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Case History: How the Mature Application of Real-Time Digitalized Drilling Fluids Properties Beneficially Contribute to Drilling Operations

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Introduction

The impact on well operations from the changing conditions of a drilling fluid has always been accepted. And until recently, it has been accepted that the periodic physical checks of a fluids engineer have provided adequate knowledge of the fluid for on-going drilling and well analysis operations.

However, the advent of real-time fluids monitoring and measuring capabilities in a digital format has opened many new opportunities. The capability of providing a high-resolution data stream of the primary fluids characteristics to supporting digital systems has already been recognized (Doschek et al, 2021).

The immediate benefit is that the real-time primary drilling fluid properties are available 24/7 and that this data stream can be distributed to the driller, the drilling team and external drilling analysis systems for evaluation. In addition, the data stream can be supported by software processes to alert the team of anomalies. Such anomalies may concern the drilling fluid quality only, but in some cases, may have an influence on wellbore operations.

This paper is based on 104465 hours of operations experience, (as of January 2024), that the provider has using an open-pipe, hands-free, remotely operated online fluids monitoring system and the current products that have been developed to contribute more directly to drilling, wellbore, and operational control aspects. The hands-free operations and remotely operating features of this unit have enabled the provider complete removal of their own personnel onsite.

Description of the unit and software features

The hardware for the RheoSense system, hereafter referred to as the RT (Real Time) fluid unit or unit, and line of products, comprised of an open pipe system robustly intended for alternative locations and extreme environmental conditions whether offshore or onshore.

Hardware

The system is constructed primarily in stainless steel with pressure sensors of the same durable steel. The progressive displacement pump and the electric motor driving the pump are the only moving and rotating components in the unit. Control of the fluid velocities across the pressure sensors is regulated by the pump combined with a precise analytic mass flow meter. The pump also draws the gravity-fed drilling fluid from any selected location – most often immediately prior to the mud charge pumps for fluid-in analysis, and after the degasser for measuring the returning fluids (fluid-out). Returning fluids can be measured from the flowline immediately after the bell nipple or flow divider prior to the shakers when the system's displacement function is activated, and the well has been cleared of cuttings.

A standard basket strainer is situated upstream of the pump. This allows fluids containing wellbore strengthening materials and lost circulation materials to be measured and monitored for more representative fluids property values. The strainer opening size can be varied at the request of the Operator if the potential risks related to this have been discussed with the RT fluid unit provider. Typically, the strainer basket is removed and cleaned – a 5-minute process – owing to plugging from undissolved polymer balls (fisheyes) and debris. The system also has rupture discs in its construction to control operational pressures.

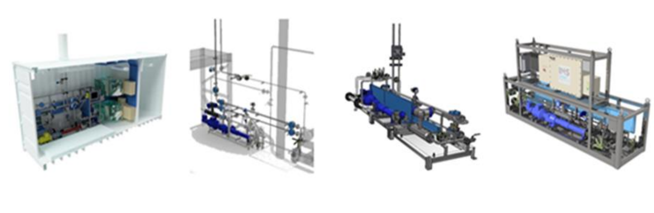


Figure 1- The final construction of each RT fluids unit is dependent upon the site location with recommendations being suggested following P&ID review or site visit. The construction of the unit can be optimised to be site specific the site in question.

To enable measuring and reporting of the 6 or 8 viscometer rheology equivalents, the flow rate ranges from 0.32 gallons (≅ 1.2 liters) to 14.7 gallons (≅55 liters) per minute in 8 steps to analyse and report the low to high shear rheology ranges. The fluid passes through horizontal pipes of 2 different diameters that each have differential pressure sensors. The differential pressure sensors then measure the pressure differentials, that is shear stress differentials in the two pipe lengths for the 8 varying flow rates, shear rate. These shear stress & shear rate values are extrapolated to viscometer values that the fluids engineer provides today.

The unit includes an in-stream Coriolis mass flow meter, that has the primary purpose of proving precise flow rates for the algorithms. However, it also has the secondary function of providing the density of the fluid and the fluid temperature.

Currently the primary density measuring system in the unit is a vertical pipe system with pressure sensors where the pressure sensors provide a differential from flow rate and gravity conditions. It will be possible with the more recent improvements of the Coriolis device to eliminate the vertical pipe system used for density today.

