

Results obtained with PWDa - a real-time drilling operational parameters analyzer

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Abstract

The anticipation of problems while drilling wells is the main goal of real-time drilling monitoring tools. The oil industry has been spending resources in sensors and in data transmission tools, but the knowledge to understand and interpret these data is not well diffused.

Petrobras has developed a computational tool called PWDa, which automatically interpret the PWD (Pressure While Drilling – sensor that provides real-time bottom hole pressure measures during the drilling process) and Mudlogging real-time data, calculating and comparing operational parameters (such as bottom hole pressure, standpipe pressure, torque, drag) and providing quantitative measures of unexpected behavior (e.g. an unexpected increase in the bottom hole or in the standpipe pressure). With this kind of analysis, this tool is able to identify and anticipate operational problems, suggesting corrective measures to be taken. This work shows the results and the difficulties found during the field tests of this application in the Real Time Operations Centers of Petrobras.

Introduction

The analysis of PWD together with other operational parameters (e.g. flow rate, rate of penetration, standpipe pressure, torque, drag) is of great value in the anticipation of several problems which are usually experienced while drilling oil wells (Aragao et al.). This analysis can help preventing several problems and optimizing the drilling operation, helping in the decision taking process and reducing time and costs spent on it.

The analysis and control of the bottom hole pressure aims to maintain it in an operational window, defined by a minimum value (normally the pore pressure) and a maximum value (normally the fracture pressure). If the pressure somehow gets out this range of values, the whole operation may be harmed, which, in an extreme case, can make the drilling unrealizable.

According to Teixeira et al (2005)., the majority of the events and operational problems has an impact on the bottom hole pressure. As an example of events of interest, one can enumerate inefficient hole cleaning, obstructions in the annular, hole collapse, kicks, washouts and mud losses, to name just a few. The analysis of other operational parameters (e.g. weight on bit, torque, drag, rate of penetration) is of

valuable help, since any problem in the drilling operation should affect also them.

For instance, in a gas kick situation on a vertical well, the ECD value would decrease, and probably an increase in the bottom hole temperature and decrease in the standpipe pressure would be seen. A washout (a hole or rupture in the drillstring) would cause the standpipe pressure to decrease. Apart from this, the single variation of some operational parameters would also induce changes in the ECD value. For instance, an increase in the rate of penetration would cause more cuttings to be released and hence an increase in the ECD. On the other hand, an increase in the flow rate can cause an increase or decrease in the bottom hole pressure, depending on the situation (since increasing the flow rate increases the annular friction losses, but at the same time makes the annular cleaning more efficient).

Usually the analysis of these data is done by a drilling data parameters specialist. However, the analysis done by the human specialist lacks of objectivity and can vary from person to person. Since the use of PWD sensors is constantly increasing, a computational tool is being developed by Petrobras, in a partnership with Engineering Simulation and Scientific Software LTDA – ESSS, to receive, treat and interpret these real-time data and, as the specialist, present conclusions, identify problems and warns the drilling operators.

One of the main objectives of PWDa is to define quantitative criteria for this analysis, reducing the subjectivity of it. Besides, the tool has the objective of monitoring the whole drilling process, supporting the decision taking process while drilling and to serve as an extra source for the study and development of new models and methods to help in the detection of events.

Real-Time Data Acquisition

The PWDa application needs to receive high quality real-time data for the analysis. PWDa acquires real time data through 2 different ways:

1. Wits Protocol: using the Wits protocol, one can use a serial cable to connect the computer directly on the server of the service company. Using this connection method,

one cannot connect remotely, that is, this method is available only when using the software on the rig.

2. WitsML Protocol: using the WitsML protocol, one can get real time drilling data by connecting remotely to the service company through the web, using an URL which provides a stream of XML type files containing the data.

However, although PWDa is perfectly prepared for all these ways of acquiring data, many problems are still found in this task. With the Wits and WitsML protocols, there are problems concerning 24x7 support, infrastructure and quality of the data sent. Configuring the Wits protocol in the rig can be a very hard task. First of all, one has to discover a numeric code for each variable to receive. This code is sometimes not known even by the service company operator in the rig. When using the WitsML protocol, one can find some problems concerning the quality and availability of the data. Firstly, the data is not always available in a reasonable frequency (which would be like 3-5 seconds for mudlogging data and 1 minute for PWD data). This can be due to the limited bandwidth, or even due to contractual reasons. Also, concerning infrastructure problems, the WitsML servers sometimes go down, interrupting the receiving of the data.

