AADE-16-FTCE-83

Unique Real-Time Hydraulics Modeling Technology Expands Operator View of Drilling Hydraulics and Reduces Non-Productive Time

Jim Friedheim and Jovani Contreras, M-I SWACO, a Schlumberger company

Abstract

As well construction challenges have increased, operators have relied heavily upon hydraulics modeling software and annular pressure while drilling (APWD) tools to provide proper planning and execution of drilling within pore pressure and fracture gradient limits. However, these traditional technologies leave deficiencies in the information required to manage wellbore hydraulic pressures with a high level of precision.

This paper describes the design and implementation of a unique real-time hydraulics modeling (RTHM) software for critically challenging wells. Based upon industry recognized algorithms, the RTHM software provides continuous equivalent static density (ESD) and equivalent circulating density (ECD) at every point from the surface to the bit. During trips and casing operations, surge and swab pressures are instantaneously expressed as ECD. Intuitive traffic light alerts allow drilling teams to meticulously manage drilling practices in order to deliver wells while staying within pressure thresholds. The RTHM software can be implemented at the wellsite, remotely or simultaneously, to provide a broad scope of hydraulic parameters not available by APWD alone.

The authors will detail how the RTHM software is configured and implemented into well construction operations, how the software delivers live feedback to drilling teams and the methods employed to utilize the output information to proactively avoid non-productive time during well construction. Several field performance examples are presented.

Introduction

Every day, deepwater and high pressure, high temperature (HPHT) exploration and production wells are becoming more challenging. Even, drilling fluids technology has been improved to include synthetic-oil-base muds (SMB-OBM) and water-base mud (WBM) with lower rheology impact on the equivalent circulating density (ECD), and drilling techniques have been improved to reduce non-productive time (NPT) events, there are some operations that are not covered yet.

ECD management is one of the operational practices that can help to drill wells economically and efficiently. Wells with tight drilling windows are evaluated continuously with annular pressure while drilling (APWD) tools in order to avoid hydraulic related problems, which lead to high NPT, but even using APWD tools creates some gaps that are not filled in, such as running casing operations, wells where APWD tools will not work due to temperature limitations, and APWD failures; high-end software applications can help significantly reduce NPT. In other APWD cases, this modeling software can enhance downhole tool performance by comparing the APWD "what is" and the scenarios provided by the software "what should be," so the customer can make decisions and prevent future problems for upcoming operations.

Combining the knowledge of downhole hydraulics, appropriate drilling fluid system properties, and operational experience are critical parts to achieving one of the most important goals set by the customer during the planning phase of a well: complete the well with the lowest NPT achievable.

Implementing real-time hydraulics modeling (RTHM) software benefits/enhances different wells scenarios such as HPHT wells, extended-reach-wells (ERD) with hole cleaning issues, and wells with narrow pore pressure (PP) and fracture gradient (FG) windows.

This paper is divided in two parts; first, RTHM software set up and configuration for well construction, and, second, RTHM software use as an important tool for successful drilling.

Real-time hydraulics modeling software

The RTHM software uses well-established industry recognized algorithms. By using transient models and surface-measured rig data, the RTHM software accurately simulates hydraulics in real time, by providing calculated downhole data primarily to control swab and surge pressures in restrictive hydraulics environment.

By constantly performing calculations in real time, the RTHM software delivers equivalent static density (ESD) and ECD data continuously and temperature profiles from the bit to the surface, which depend on the pressure-volume-temperature (PVT) data of the fluid's phases. Additionally, this occurs at multiple points of the well, unlike using an NAPWD tool.

The main cornerstone of the RTHM software is the temperature profile. In order to calculate the ESD and ECD profiles, the software uses a transient model to show the effects on density and rheology; if surface (suction pit and flow-line) mud and downhole temperatures are available in real time, they can help to update the temperature profiles dynamically. If temperatures are not available in real time, this information can be manually input into the software.

Rheological data from samples taken at the rig (Fann 35A) and at the lab (Fann 70/75) are inputted into the software and provide sufficient accuracy to calculate the rheological profile; this is known to affect the temperature and pressure rheological properties. The RTHM software creates rheological profiles based on “data cubes.” The shear-stress values are defined from these data cubes in downhole conditions by interpolation.

