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Real-Time Drilling Fluid Measurements Provide Value Via Data-Driven Decision Making for Cost-Sensitive Unconventional Environments

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Abstract

A new approach to real-time automated drilling fluid measurement systems leads to enhanced collaboration and decision making between field and remote operations personnel. The approach is based on straight forward technology that can easily be understood by all, operated by field personnel, and robust enough for fast paced unconventional operations. The sensor information offers real-time actionable data without the demand to replicate the traditional daily mud report, streamlining wellsite activities for drilling fluid treatment as fluid conditions change.

The automated drilling fluid measurement system (mud skid) was designed for reliability and simplicity. The idea is to use trending data over the single data point mud check to drive real time decision making across teams. Rather than replace the fluids specialist on location it enhances their role to drive operational excellence and consistency in their day-to-day rig support. Everyday across multiple rigs, drilling fluids specialists use the data to adjust treatment schedules, optimize activities, and capture unplanned events as early as possible to lower treatment cost with the support of the remote operations center (ROC). The ROC's monitoring activities drive fluid enhancements across multiple locations via data transparency and analysis, sharing of best practices, and event detection. With a few proven and fit for purpose sensors, the mud skid adds value within the cost limits of the unconventional well market.

There is an opportunity for value generation via the use of economical drilling fluid sensors where costs traditionally limit full-scale automated drilling fluid measurements. The mud skid unit provides sufficient data to generate value without prohibitive expenses. The mud skid unit and the data collected are now part of standard operations across multiple rigs and basins. The data streams, available in real-time to everyone from the derrick hand to the drilling engineer, have created a new workflow for decision-making, fluid maintenance, trouble-shooting, and early event detection. As more events are captured by the sensors, there are additional opportunities to train machine learning algorithms and develop predictive models.

This paper will review the development process, deployment, and delivery of the mud skid unit with case histories demonstrating the advantages and opportunities for simple, real-time data streams.

Introduction

A vision for fully-automated, autonomous drilling systems was outlined more than 10 years ago (Macpherson et al 2013). Working groups continue to break down key areas for research and development to achieve this goal. Advances in automation technology, data acquisition, and data processing continue to rapidly address technology gaps. Full automation and autonomy may remain in the distant future, particularly for land operations, but real-time data domain provides actionable information at the rig site and opportunities to collaborate with the entire drilling team.

In the drilling fluids domain, automated drilling fluid measurement systems have been tested and deployed, primarily on offshore rigs or in remote operations with high daily drilling cost where risk mitigation costs are offset by rig time savings. Onshore, adoption of these systems is restrained by the daily cost and maintenance requirements in an environment where speed and consistency are a priority over individual well risks (Jacobs 2022).

API RP 13B-1 (2019) and 13B-2 (2014) provide standard procedures for drilling fluid testing as reported on the daily mud report. Because this is a recognized industry standard, automated fluid measurements seek to duplicate the measurements as set by the API for reporting. One method is to automate existing test equipment and add data acquisition boards (Contreras et al 2019, Okesanya 2021). In many cases, the most efficient and cost-effective data acquisition method uses sensors and machine learning tools to create a model that imitates familiar equipment output within statistical boundaries (Dotson et al 2017, Gul et al 2020, Kamal et al 2020).

Real-time measurement, including properties on the daily mud report, generates value through early intervention to limit risk and unnecessary cost. While the API provides a clear set of standards for reliability and accuracy, actionable, non-API sensor data still facilitates intervention and collaboration through trend identifications and alerts.

The automated fluid measurement system (mud skid) was designed to address the cost sensitivity of unconventional environments while providing drilling fluid data information capable of reducing drilling risk and improving efficiencies. When everyone from the derrick hand tasked, with adding products, to the drilling fluid specialist making treatment recommendations to the office and remote operating center can respond to the same information, decision making processes improve across all functions of the operation.

Drilling Fluid Specialist Rig Site Responsibilities

In unconventional drilling, there are several models for drilling fluid service. The most common includes one on-location drilling fluid specialist throughout the operation. Other models include two on-location specialists, usually for critical wells, or daily drive-by service where the drilling fluid specialist is not on location at all times. The drilling fluid specialist oversees the logistics of maintaining product on location, cost and volume accounting of the drilling fluid, aligning fluid movements and activities with upcoming operations, and maintaining the drilling fluid to specifications within the drilling fluid program. While many rigsite drilling fluid activities are routine, anticipation of upcoming fluid requirements and quick responses to changes in fluid properties limit risk to drilling performance and excess cost to regain programmed fluid properties (Gautier and Offenbacher 2021).