The flow-through open pipe system of the RT fluid unit enables additional sensors such as pH, oil/water ratio and emulsion stability to be included as requested.

Personnel intervention of the equipment for flushing is not required. The open pipe configuration of the system is self-flushing when changing from one fluid type to another. Flushing or purging is only recommended should the equipment be idle for more than 3 days, for example when extended logging runs are conducted or possibly for running casing and cementing. However, intervention may be needed to clean debris from the strainer as needed by local personnel.

The robust design of the unit has enabled an up-time of over 99.4% for the last 12 months. A maintenance case history has been included in the Case Histories section of this paper.

Software:

The RT fluid software system operates with the universal OPC UA data format. This format has been selected intentionally for its conversion and adaptability to all other third-party data formats that may be in use. The Operator also has the opportunity to retrieve the produced data via tags and store the data in their own systems. To be noted is that the RT fluid unit's provider does not assume ownership of the data produced nor store the data for more than 30 minutes. The primary responsibility of the provider is to produce and distribute the fluid data values to the Operator for their use at their discretion through their selected vendors systems.

The standard RT fluids unit provides density, rheology and gel strength data alternatively in API or SI values.

The unit can be manually started or soft-started for monitoring operations. And shut down in a similar manner. The primary functions of measuring density and rheology are gained by instantaneously & continuously monitoring shear stress/shear rate input and converting that data to density and rheology values as provided by a fluids engineer. The density and 6 or 8 rpm speed viscometer rheology data is updated each 5 seconds and shown on the HMI screen as well as being streamed to selected smart devices at any location as data trend curves.

The streamed data values in their digital form – limited to 3 decimal points - then can be utilized to support drilling fluids related programs and products, as well as being integrated into drilling analysis systems for greater overall value to a drilling operation.

Density, Rheology and Gel Strengths

The density, rheology and gel strengths are measured at ambient temperature, where the rheology values are reported at ambient; API 120°F (SI 50°C); and 150°F (65°C) temperatures. The HMI screen allows the fluids engineer to add the manually measured values in for comparison. The rheological and gel strength values are gained from following the API procedures for measuring these values as a fluids engineer does. Gel strengths, if activated, are automatically taken each 2 hours or as requested – where the fluid flow in the system must remain static for 10 seconds or 10 minutes.

Access to the core fluids properties of density, rheology and gel strengths measured at ambient temperature and also reported at API temperatures in real-time, enables analysis of data value trends. In turn any fluid and related wellbore anomalies detected can be attended to proactively for operational benefits.

Application of the services for operations

Crew training

In all cases a short training session has been given to the rig crew overseeing the unit onsite. This consists of how to set up the unit for fluid sampling, the flushing and purging of the RT fluid unit, how to clean the strainer and with basic troubleshooting information. A concise operating procedure is provided as well as laminated graphic quick start/stop instructions. Practical awareness training of aligning suction and internal unit valves – there is only a single piping system through the unit – has also been provided. In addition, the crews were given instructions for the start/stop processes that are controlled from the HMI screen or their control station.

Benefits of digital data from RT fluid unit

1. By visually displaying the density and rheology data curve trends coupled with out-of-specification boundaries and an associated stakeholder alert system – see Figure 7.
2. Digitalized fluid property trends shown and/or integrated with drilling analysis systems.
3. Fluid interface identification for pill isolation purposes with HSE and economic benefits – see Displacement function.
4. An advisory platform to communicate observations and recommendations to the stakeholders.
5. Continuous drilling analysis and hydraulics models are possible for improved well control and operations.
6. To serve as a fluids treatment prompt or conversely integrated into an automized treatment control package – see Figure 4.
7. Fluid into the well versus fluid out where lag time is corrected for as an option.
8. Examples of the value gained when all stakeholders are informed in RT of drilling fluid changes will be provided.

Examples below from the RT fluid unit show two of the HMI screens and the method the data values are displayed.

The API Data screen shot shows live density, rheology and gels values. Note that the ambient rheology values have been converted to API data values at 120°F and 150°F. The screen also allows manual rheology data values from the fluids engineer manually entered if deemed of interest as well.

Note: The data values shown are updated each 5 seconds. All values are updated as the varying pump rates proceed through their cycle from lower (shear) to higher (shear) flow, where each of the flow rates will influence the individual respective and resultant rheology data points.