Design and technical issues

Customers decided to use the ECD management service provided by the RTHM software in order to reduce the NPT associated with hydraulic events. The service is used primarily to monitor drilling and surge/swab operations. Using the RTHM software with an APWD tool in the drillstring complements and enhances the downhole tool’s performance. Even when the APWD information is not available, the RTHM software plays an important role in operations; for example, when running casing, adjustments to tripping speeds and stage-up pump rates made on time can significantly help avoid NPT. Knowing the customer’s major issues can aid in designing and focusing the service to be a differentiator for them.

The service is monitored continuously by experienced engineers who fully understand how ECD management can increase the potential of successful drilling and completion of challenging wells. Active participation with the drilling and fluids teams during the planning stages and during the construction operations will allow the operator to approach technical limit drilling. Early detection and correct identification of unscheduled events is a key factor in the success of this service.

System description and set-up

The RTHM software uses a communication protocol to acquire the real-time surface/downhole data (WITS/WITSML) from the rig-site. This data is used by the software to perform real-time calculations. Calculations are performed every 1 to 5 seconds, depending on the feed rate. If necessary, the calculated data can be sent backed to the rig floor using the communication protocol described above.

The software relies on the continual stream of surface data, but periodic manual entries can be inputted as they are not measured by rig sensors (i.e., mud properties, formation temperature profile, bottomhole assembly). The desired/minimum set of variables required by the software are listed in **Table 1**. The usage of the bottomhole circulating temperature (BHCT) is important in order to calibrate the temperature profile. The service can be run either remotely or at the wellsite (**Fig. 1** and **Fig. 2**), depending on the customer’s need; data can be taken directly from the mud logging unit or from the server. The selection of the feed depends on the fidelity and quality of the data. Conventional rig sensors are adequate to run the service, but sensors that provide a higher level of accuracy, such as Coriolis meters, can make a difference in the quality of the inputs (flow rates, densities, and temperatures).

Some initial and regular data is required in order to set up the service; most of the can be found in the drilling/mud program:

- Well sketch
- Well survey plan data
- Bottomhole assembly description
- Formation temperature profile
- Anticipated pore pressure (PP) / fracture gradient (FG)
- Cuttings characteristics

Implementation

Once all the information and connections is set-up, the primary function of the RTHM software is to provide simulated APWD data when APWD data is unavailable, but it also provides data when the APWD data is available to detect deviation or future problems. This could be while tripping, making a connection, or running casing, as well as in situations where the hydraulics window is narrow due to formation instability or over pressure coupled with weak formations or loss zones.

While drilling, the personnel monitoring the RTHM software uses the simulated ECD values in conjunction with the APWD ECD to identify, analyze, and interpret downhole conditions. The APWD tool provides actual downhole ECD at a set frequency (i.e., 20 seconds), whereas the software provides calculated ECD at all points of the annulus at a frequency of 1 to 5 seconds, depending on data input frequency. Variances are quickly spotted and investigated, which often lead to early identification of downhole problems. The RTHM software complements the APWD by filling in the real-time blanks.

Continuous ESD and ECD measurements

APWD tools are extensively used in drilling operations, and the readings provided by these tools are vital to making decisions about completing the well while avoiding problems. One of the major concerns for the customer is when the pressure measurements are not available, mostly when a narrow drilling window is expected; on other occasions, the data is being recorded by the tool, but it is not available in real time. Other examples of APWD gaps are: when the mud pumps are staged up, some of the APWD tools do not send signal to surface unless the minimum tool flow is reached, and high bottomhole temperatures.

Unlike the APWD, the RTHM software calculates the ECD at any point of the well, not just at a single point.

Additionally, to the ECD profile the RTHM software also calculates the equivalent static density (ESD) regardless of the APWD; whereas the APWD usually takes static densities in every connection, the RTHM software is calculating this one in real-time, so that adjustments can be done on fly and potential wellbore problems can be avoided before they come evident on surface. **Fig. 3** provides an example of reduction in mud weight while drilling; the real-time ESD calculation is shown at all times and indicates there is no need to pull out to the casing shoe to circulate to reduce the mud weight. The ESD calculations are compared against the APWD every connection. This is an example of saving rig time.