The primary means of communicating drilling fluid activities is through the daily mud report, which is distributed to rig-site and office locations via email. The daily mud report usually includes 2-4 reported mud checks per day, treatment activities, and volume and cost accounting information. This often leads to the incorrect assumption that drilling fluid is only tested 2-4 times per day with no feedback or monitoring between tests (Broussard et al 2010, Dotson et al 2017). The drilling fluid specialist regularly monitors fluid properties and recommends treatments throughout the day. In many cases, it is only wellsite personnel aware of these activities.

Property trends are key to monitoring changes in the drilling fluid and initiating additional tests and treatments. Funnel viscosity, while limited in utility for detailed analysis, is an important trending tool. A funnel viscosity is performed every 15-30 minutes, depending on the activity. Changes in the reading from typical trends serve as a call to action to check for contamination and start a treatment. Data analytics platforms provide quick analysis of the most likely scenarios during the well planning phase as the drilling fluids program is written (Welker et al 2020). For most unconventional basins, contaminants and drilling issues are well-known by area, particularly given the volume of wells drilled.

State of Automated Drilling Fluid Measurement Systems

Automated drilling fluid measurement systems continue to advance, with some regular applications offshore. These systems utilize sensors to replicate any number of tests on a daily mud report. A common business model includes measurements and data as a packaged service at a day rate that matches or exceeds the daily cost of the drilling fluid specialist on location. The Table summarizes different offerings and measurement techniques as published chronologically.

Most equipment requires some form of calibration at regular intervals, particularly as the test results more precisely match manual measurement techniques. This means that additional equipment is still required to replicate and correct sensor outputs. In some cases, this requires personnel and equipment to maintain the equipment, further increasing costs. In one instance, the sensor provider is on location with a technician and a separate trailer to perform calibration checks. As these technologies mature, it is expected that maintenance costs will diminish through improved reliability and experience.

Output data relies on modeling to represent manually acquired data. Machine learning tools interpret received data sets with increasing accuracy. Many systems acquire data at circulating fluid temperature and rely on these models to represent standard temperatures for properties such as viscosity. Some individual tests directly replicate API procedures, but no system practically replicates and reports the tests as stated in the API Recommended Practices. It is nearly impossible to audit black box systems, but they remain an important part of automated measurements capable of providing actionable data and new fluid information, including real-time hydraulics. In addition, this real time data is visible to everyone alongside other drilling data to improve decision making and add context to activities across the wells team.

Table: Automated measurement systems and techniques in chronological order of publication. An asterisk* denotes fluid heated to constant temperature for measurement. Common water-based probes for pH, dissolved oxygen, and total dissolved solids are not included.

Reference	Density	Funnel Viscosity	Six-Speed	Filtration	Solids Analysis	Particle Size Distribution	Electrical Stability	Oil/Water
Bloys et al 1994 Murch et al 1994	Not stated	-	Pipe (Helical)	-	XRF	-	-	Probe
Omland et al 2007	-	-	-	-	XRF/ Raman	Optical	-	-
Saasen et al 2009	Coriolis	-	Couette	Auto-loading cell	XRF/ Raman	Optical	-	-
Broussard et al 2010	Vibrational	-	Couette*	-	-	-	-	-
Stock et al 2012	Coriolis	-	Couette	-	XRF	FBRM	-	Probe
Canty and Hallbach 2014	-	-	-	-	-	Optical	-	-
Dotson et al 2017	Coriolis	-	Couette	-	-	-	-	-
Contreras et al 2019	-	-	Couette*	-	-	-	-	-
Kamal et al 2020	Vibrational	Paddle	Couette*	-	-	-	Probe	-
Taugbøl et al 2019, Taugbøl et al 2021	Pipe / Coriolis	-	Pipe	-	-	-	-	-
Magalhães et al 2020	Coriolis	-	Couette	-	-	-	-	Microwave
Gul et al 2022	Coriolis	-	Pipe*	-	-	-	Probe	-

The Mud Skid, an Unconventional Approach

The design approach for the automated fluid system was unconventional, in that it was not intended to simply replicate a laboratory test. The primary focus was on pinpointing which fluid information is most critical and actionable to the operation and provides immediate value to the rig crew and remote operations center.