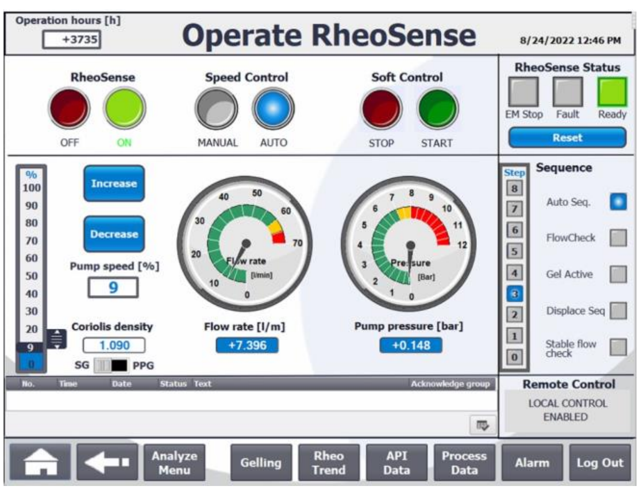


Figure 2 – Depicting the RT fluid unit start-up screen on the HMI panel. This control screen can be situated at the unit or alternatively in a non-EXL zone.

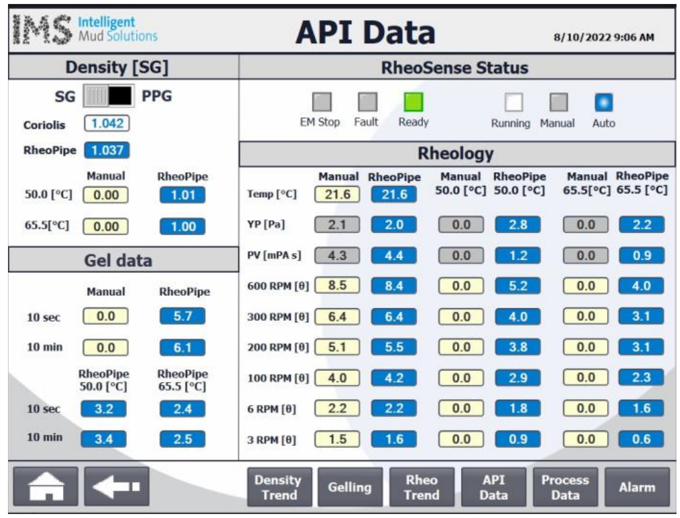


Figure 3 – The HMI API Data screen displays the two independent and high-resolution density values, RT fluids unit rheology & gel strength values at ambient & API temperatures and enables manual input of the fluids engineer's values. All RT fluid values are updated each 5 seconds.

Current digital and software tools available

The online real time software provides clients with an easy-to-use digital fluid analysis platform available via their web page on any smart device globally. The intuitive real-time visualization of fluid measurements helps clients turn data into valuable decision tools – not only for the drilling fluid being monitored but also when related to drilling and wellbore conditions, particularly torque & drag fluctuations. This is owing to the streamed real-time values showing property trends. And as the data is logged, it can be used historically. An autonomous fluid analysis report, auto distribution to pre-identified receivers, and the advisory AI tool empowers all stakeholders, particularly the fluids responsible person and driller of fluid and well performance.

Asset management tool

The asset management tool enables an Operator with multiple RT fluid units operating on varying locations to select an individual operation for review and evaluation. This provides any of the Operator's stakeholders with accessible and improved asset visibility for their respective operations, and in turn ensures operational control with a stable IOT tool. The asset management tool is accessible for approved stakeholders from anywhere, anytime 24/7.

Viewing of fluids property trends

Live viewing of the real-time monitoring system helps engineers evaluate and react to current events of the fluid operations. The respective organization can log and track real-time data to proactively react to trend changes and better recognize abnormalities that fall outside the set parameters of the fluid system being used. This can be likened to the properties and parameters of a written drilling fluid program but is available as real-time streamed data to all stakeholders. This viewing or overseeing system synergizes with the advisory system of the unit as noted below.

Fluids Reporting facility

The reporting product presents fluid properties graphically as data stream curves. The reports are created and automatically delivered to specific email addresses on a regular basis as requested by the user. The data curves are time-stamped for digital or visual correlation with drilling events and/or drilling analysis systems.

The RT fluids reporting system retains the same high-resolution values as for actual operations, i.e. updated data points for each 5 seconds. This enables the data values to be used historically in finely scrutinized detail form as comparative information with drilling analysis systems.