Hence, the real time drilling data acquisition is still the main challenge when using an application like PWDa. In this sense, efforts are being made to minimize all the problems concerning this subject and to assure the necessary data quality and frequency to provide good diagnostics results.

Methodology

A brief description of the methodology used in the application is given in this section. For the identification of abnormal behavior of the operational parameters while drilling, the application compares theoretical values of ECD (Equivalent Circulation Density), ESD (Equivalent Static Density), torque, drag and standpipe pressure with the real values of these parameters acquired by the PWD and surface sensors. Divergent behavior between the theoretical and measured values indicates that an abnormal situation may be happening.

The transient models used to forecast ECD, ESD, standpipe pressure and all the other operational parameters were all developed at Petrobras Research Center. There are other commercial applications available which forecast these parameters through stationary models. This approach is not considered adequate since it doesn't take account for the history of the whole operation, that may affect the current values of the parameters. The drilling job is an intrinsic transient process, which never reach a steady-state. Therefore, an application which forecast these parameters, must necessarily use transient models.

The steps for the identification of an operational problem are:

1. Using the mudlogging parameters (such as ROP, flow rate, drillstring rotation, torque, drag, well depth, bit depth, etc.), the application calculates the transient

cuttings profile along the depth of the well, considering past values of this profile.

2. Considering the profile of cuttings concentration, the application calculates a pressure profile (inside of the drillstring and in the annular space) along the well.
3. Besides the pressure profile, the application calculate also the expected torque and drag, as well as the expected change in pressure due to surge and swab effects (maximum and minimum values in situation of pumps turned off for comparison with the received maximum ESD and minimum ESD) and maximum pressure values during the reestablishment of the circulation (gel breaking).

Using the calculation specified above, the expected ECD, average ESD and standpipe pressure are calculated. These values are compared with the measured values. Significant differences between the values or their moving averages may indicate events which were not taken into account in the modeling (potential problems). Once the program identifies different tendencies between the measured and expected curves, the identification rules module is called for the identification of possible problems. In the case that this module detects abnormal situation, PWDa emits an alarm and suggests corrective or preventive measures.

Several interpretation rules were developed and implemented, based on the discrepancies between the measured and predicted curves. This allows the application to analyze the curves as the human specialist does, but using quantitative criteria and without subjectivity effects.

Results

The hydraulic calculations of PWDa were already validated through hundreds of tests in Petrobras wells. The ECD, standpipe pressure and solids concentration profile have shown to be reliable and their calculation are fast enough to be execute on a real-time basis. Ultimately, several tests have been carried for the validation of the events identification module described in this work. In general, the results were very satisfactory, and some successful cases of identifications are shown in this section.

Figure 1 shows a screenshot of PWDa during the real-time data monitoring of a vertical well. The trails numbered 1 to 3 show the comparison between the received and calculated data. In the trail named "observations" the interpretation of the events can be observed.

Tests have been carried with three wells, named here as Well A, Well B and Well C, where the calculated pressure values, as well as the interpretations were evaluated. These tests were carried during one or more runs of these exploratory wells. During these tests, PWDa has worked during several days, receiving drilling data, calculating, forecasting operational parameters and interpreting abnormal behavior without major problems.

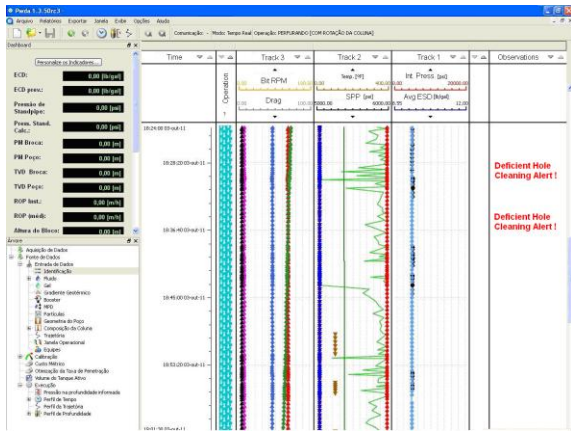


Figure 1 – PWDa’s Graphical User Interface.

