters (torque, drag, temperature, etc) that may have a different behavior depending on the specific symptom of the phenomenon happening. Sometimes, however, it is not possible to distinguish one unique cause for an abnormal behavior. When it happens, the program presents a list of possible causes and, for each one listed, possible preventive and/or corrective attitudes to be taken.

Several routines to predict hole-cleaning and pressure curves and to interpret differences between predicted and measured parameters were developed. Some of the routines developed are:

- Electronic Tools Internal Friction Loss Calibration: There are several electronic tools in drillstring composition, such as PWD, LWD (Logging While Drilling), directional tools (that help to keep the well in the desirable direction), etc. These tools are placed usually above the bit and do not have a defined internal diameter. On the other hand, most of the drillstring internal friction loss occurs inside these tools. So, the correct estimation of electronic tools internal friction loss is a very important step to calculate the predicted pump pressure. This routine helps to estimate the internal friction losses in equipments and tools based on flow rate test data (automatically acquired). These tests consist in pumping the fluid with different flow rates and to acquire the real pump pressure.

- Annular and drillstring friction losses calibration: Before the bit starts drilling (when there are still no solids in the annular space) the predicted friction losses in the drillstring and in the annulus are adjusted to the measured friction losses. The calibration guarantees that future differences between predicted and measured curves are due to non expected occurrences and not due to model uncertainty.

- Solids concentration and pressure profiles: drilled cuttings removal conditions are simulated, generating a cuttings concentration and a dynamic pressure (hydrostatic + friction losses) profile. From this routine, important predicted parameters are generated such as bottom hole ECD, pump pressure and average solids concentration. These predicted parameters are compared with the real ones.

- Fluid displacement: During the drilling job, different fluids can be pumped into the well at the same time. If the hole cleaning conditions are not adequate in a vertical well, for example, a viscous fluid should be displaced to enhance solids removal. If the well is inclined or horizontal, a thin fluid should be displaced (to increase turbulence and resuspend solids) followed of a viscous fluid (to carry the solids). This routine allows the program to account the impact of viscous and fine pills displacement on friction loss and solids concentration profile.

- Surge & Swab pressures: Drillstring movement can cause bottom-hole pressure variations. When the drillstring is tripped out, the pressure tends to decrease (swab effect). When drillstring is tripped in, annular bottom-hole pressure tends to increase (surge effect). During the drilling job, the drillstring is pulled in and out several times (for simple connections, bit exchange operations, electronic tools problems, etc). If it is moved with no care, bottom-hole pressure variations can reach frac or pore pressure (Kimura *et al*). This routine predicts the increment or reduction of the pressure due to drilltring movement.

- Gel breaking: One of the main functions of drilling fluids is to transport solids generated by the bit to the surface. The gelation phenomenon is a very important characteristic of drilling fluids, once it helps to keep drilled solids in suspension during pumps-off times. However, when the circulation is resumed, an extra energy must be dispended to break the gel structure formed and pressure peaks are observed (Gandelman *et al*). Important parameters governing gelation are temperature, pumps off time and start up flow rate. This routine calculates the pressure increment due to gel breaking when circulation is resumed after a static period (for a connection, for example).

Besides the described topics, a modulus for identifying non expected phenomena and predict potential problems was developed. When the behaviors of a predicted curve and its correspondent real measurement are different, the interpretation modulus is activated and tries to determine the cause of the problem. The program warns the user that a problem may be happening and suggests corrective and/or preventive actions to be taken.

Figure 2 is an example of how the program identifies the behavior of an acquired or calculated (predicted) curve. The figure shows how PWDa identifies the tendency (increasing, decreasing or constant) of the real bit depth curve (red line). A new curve is created (the green one) to describe the behavior of the curve analyzed. When the curve assumes the value 1, it means the curve analyzed is increasing. The value -1 means the curve is decreasing. The value 0 means the curve is constant.