Additionally, the software shows the casing shoe depth and total bit depth, but is not limited to these outputs. Depending on the customer's need, the software can display the ECD/ESD at any point of the well, which allows the customer to create a better picture of what is going on between the total depth and the casing shoe, as shown in the **Fig. 4.**

When the APWD tool is not installed in the drillstring or it is unavailable, the RTHM software is always available because it is not dependent on the APWD; thus, the wiper and any other operation can be monitored and followed up. In cases where the APWD data is intermittent or eventually fails, the RTHM software can play an important role in saving rig time; for instance, if the calculated data has been consistent and tracking all the way with the actual APWD, the customer can rely on the information delivered by the software and finish drilling the last part of the sections instead of pulling out of the hole to replace the APWD tool.

Tripping and Casing operations

Using APWD ECDs readings during a well section can help improve drilling performance, save rig time, and characterize the drilling window to adjust the FG/PP curves. This could all be lost if mud losses are encountered while running casing/pipe due to exceeding the FG, unleashing a poor cement job causing formation damage, or a well-control event while swabbing. Unfortunately, the APWD surge/swab pressures are not available until the memory data is recovered at surface and, most times, the well was fractured/swabbed because the drillstring was picked up/set in slips to fast; problems that can be prevented by following good tripping practices or adjusting the tripping speed.

The RTHM software determines the swab/surge ECDs, (using acceleration and velocity calculated in real time or acquired as a real-time input) and swab/surge densities (as a function of temperature, pressure, and time). If the APWD memory data is available, the real-time calculations performed by the RTHM software can be compared against the APWD once the memory data is recovered, as shown in **Fig. 5** and **Fig. 6**. If the data is not available, the RTHM software can model the tripping pressures (**Fig. 7)**.

Traffic light alerts

Sometimes, operational personnel find it easier to follow instructions based on signals instead of numbers (i.e., adjust the tripping speed to 1 ft/sec so the maximum ECD is below the fracture gradient). The RTHM software feature a "user-friendly" interface to display how close/far the well is to the reaching the fracture gradient or pore pressure, depending on the actual tripping speeds or ECD while circulating/drilling. The driller can see two traffic lights (with green-yellow-red lights) in the displayed screen and perform the adjustments needed (**Fig. 8**). These traffic lights compare the calculated ECD at the shoe (or any other point set by the user) against the fracture gradient and the calculated ECD at target depth against the PP; visual color alerts are displayed as an indication that the limits established are being approached.

Hole Cleaning performance

Hole cleaning issues can lead in serious problems, like pack-off events or fracturing the formation leading to mud losses, which result in high NPT (**Fig. 9**). Proper cuttings transport can significantly help downhole hydraulics, although predicting cuttings transport behavior can be difficult using a conventional model. The RTHM software combines the analytical and fuzzy logic techniques and experimental data to handle the complications caused by the high amount of variables involved in calculations. The RTHM software uses S and Z-shaped transfer functions for the fuzzy logic implementation so that continuous and dynamically curves are created in order to determine which part of the hole is cleaned or not based on the actual drilling parameters and mud properties.

Some of the actual models are based on steady state considerations, and the RTHM software considers the transient phenomena that affect cuttings transport and bed evolution so that the software continuously tracks packets of cuttings as they are generated in the annulus and move along the well until they reach the surface. The RTHM software reports hole cleaning efficiency as "very good," "good," "fair," and "poor," and the efficiency is predicted as a function of relevant parameters. The RTHM software also calculates the cuttings concentration and the bed height at any point of the well.

Even the best approach has not been decided, yet there are some innovative solutions to monitor the hole cleaning efficiency, and some of these technologies continually measure and record the amount of cuttings at the outlet of the shakers using a cuttings flow meter (CFM). In conjunction with the RTHM software, the CFM can help optimize the main drilling parameters that affect the cleaning process; the RTHM software calculates the cuttings concentration at surface and the cuttings cumulative volume, so that this information can provide an insight about "what is" versus "what should be," as shown in **Fig. 10** and **Fig. 11**. Using the CFM technology to monitor hole cleaning, the APWD and standpipe pressure trends vs the calculated data based on the drilling parameters can help to determine hole cleaning problems (**Fig. 9)**.

Conclusions

The challenges in the actual operations makes the RTHM software important for managing downhole hydraulics and helping operators further achieve the technical limits. Even though several improvements in hydraulics modeling have been done during the past years, more work is still needed.