Design Objectives

The mud skid design leverage's reliability, simplicity, and modularity to acquire and transmit real-time drilling fluid data to the cloud. Many sensor systems require regular access to service technicians to repair and calibrate equipment, increasing costs and the risk of downtime. To limit maintenance, only sensors with proven reliability were considered. Sensor data would use a traditional edge device to acquire and convey information to the electronic data recorder for reporting alongside traditional drilling data with the option to set limits and alerts. A critical point was to ensure that everyone on the rig had access to the data via the rig's electronic data recorder (EDR) system.

The mud skid measures fluid rheology, density, temperature, and a proxy for funnel viscosity. It also includes diagnostic sensors that measure the health of the skid, and alert if maintenance is needed. Each sensor was included as a module so that servicing equipment is as simple as swapping a failed component for repair offsite. The modular design also creates opportunities to test and integrate new sensors for critical wells or to expand the feature set in the future after the mud skid is adopted. Another design criteria was that the unit can be connected by rig-site personnel in 30 minutes or less without special technicians for each rig-up. This is particularly important for unconventional wells drilled in high volumes with short times between finishing one well and starting another.

To limit transportation costs, the mud skid was targeted to fit in the bed of a pickup truck and tolerate the jarring of a remote lease road. The compact design measures 72"x 40"x 46.25" and provides significant cost savings and the simplified logistics of not requiring a large flatbed trailer for a unit that moves from well-to-well at regular intervals.

Development and Field Testing

With the established design objectives, the operator evaluated available equipment and designs. Different sensors were obtained and tested via a flow-loop to evaluate performance against lab-built and field drilling fluid samples with varying properties. For density, a Coriolis meter was selected due to its widespread use and proven performance in automated drilling fluid measurements for managed pressure drilling (Kuroda et al 2017). For example, the moving parts of a Couette-style viscometer increase risk of added maintenance, but capillary viscometers use basic pressure sensors to calculate viscosity without moving parts (Broussard et al 2010, Taugbøl et al 2019).

For rheology a helical pipe viscometer was selected. Curved pipes require more complex calculations, but they addressed the size limitations set for the skid. The capillary viscometer presented a new challenge to meet the compact design requirements established in the concept phase. A capillary viscometer requires a minimum length of pipe to establish friction pressure loss across two sensors to calculate viscosity. This is the reason many automated fluid measurement systems are 12'-15' long – too large for a flatbed truck. An alternative design uses pipes of similar length, but in a stacked helical coil configuration (Bloys et al 1994, Gul et al 2019).

The final concept was constructed into a test skid for field evaluation. The test skid was deployed on numerous wells to refine the overall design, improve models, and finalize a production design. Debris tolerance was evaluated and refined, including determining appropriate filter sizing to limit large particles that could plug the unit without constantly plugging the filter or requiring excess maintenance. Rig crew acceptance was tested, and lessons learned on a successful deployment were noted. The overall maintenance schedule was evaluated, and best practices were established. With maintenance schedule calling for the crew to trigger a flush with clean fluid once per day, the failure rate for the skid was less than once every 5000 hours of run time.

A production skid (Figure 1) was manufactured and deployed to begin introducing real-time drilling fluid data sets to drilling workflows. To scale further, the operator partnered with an EDR provider with an existing presence on most rigs across North America. The EDR provider was able to facilitate field support through their existing network of field technicians and increase reliability with expertise in remote equipment management.