The calculation done by the tool during the tests with the 12 ¼” section of Well A was evaluated and it was verified that the application provided fairly good results. Also, correct diagnostics were made by the application. In October the 3rd, at 1:15 PM, PWDa detected a mud loss, as shown by Figure 2. It is possible to note a decrease of approximately 70 barrels in a short interval of time (Red curve, Trail 3). This is a relevant decrease, which triggered the event of mud loss. The mudloggers responsible for the monitoring of this well confirmed that an equalization of the mud tanks. Therefore, although no real mud loss to the formation happened, according to the data PWDa received, this can be considered a correct diagnostic.

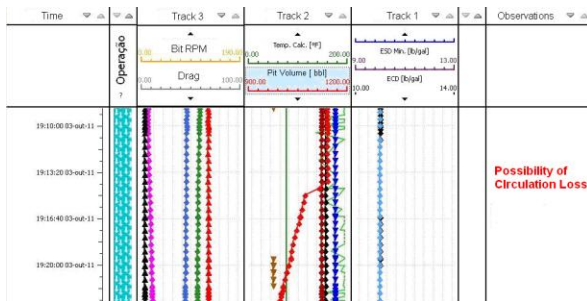


Figure 2 – First mud loss detection – Well A.

Several consecutive mud loss events were detected still in this run of this well. On October the 5th, a constant and severe decrease in the pit volume could be seen since 08:20 AM, as shown in Figure 3, which show also the identifications made by PWDa. Although not officially confirmed by the mudloggers, some arguments show that this mud loss to the formation really happened.

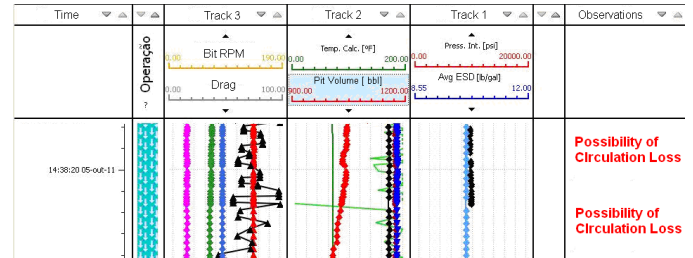


Figure 3 – Second mud loss detection – Well A.

Firstly, there was no tank equalization during this period. Also, it was estimated that the pit volume would decrease approximately 7,8 barrels from 7:30 AM to 8:30 AM due to the increase in the open well because of the drilling. However, a 28 barrels decrease was observed in this period.

Another indication of the mud loss was the behavior of the pit volume curve according to the changes in the mud flow. Figure 4 shows the behavior of the pit volume and fluid flow across the time. One can note that the mud losses seem to stop when the drillers decreased the fluid flow (as indicated by the pit volume curve trend, indicated by the black arrows). For instance, at 5:25 PM, when the fluid flow was reduced from 940 to 840 gallons per minute, the losses stopped. On the other hand, when the fluid flow increased again to 900 gallons per minute, the losses appeared again. Since there was no relevant change on the ROP, this is a clear indication that the mud losses were occurring. An increase in the mud flow increases the head losses in the annulus, increasing also the bottom hole pressure and inducing the losses.

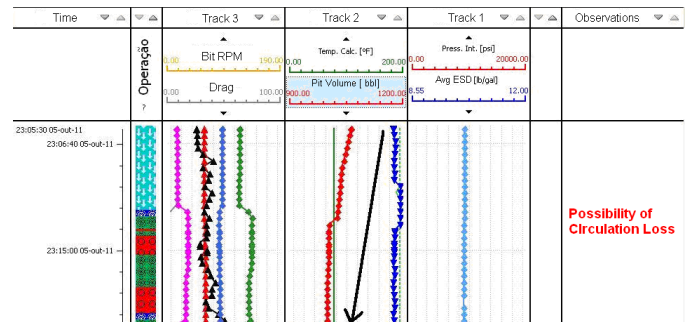


Figure 4 – Behavior of the pit volume according to changes in mud flow – Well A.

The last relevant detected event on this well was deficient cleaning conditions. PWDa has detected, on October the 6th, around 4 PM, that a solids accumulation may be occurring in the annulus. This could indicate inefficient hole cleaning conditions, which may lead to the prison of the drillstring, which is a serious operational problem. This was detected due to an increase in the ECD, while the standpipe pressure remained constant. The problem was reported to the rig, and the adequate measures were taken. Figure 5 shows the detection of this problem.