Real-time hydraulics have become necessary to fill-in the gaps left by the APWD tools, and the RTHM software complements and enhances the data, thus facilitating decision making, providing the customer with a complete overview and allowing pertinent changes in on-going operations to reduce the NPT.

Real-time hydraulics can be consistently accurate if the information provided by the rig sensors is adequate and all the information input manually by the user is filled out accordingly. The quality and consistency of the sensors can significantly improve the quality of the results, especially when the swab/surge calculations are critical. The RTHM software demonstrated an excellent correlation with the compared APWD and has been compared with the APWD memory log following trips in/out of the hole. Confidence in the RTHM software's ability to control swab and surge pressures is then increased, helping the customer achieve significant saving in rig time, mud losses, and services.

Acknowledgments

The authors thank M-I SWACO, a Schlumberger company, for supporting this work and for permission to publish this paper.

Nomenclature

BHA = *Bottom-hole assembly*
WITS = *Wellsite Information Transfer Specification*
WITSML = *Wellsite Information Transfer Specification Markup Language.*
MD = *Measured Depth*
CFM = *Cuttings Flow Meter*
ESD = *Equivalent Static Density*
ECD = *Equivalent Circulating Density*
APWD = *Annular Pressure While Drilling*
RTHM = *Real-time hydraulics modeling*
NPT = *Non-productive time*
HPHT = *High pressure, high temperature*
WBM = *Water-base mud*
OBM = *Oil-base mud*
SBM = *Synthetic-base mud*
FG = *Fracture gradient*
PP = *Pore pressure*
BHCT = *Bottomhole circulation temperature*

References

1. S.O. Madu, et al: "Case Histories of Drilling Challenges and Prediction of Equivalent Static Density of HPHT Wells in Niger-Delta", SPE 167581, Annual International Conference and Exhibition, Lagos, 30 July – 1 Aug 2013.
2. A.K. Thorsrud, et al: "Application of Novel Downhole Hydraulics Software to Drill Safely and Economically a North Sea High-Temperature/High-Pressure Exploration Well", IADC/SPE 59189, Drilling Conference, New Orleans, 23-25 Feb 2000.
3. Eric van Oort, et al: "Real-Time ECD Simulation and Management Using a Remote Operations Center", SPE/IADC 92605, Drilling Conference, Amsterdam, 23-25 Feb 2005.
4. S. Peng, et al: "Real-Time, Downhole Hydraulics Modelling Helps Operator Drill the Well and Run Liner Under a Narrow Fracture/Pore Pressure Window Condition", SPE/IADC 85309, Middle East Drilling Tech Conf., Abu Dhabi, 20-22 Oct 2003.
5. Zamora, M., et al: "Major Advancements in True Real-Time Hydraulics", SPE 62960, Annual Technical Conference, Dallas, 1-4 Oct 2000.
6. Naegel, M., et al: "Cuttings Flow Meters Monitor Hole Cleaning in Extended Reach Wells", SPE 50677, European Petroleum Conf., The Hague, 20-22 Oct 1998.
7. Cayeux, E., et al: "Real-Time Evaluation of Hole Cleaning Conditions Using a Transient Cuttings Transport Model", Drilling Conference and Exhibition, Amsterdam, 5-7 March 2013.
8. Schlumberger SWT DOST KDSC: "Hole Cleaning Technical Manual v1.0", Technical Manual, Houston, 30 March, 2015.

Tables

Table 1. Surface data variables required for the real-time software

Variable Input	Comment
Weight on hook	Used for tripping
Avg StandPipe Pres	To compare vs the calculated
Mud Weight In	Manual Input if not real-time
Mud Temperature In	Manual Input if not real-time
Rotary Speed	Used for Hole Cleaning
Hole Depth (MD)	Required Input
Bit Depth (MD)	Required Input
Block Position	Used for swab/surge
Rate of Penetration	Used of Hole Cleaning
Weight on Bit	Eccentricity calculations
Mud Flow In	Required Input
Time	Required Input
Riser Flow	Used for Hole Cleaning
APWD ECD	To compare vs the calculated
Ann. Temperature	Manual Input if not real-time