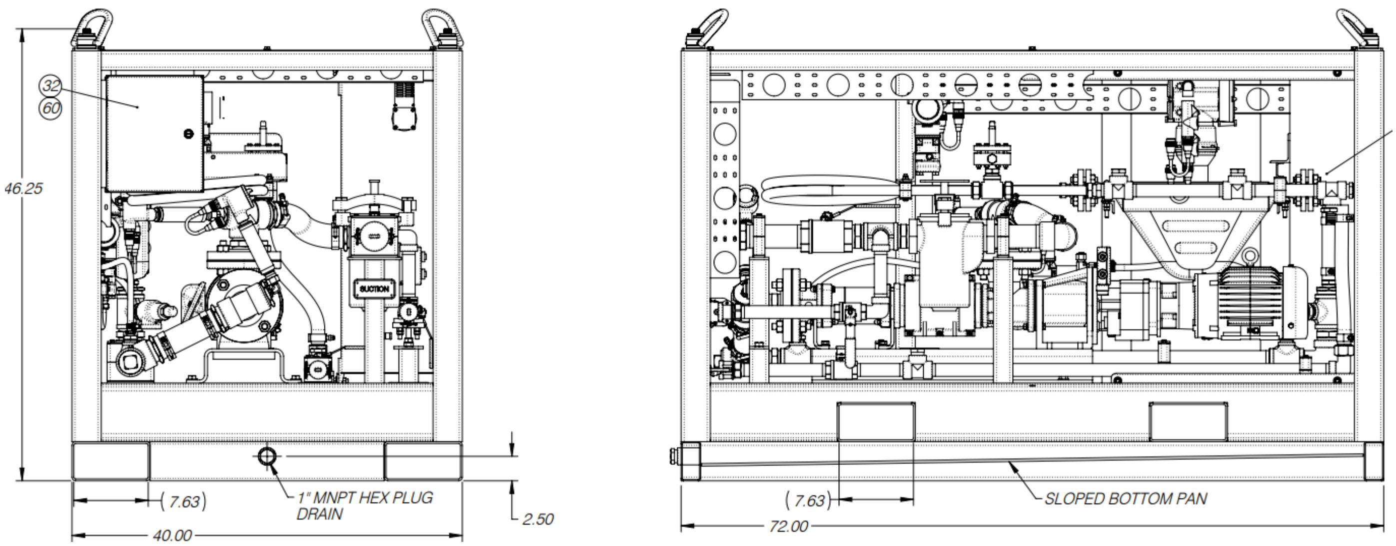

Fig. 1—Production skid drawing

Automated Fluid Measurement Introduction

Operational changes can create fear and anxiety, particularly with automation where the field personnel required to support the equipment are left wondering if it will ultimately replace them (Thorogood 2009). Automation typically creates complementary roles between person and machine but does not necessarily replace personnel.

At the initial deployment (Figure 2), representatives from the operator's development team were on location to continue system evaluation and optimization alongside the drilling fluid specialists and rig personnel. This created the opportunity to demonstrate the automated measurement features as supporting existing roles. The drilling fluids specialist can recommend treatment and observe its effects in real time and adjust treatment on-the-fly. The drilling consultant can monitor activity without having to step away from other activities.

Perhaps the biggest impact to collaboration is the remote operations (ROC) center the operator uses to maximize drilling efficiency. The ROC (Figure 3), located at the operator's campus in Houston, Texas, includes domain experts across disciplines that optimize well performance in real time using these data streams. Changes in fluid properties can be seen by everyone for discussion and planning to harmonize drilling parameters with other well performance factors.

Fig. 2—Mud skid operating on location

Fig. 3—ExxonMobil Remote Operations Center

With cloud data stored in the EDR, drilling fluid properties are available anywhere. With appropriate permissions, the drilling fluid specialist can view data using the EDR provider's existing infrastructure to monitor the output from their phone or workstation whether they are on or off location. This is particularly helpful to confirm treatment schedules. Without having to walk to the hopper and check, the mud skid can reflect the impact of treatment on drilling fluid properties as they occur over multiple circulations.

Case Histories

As mud skid adoption continues, more and more events are captured by the sensor data that generate consensus on treatments and accelerate treatment decisions to limit drilling fluid property variations. These case histories include the visualizations generated alongside typical drilling data posted on the electronic data recorder. One series of case studies not presented is where nothing happens when a change occurs. The consistent trends help to isolate concerns and eliminate fluid changes from consideration as events occur.

Water Flow

Water influxes are a persistent issue in many unconventional basins from the large amounts of produced water injected into disposal wells. Abnormal pressures make it difficult to determine a sufficient drilling fluid density to limit invasion without inducing losses. In this example (Figure 4), the water influx was captured during tripping operations when breaking circulation. Alarms were set to capture the water influx based on the increase in viscosity that appears as an invert emulsion system is contaminated by excess water.