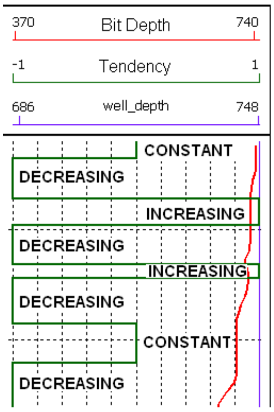

Figure 2. Behavior analysis of a real curve.

4. THE SOFTWARE

PWDa software allows the user to operate it in two different modulli. The first modulus acquires real time data and interprets them while drilling. In the second modulus, the program is fed with parameters of a drilled well and makes a retro-analysis of the data. Figure 3 shows a schematics of the communication between the program and the data source. From a hydraulic and hole-cleaning simulator PWDa acquires important information such as the drillstring composition, well geometry, casing shoes depths, riser depth, drilling fluid parameters, etc. From the service companies, the software acquires real time operational parameters (real time or retro-analysis).

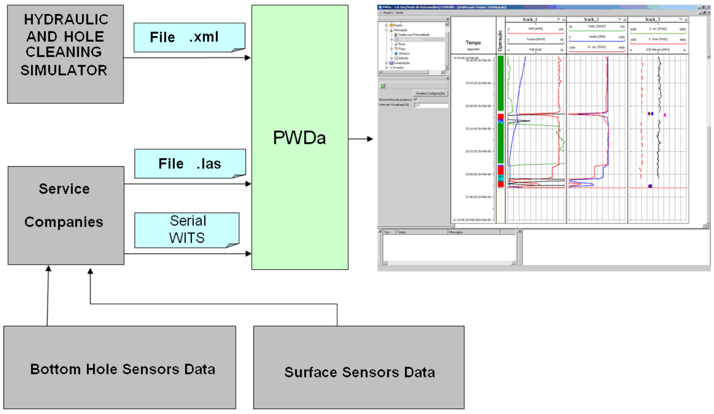

Figure 3. PWDa data acquisition schema.

PWDa present version (for vertical wells) is able to identify several operational problems, such as deficient hole cleaning, annular obstruction, bit jets obstruction, undesirable influxes and others. Figure 4 shows a screen of the software receiving and interpreting real time data of a real well.

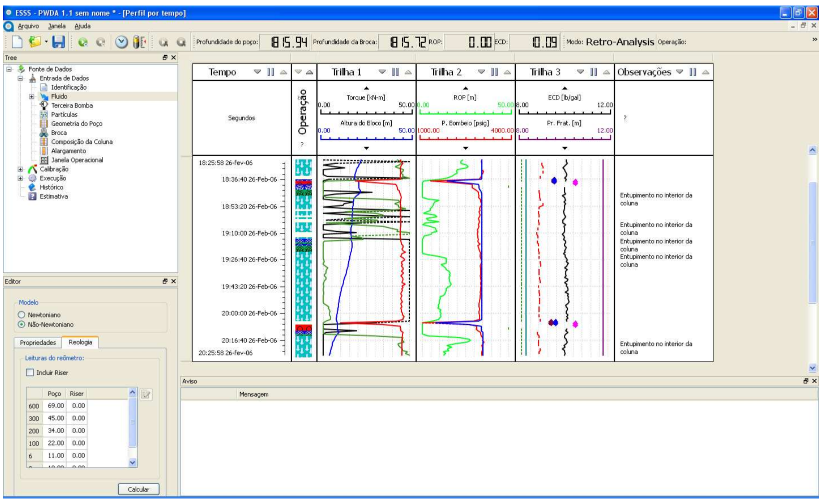

Figure 4. PWDa output screen.

5. VALIDATION OF CALCULATION AND INTERPRETATION PROCEDURES

Some tests to validate the calculus and the interpretation modulus procedures were performed with adequate results. The tests involved real time data acquisition from a real drilling job, real time acquisition of simulated data and retro-analysis.