Figures

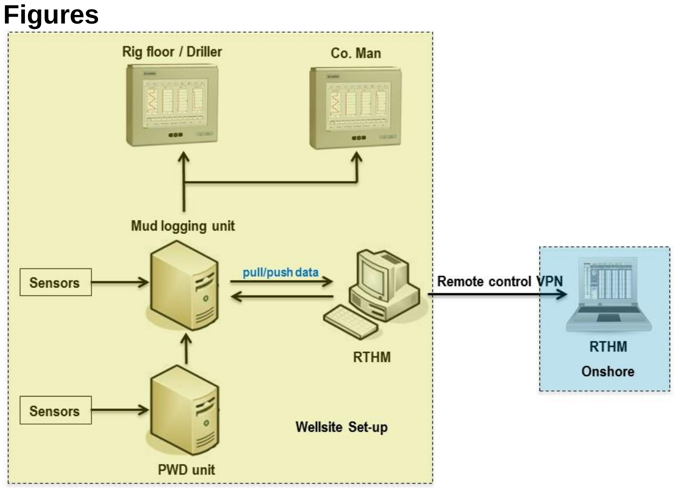

Fig. 1. Basic configuration for wellsite communications. Calculations are performed at the wellsite and managed onshore.

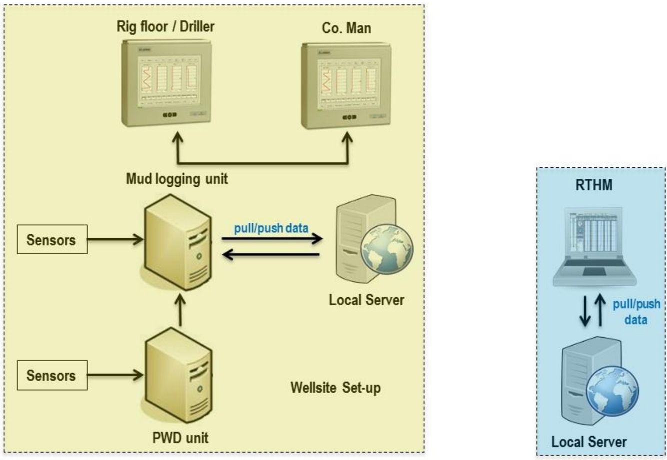

Fig. 2. Basic RTHM software configuration for remote communications. All calculations are performed onshore.

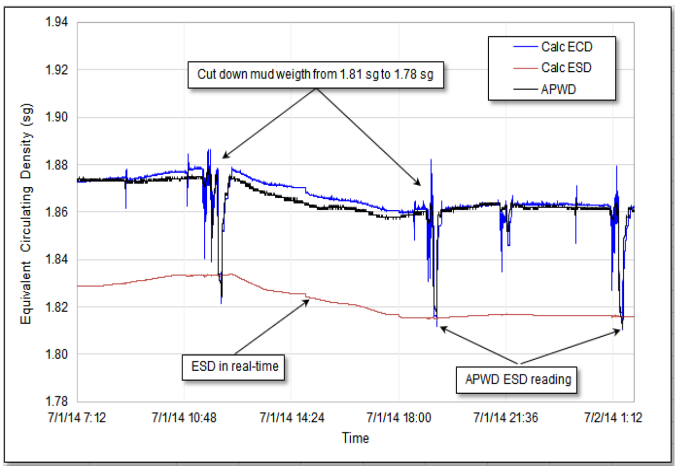

Fig. 3. The RTHM software performs ESD calculations in real time, and the results are compared every connection against the APWD.

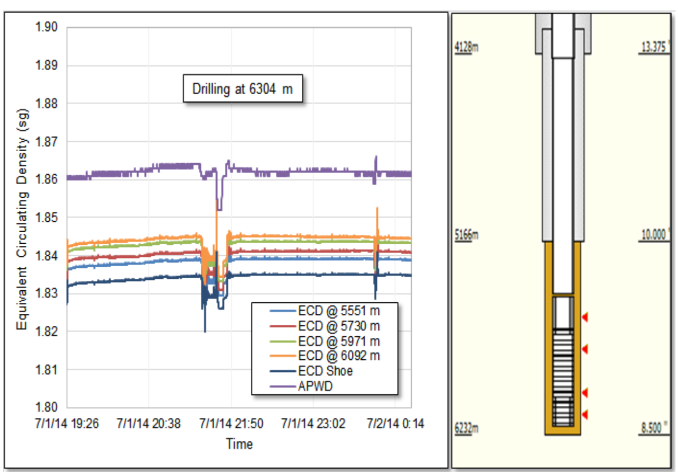

Fig. 4. Different points of interest are monitored in real time in addition to the ECD at the APWD's position. Five points of interest are monitored (i.e., a week sand below the casing shoe).