The mud skid capillary viscometer captures an increased pressure drop (a proxy for funnel viscosity) across the tubing as MA_Pressure_Drop increases from 65.90 to 76.30. The calculated 6 rev/min reading, as represented by MA_6_RPM increases from 4 to 7.6 degrees. The alarm provided immediate recognition of the event – later confirmed with an increasing funnel viscosity from 64 sec/quart to 80 sec/quart and quantified by retort water increase from 14.7% to 19.3% v/v.

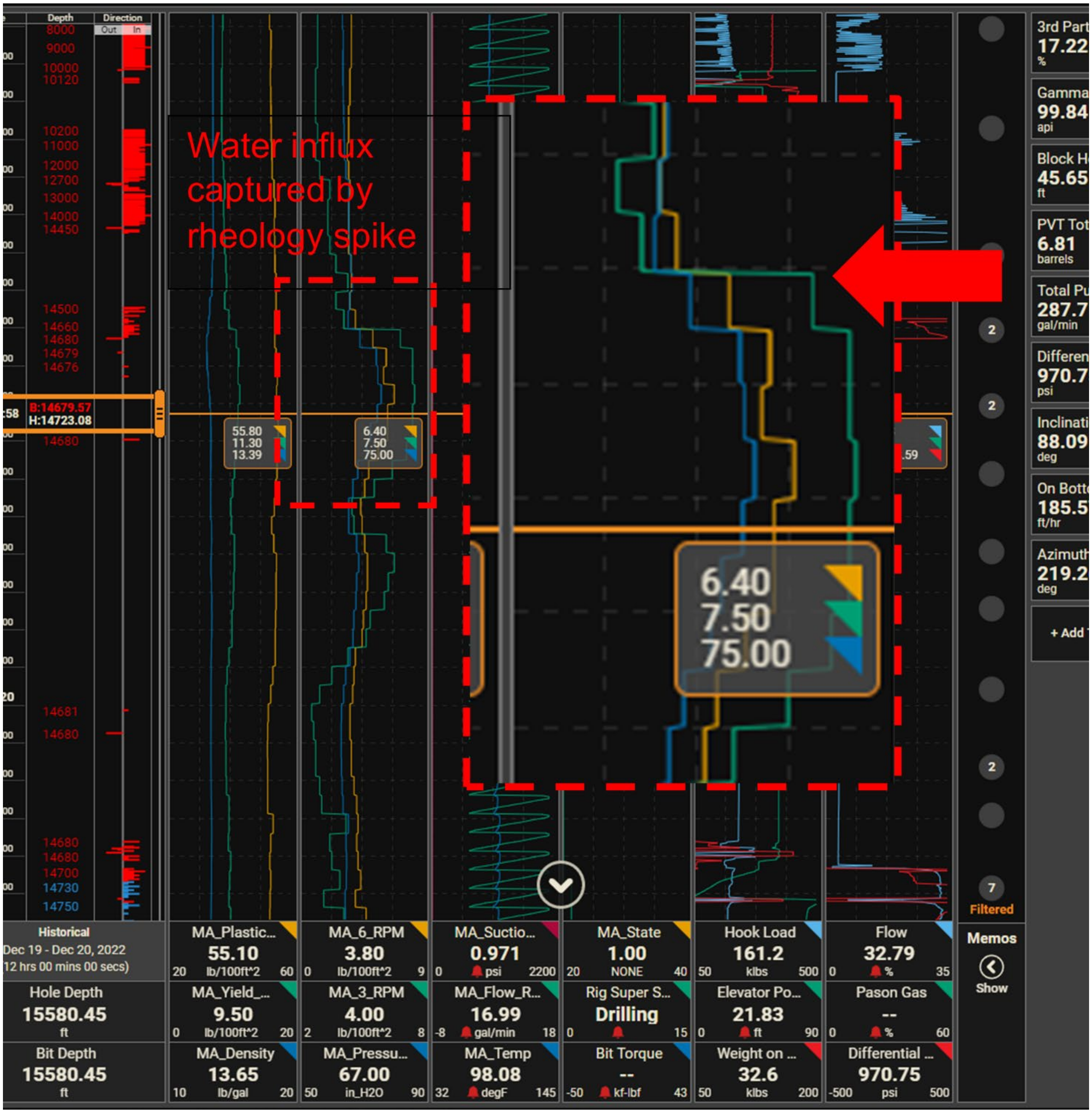

Fig. 4—Electronic data recorder output of fluid monitoring properties during a water flow. Note the increasing viscosity.