5.1. Tests with Simulated Input Data

With simulated input data (ECD, flow rate, pump pressure, drillstring rotation and other operational parameters) it was possible to evaluate the response of the calculated parameters when the drilling conditions job vary. For example, the simulated rate of penetration was increased from 5 m/h to 30 m/h, causing an immediate response in solids concentration and bottom-hole pressure. The solids concentration near the bit immediately started to increase while the bottom-hole pressure increased slowly as the bigger amount of solids reached higher portions of the annulus, increasing hydrostatic pressure. Figure 5 shows the solids concentration curve (red line) near the bit. Note that the lower portion of the annulus (just above the bit) has the larger solids concentration since the figure shows the situation just a few instants after the ROP was increased. As the time passes (if ROP remains constant), the solids concentration tend to be increased in the whole well.

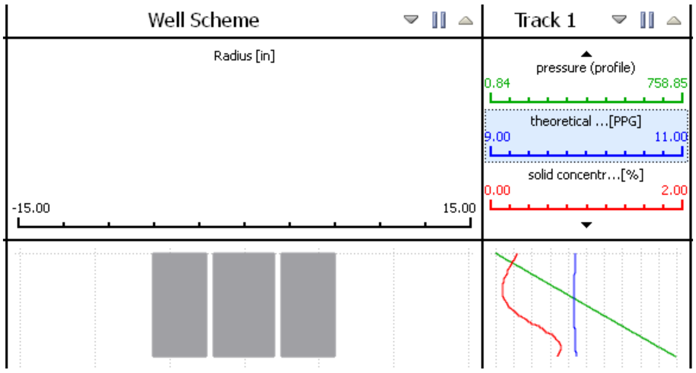

Figure 5. Increment of solids concentration due to a higher rate of penetration.

Figure 6 shows a small increase of ECD (red line in the third track) after rate of penetration (green line in the second track) is increased.

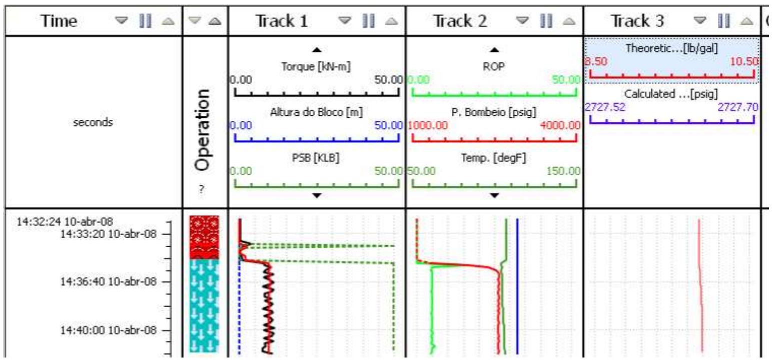

Figure 6. Small increment of ECD due to a higher rate of penetration.

Figures 5 and 6 above also illustrate the intrinsic transient character of the software.

5.2. Comparison with Simulation Results

Besides, the response of the software was compared with the PETROBRAS hydraulic and hole cleaning simulator results (SIMCARR). The two software concepts are very different what makes the comparison difficult. While SIMCARR is a steady state simulator, PWDa is a transient software. However, if PWDa is tested in a controlled environment in which the input parameters are handled, it is possible to keep them constant for a long period of time, until the response (predicted ECD, pump pressure, solids concentrations, etc) reaches a steady state condition. The steady state response of PWDa should be similar to SIMCARR response. It does happen. Table 1 shows the comparison between SIMCARR and PWDa results (bottom hole ECD, last casing shoe depth ECD, solids concentration at the last casing shoe depth, solids concentration in the riser and pump pressure). The simulation was run for a vertical well with the following operational parameters:

- Final depth: 3750m
- Riser (ID = 19 ½ in) until 1200 m, casing shoe (ID = 8.681 in) at 1325 m and open hole (diameter 8 ½ pol) until final depth.
- Flow rate: 500 GPM
- ROP: 10 m/h
- Cuttings – equivalent diameter: 0,1 in ; density: 21 lb/gal
- Drillstring composition: drillpipes only (OD = 5 in; ID = 4.276 in)
- Bit jets: 5 jets with a 14 in/32 diameter
- No drillstring rotation
- Drilling fluid - density: 10 lb/gal; Rheology: L600 = 60, L300 = 50, L200 = 37, L100 = 28, L6 = 11, L3 = 10.