Fluids Advisory system

This advising technology system gathers the complete data stream from RT fluid unit and its associated products. Riverbank limitation boundaries can be digitally set alongside any significant fluid property selected to flag the stakeholders should the respective property deviate outside the boundary. A second riverbank boundary can also be added to each selected property and when a fluid exceeds this secondary boundary it will result in an email note being sent to the stakeholders for their attention and action.

Under development from the property data gathered, is the fully integrated fluids control and treatment system, that is the 'brain' of total fluids operations.

Integrated treatment control system

The control and treatment system will be an advisory tool to guide the operations stakeholders with fluids optimization recommendations as well as the remedial actions required. The remedial actions will advise as to fluid treatments and the control of drilling conditions.

The provider of the equipment already has been involved in international project studies and developments (Boubi et al, 2017). The provider continues the earlier developments of these systems in conjunction with 2 global suppliers of automized equipment and components used in oil and gas drilling and production operations. These developments are on-going in the RT fluid unit provider's Technology Center.

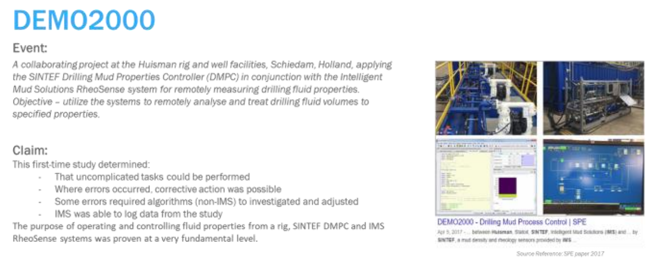


Figure 4 – a summarizing overview of the DEMO2000 integrated treatment project. This project was conducted in conjunction with automized rig operations in 2017. On-going fluid treatment studies are being conducted at the IMS Technology Centre today.

Displacement function

The displacement function is applied to the returning fluid flow to enable the early identification of a pill, slug, or spacer in the returns. The system uses real-time density and rheology changes to activate fluid isolation action. The density and rheology values have been modified into a software system for this purpose that in turn identifies a pre-determined cutoff contamination point of the different returning fluids.

With the equipment in its displacement mode and hooked up to the returning fluid volumes, the fluids are sampled near the bell nipple. The displacement system recognizes for example a 15% change in the fluid properties to either advise the solids control hand to divert & isolate the new returning fluid or to automatically activate a remotely operating manifold & valve system to isolate the new returning fluid.

The displacement system has been programmed to recognize up to 3 different fluids, such as for a completion clean-up train.

The use of the RT fluids unit and its hookup for this procedure requires a separate dedicated gravity fed pipe from the flowline after the bell nipple, fluid flow divider prior to the shakers or feed from the shaker box.

The purpose of this function is to:

1. Identify and isolate a contaminating fluid at the earliest opportunity and in the shortest time.
2. Reduce expensive treatments resulting to an active drilling fluid.
3. Reduce the volumes of contaminated fluids requiring disposal.
4. Remove personnel from the shaker room, by so reducing HSE exposure conditions.
5. Reducing associated logistics of disposal.

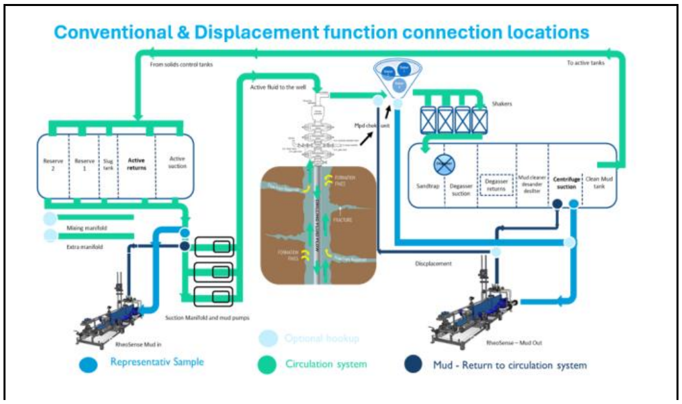


Figure 5 – an illustration of possible RT fluid unit hook-up locations. Also showing the Displacement functionality connection location after the well returns riser

Supporting functions to maximize the RT fluid unit

Additional fluids property sensors such as pH, oil/water ratio, emulsion stability can be installed and used when requested.