Diesel Sweep

In this example (Figure 5), the directional company required regular diesel sweeps to clean the rotary steerable system tools. For the drilling fluid specialist, these sweeps create issues as they dilute drilling fluid properties and reduce the drilling fluid density. Excess sweeps created persistent issues and questions about the amount of product required to maintain the system. With the mud skid, everyone can see the impact of the sweeps to better balance the timing and frequency to support programmed drilling fluid properties.

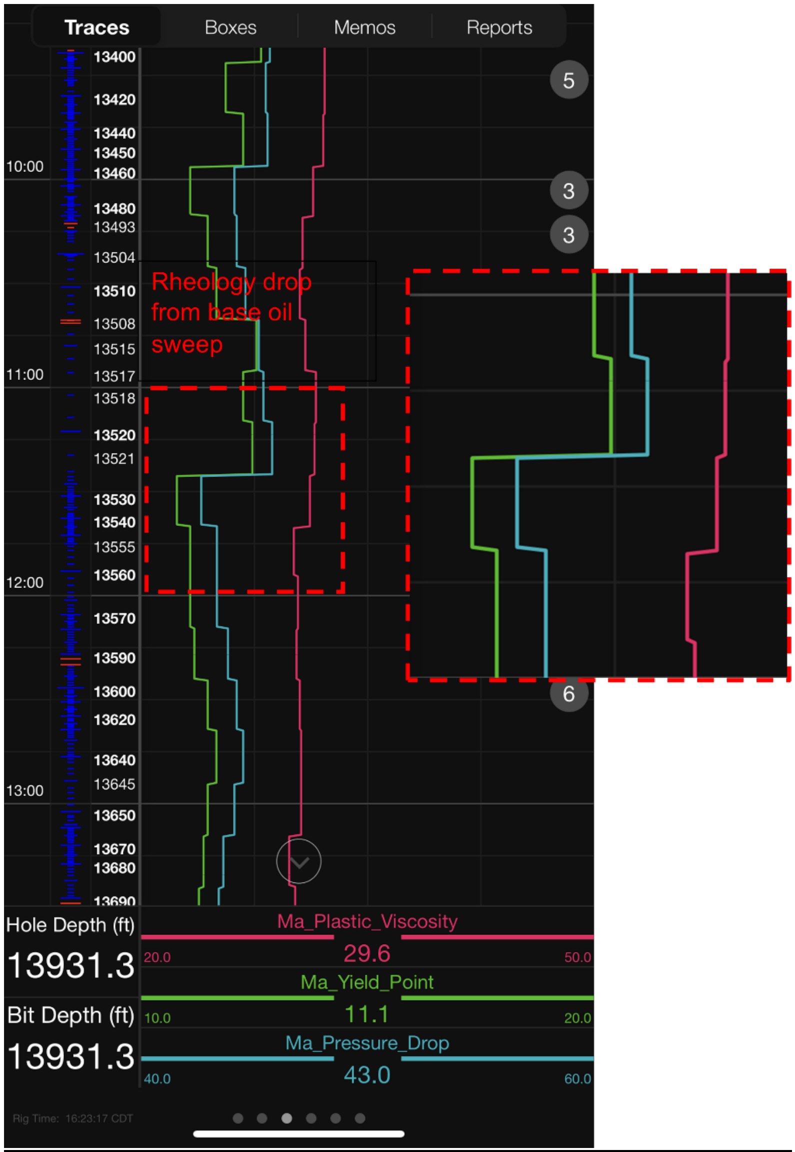

Fig. 5—Electronic data recorder output of a diesel sweep on viscosity

Treatment

In the Delaware Basin, direct emulsion systems offer a unique solution to drill through a salt section above a depleted zone (Strickland et al 2018). The saturated brine phase mitigates washout while the dispersed oil phase reduces the density to mitigate losses below the salt, thus eliminating the need for an additional casing string.

In this example (Figure 6), the direct emulsion system treatment was managed and monitored using mud skid density measurements. Because of the need to maintain the density within a narrow margin, additions of oil and brine were monitored throughout the intermediate section to reduce or eliminate formation losses.