Table 1. Comparison between SIMCARR and PWDa responses.

Parameter	SIMCARR	PWDa
Last casing shoe depth ECD (lb/gal)	10,50	10,52
Bottom hole ECD (lb/gal)	10,54	10,56
Solids concentration at Last casing shoe depth (%)	0,36	0,40
Solids concentration in the riser (%)	0,24	0,27
Pump pressure (PSI)	3104	3183

The responses of the two softwares were very similar. Some difference may occur because the models each program uses are conceptually different. The differences observed, however, are very small and acceptable.

5.3. Tests with Real Time Data Acquisition

Some tests were carried out at rigsites in which the software received real time data for a long period. A continuous debugging and software improving process was carried on. After this period, the predicted values were very close to the real ones, showing the program is able to predict them properly. Figure 7 is a screen shot of PWDa during the last test. Note the real ECD (black curve in track 3) and predicted ECD (red curve in the track 3) are almost overlapped. The peaks observed in real ECD curve are due to problems in the rigsite and sensors communication.

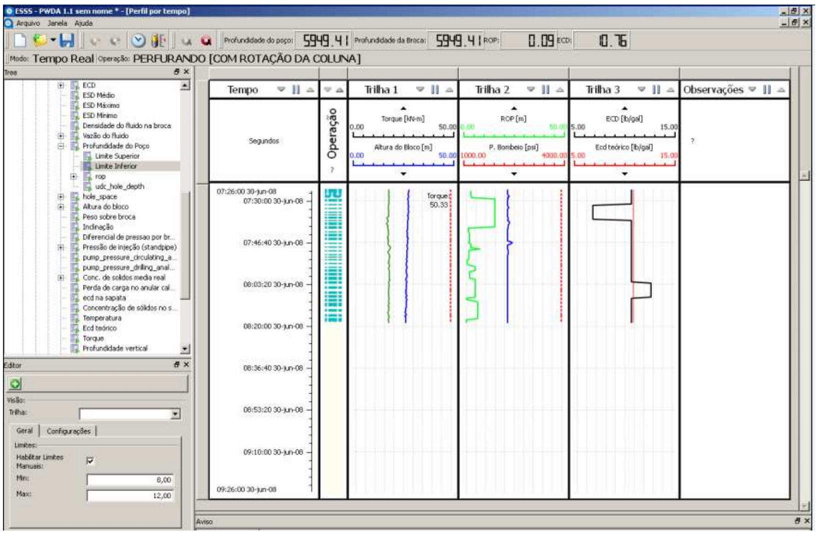

Figure 7. Real and predict ECD curves overlapped.

6. FUTURE IMPLEMENTATION

Besides new testing with the present version, the second version of the software (for inclined and horizontal wells) is being developed and should be available for tests around the beginning of 2010.

A new modulus to interpret torque and drag data is also in development and may be integrated to the vertical wells version. The interpretation of torque and drag data is a plus that will bring a great benefit to the interpretation modulus.

7. FINAL REMARKS

A first version (for vertical wells) of a computational tool to interpret PWD and mudlogging data was developed, tested and is now available. The first tests were well succeeded, but more tests are required to guarantee the program is able to identify several different problems with an acceptable precision.

The next steps are the development of a version for inclined and horizontal wells as well the incorporation of torque and drag parameter analysis rules, rheological corrections due to temperature effects and oil based muds thermal expansion prediction.

A big effort is being done to develop new interpretation rules and integrate them to the software. This will increase the reliability of the interpretations and the software capability to identify a bigger amount of events.

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9. RESPONSIBILITY NOTICE

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