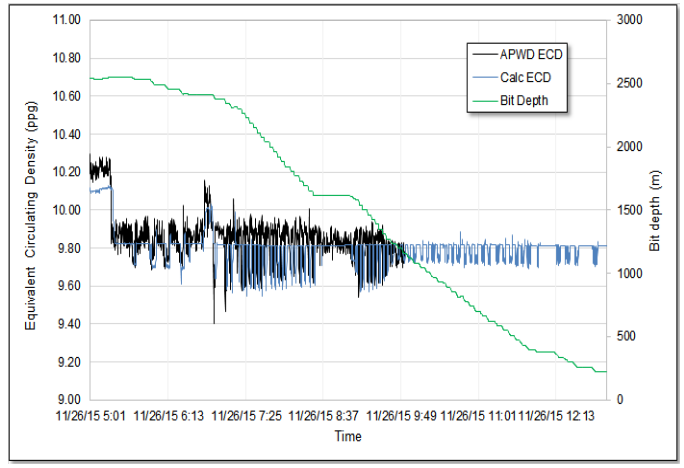

Fig. 5. Comparison of APWD ECD memory data and RHTM software while pulling out of the hole after the APWD memory data is recovered.

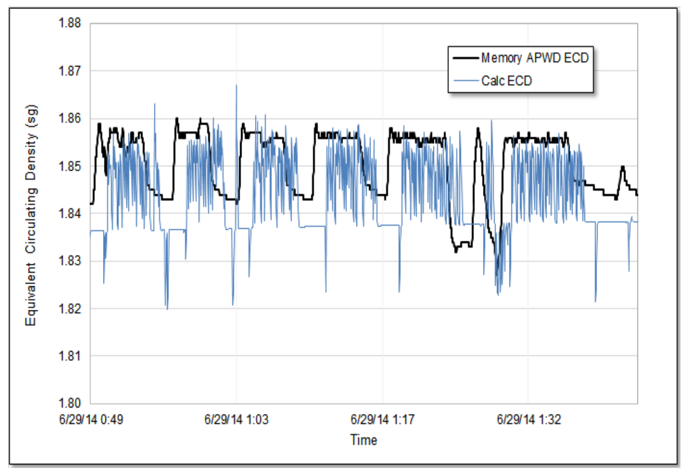

Fig. 6. Comparison of APWD ECD memory data and RHTM software while tripping in the hole after recovering the APWD memory data.

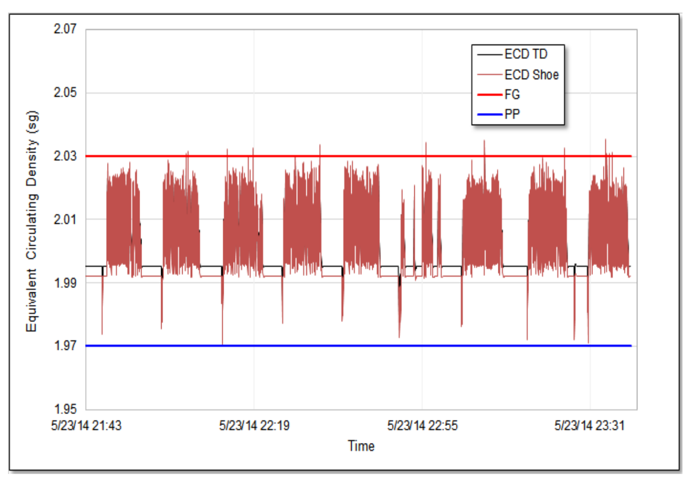

Fig. 7. A surge casing run monitored with the RTHM software managing the calculated ECD between 1.97/2.03 sg PP/FG. As measurement to prevent mud losses.