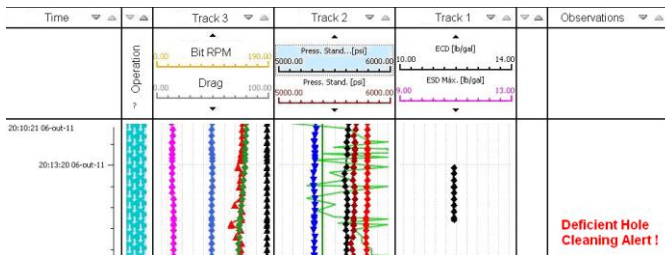


Figure 5 – Inefficient hole cleaning detection – Well A.

The second test were carried during the drilling of the 12 ¼” section of Well B. During this section, PWDa detected a decrease in the rate of penetration on November the 5th, 7 PM. This decrease was also detected by the mudloggers, and induced a tripping out of the drillstring. Firstly, it was thought that it was a bit wear. However, it was seen that the bit was in good conditions and hence concluded that it was a hard stringer. Figure 6 shows this alarm, and the increase in the DC exponent, which is actually what PWDa analyses for this kind of event.

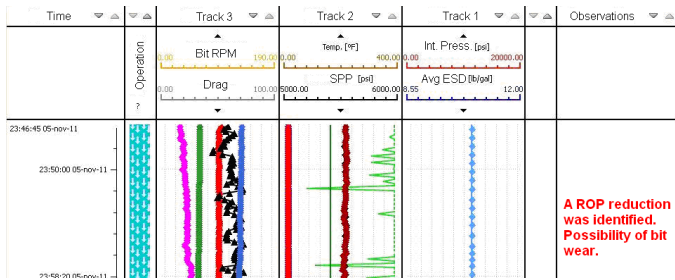


Figure 6 – Decrease in the ROP (possible hard stringer) detection – Well B.

The third test was carried during the drilling of the 12 ¼” section of Well C. This was considered the most challenging well in these pilot tests with PWDa, specially on this run. The operational window was extremely narrow and it was expected abrupt changes in the pore pressure. Figure 7 shows an sketch of the operational window. The blue curve is the pore pressure, while the pink one is the fracture pressure. Besides this, the mud weight used was inferior to the pore pressure, and hence MPD – Measured Pressure Drilling and CCS – Continuous Circulating System were used to aid in the drilling. The real time monitoring of the use of these techniques is extremely important for such a critical operation like this.

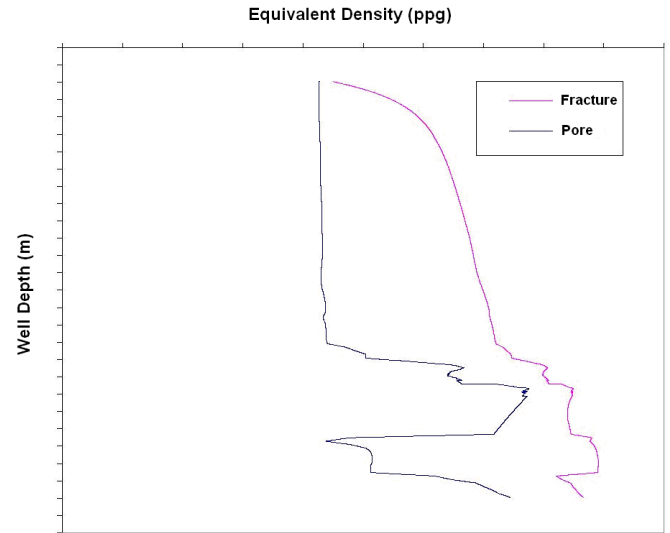


Figure 7 – Operational Window sketch – Well C.

PWDa detected during the beginning of the section some mud losses, which were expected by the drillers during this period. Figure 8 shows some of these detected events. Moreover, during November the 11th, PWDa presented a series of warnings indicating decreases in the rate of penetration. The responsible for the operation were warned about this and concluded that the warnings should be right, since the bit was at the end of its service life. Figures 8 and 9 show these two events detected.