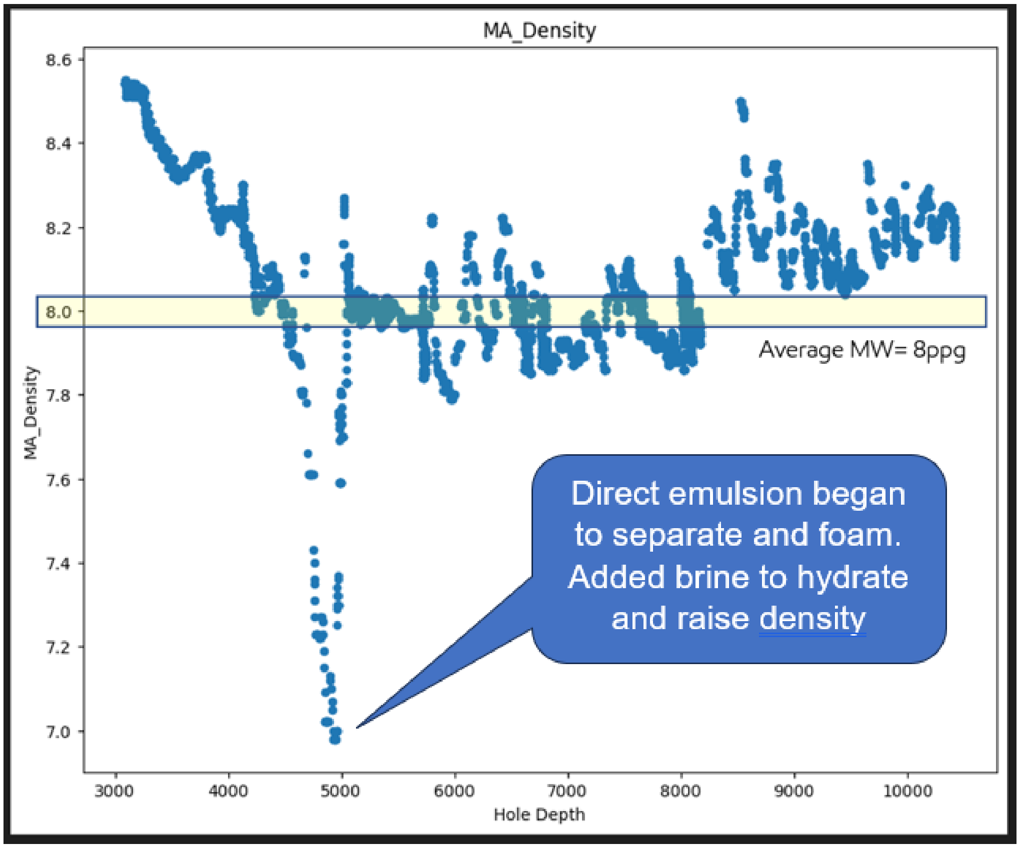

Fig. 6—Electronic data recorder output of a diesel sweep on viscosity

Cuttings Detection

The mud skid has a feature to ensure debris does not cause a failure of the skid requiring maintenance with a sensor displayed on the EDR that trends the pressure required to pass mud through a filter. When going through the testing phase the filter needed to be cleaned more frequently on one of the rigs. Upon investigation it was found that there were holes in the shaker screens allowing cuttings to come into the drilling fluid and carried all the way to the suction pit and ultimately downhole. The filter provides early detection for unwanted cuttings traveling through the active system.

Future Opportunities

Continued success with the mud skid has established its position as cost effective for even low-cost unconventional wells. The operator seeks to deploy a mud skid on all rigs working in these basins. Other operators are also testing the mud skid. The flexible base design and continuous feedback will allow the existing units to continually improve without major redesigns.

More data creates more opportunities to refine models and observe drilling fluid trends alongside drilling data. This has the potential to lead to better models for automated processes, alerts, and risk mitigation. With the modularity of the mud skid, additional sensors can provide additional information for trial, temporary inclusion on critical wells, or permanent additions without major modification to the equipment.

Conclusions

The new Mud Skid Unit has demonstrated the following:

- Actionable data is available at a lower cost through effective sensor application and modeling
- Non-API data sets create value in cost-sensitive environments
- New collaboration opportunities become available as data is available to multiple parties from the rig site to the remote operating center
- New steps in drilling fluid automation may not need to replicate traditional paths to improve operations

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