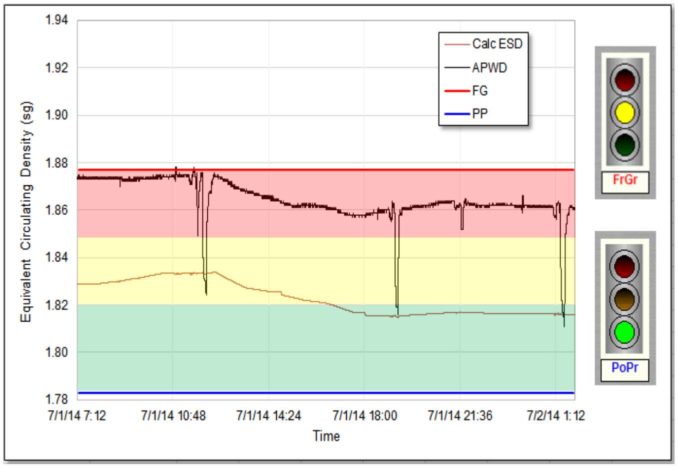

Fig. 8. The RTHM software display uses a traffic light format to indicate how close or far are we to the FG/PP.

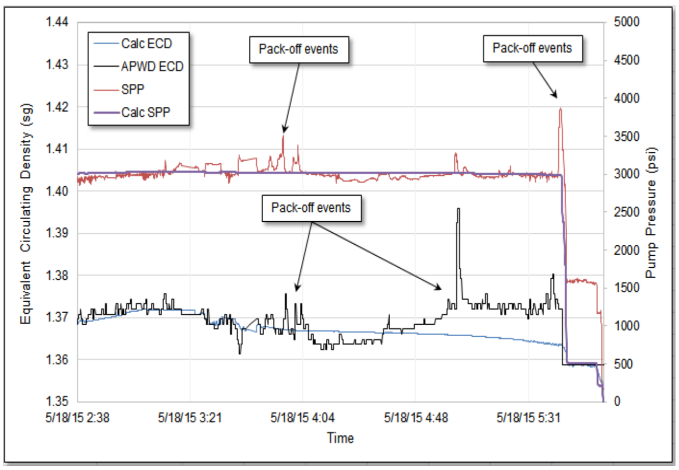

Fig. 9. Comparing the APWD and SPP vs the calculated values, can help to avoid hole cleaning problems that lead in NPT.

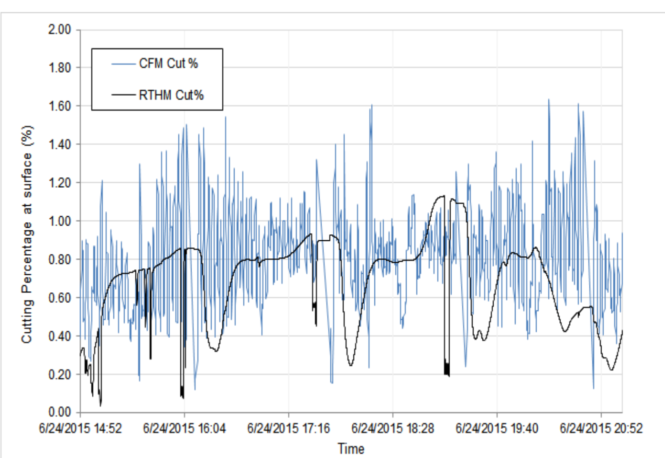

Fig. 10. Using the CFM technology, the cuttings concentration at surface can be compared against the calculated cuttings concentration.

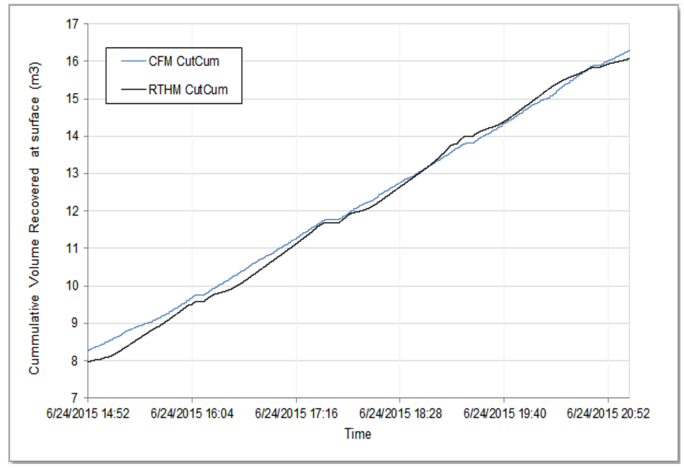

Fig. 11. The RTHM software calculates the cumulative volume recovered at surface, this can be compared vs the actual volume in order to determine if cuttings are remaining in the well or not.