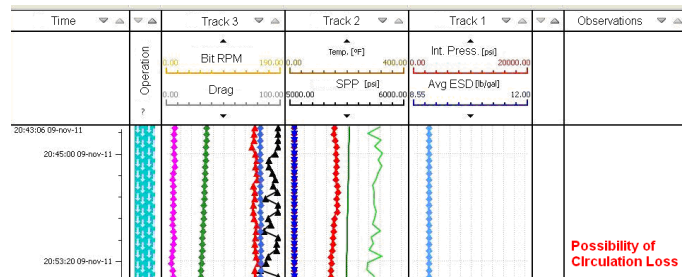


Figure 8 –Mud loss detection – Well C.

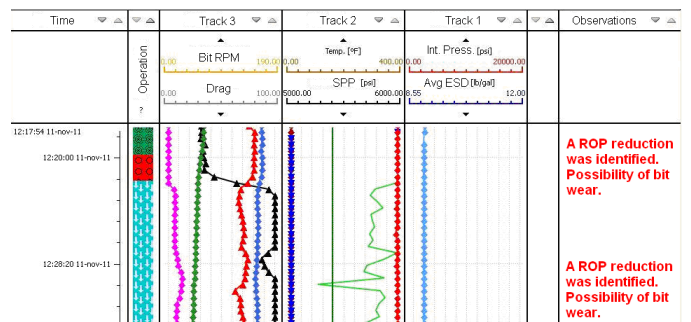


Figure 9 – Decrease in the ROP (possible bit wear) detection – Well C.

However, the most relevant event detected by PWDa

on this section later of November the 11th. While the bit was at 4092m, an alarm of evidences of kick was shown. PWDa detected that the rate of penetration started to increase, at the same time as the bottom hole pressure started to decrease. This is an indication that some influx may be occurring, and the pore pressure may be increasing. As one can see in the Figure 7, exactly at this depth it was expected a fast increase in the pore pressure, and the drillers were just waiting for the first evidences to take the appropriate measures. This was informed to them, and a meeting to discuss the measures was realized. Figure 10 shows this identification.

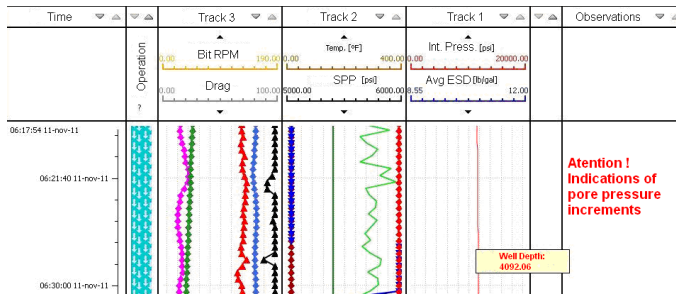


Figure 10 – Evidences of Kick detection – Well C.

Final Remarks and Future Work

PWDa is a drilling problems diagnostics tool that was developed to optimize time and costs during the drilling of Petrobras wells. It has been adjusted and optimized across two years of simultaneous implantation and development.

Results show that the PWDa models are reliable and fast enough to provide accurate results for theoretical standpipe pressure and theoretical ECD on a real-time basis. Usually a very good agreement between the measured and theoretical variables is seen. Also, correct drilling problems detections show that the logics that actually detect the problems based on the trends of the drilling curves provides fairly good results. PWDa detections influenced the decisions taken during the drilling of wells to optimize the operation with good results.

However, there are still some aspects to improve. Concerning the software architecture, PWDa is a desktop application, in the sense that it works when installed on a single machine. Although this makes its installation and configuration much easier, some inefficiency can be experienced when receiving data with higher frequency, or when acquiring and calculating continuously through several days, due to memory restriction. An overcome would be to remodel its architecture to a client-server application, where the end-user machine would be just “visualizing” and sending “orders” to the server, whereas all the acquisition and calculation logics would be run on a high performance server. This would make the application much more stable and efficient.

Kick control is a potential application of a real time drilling tool like PWDa. In the situation that a gas or liquid kick is confirmed, the BOP is closed and the driller must control the kick situation, repelling the formation fluid which

has entered the well. There are several methods to do this, but in all of them one must carefully monitor the pressure variations in the bottom hole, in the choke and in the casing shoe. A real time kick control simulator could be implemented in the PWDa framework, using the real time data to aid the driller in this crucial operation.

Some operational problems, such as prison drillstring are very hard to anticipate by just analyzing the operational parameters variations based on fixed rules. This kind of event could possibly be detected by using patterns recognition techniques, such as Neural Networks and Data Mining. A future work could also be the implementation and evaluation of such techniques for detecting more complex operational problems.

References

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