Field integration with external systems

The RT fluid unit and systems provider is an independent oil & gas industry company. Its independence has given it the primary advantage of developing hardware and software packages that can be flexibly used by any operating company, and at any location.

The provider uses an adaptable software language and communicates through commonly used land and cloud-based networks for the distribution of the data values streamed. With the experience of diverse global operators to date, the provider has always been able to integrate and communicate successfully.

This experience has been significant in identifying communications caveats are apparent, such as with WiFi connections, cable connections where distance and/or external equipment has interfered, and with operations through firewalls.

The RT fluid unit provider is clear – it does not own or use the data values produced. The provider stores the produced data values for 30 minutes only. It is the client that takes immediate ownership of the data values and that determines their end use of it.

The foremost intention of the RT fluid unit and system provider has been to competently stream the primary drilling fluid characteristics to all stakeholders. This will in turn enable the users and stakeholders to integrate the data into their control center architecture (Fjedheim et al, 2008).

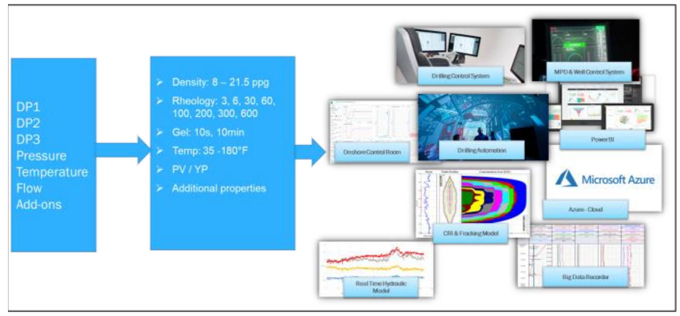


Figure 6 – graphically illustrating the potential of digital data distribution opportunities into alternative analytical systems.

Quality control of the RT fluid, sensors, & software

The provider has a very stringent quality control and approval process. This is evident from the over 104465 hours of operations time to date and the greater than 99.4% uptime achieved over the last 12 months.

The fully digitalized systems enable a continuous overview and monitoring by the provider of the equipment's hardware and software performance for all units in the field. This overview is conducted on a weekly basis for each unit unless an alarm prompts the provider to attend to a specific unit immediately. The units are monitored for data variances that could be indications of calibration, maintenance or immediate contact with the client for the respective unit.

Any data value variances identified are followed through by a call to the Operator, to the onsite persons engaged with the units, i.e. fluid pit hand, derrickman or shaker hand, and possibly the fluids engineer if present onsite. A procedure of question/answer and elimination is conducted to identify and eventually correct the issue at hand.

The provider does not have its own personnel onboard – this is not necessary as the Real Time fluid unit and associated systems are:

1. Uncomplicated with respect to its operations, and
2. Can have software calibration and updates conducted remotely, i.e. by the provider from their headquarters.

Development of additional sensors to the present RT fluid unit has proceeded cautiously with the aforementioned thoroughness as the driver. In some cases, sensors and systems already available in the market have been tested in the provider's Technology Center and set aside while more robust and reliable alternative analysis sensors are or have been investigated. The provider's objective is to include additional sensors into the continuous flow of the RT fluid unit. Some exceptions to this have been accepted. An example is the pH sensor which is automatically immersed into the fluid of the RT fluid unit while the fluid is in static condition when performing gel strength tests.

RT Unit hardware and software maintenance

An operating and maintenance case history is provided below in this paper to illustrate the robustness, durability, and stability of the Real Time fluid unit – see Case 2.

Significance of density, rheology, gels as digitized data values

The RT fluid unit and system streams the updated data values continuously. The primary fluid characteristics provided by the RT fluid unit are density, rheology and gel strengths. These data values are streamed to the stakeholders.

The significance of focusing on these characteristics is in line with the process an onsite drilling and drilling fluid operation follows. The process is described below:

1. Derrickman/pump hand and shaker hand provide density & FV each 15 – 30 minutes – if this deviates, then
2. Mud engineer checks the same and runs a 6/8 rpm rheology and gels repeatedly - maybe 3-5 times over 60 minutes to see if a better understanding of the mud can be gained. This approach attends to 80% of the fluid anomalies!
3. If the density, rheology and gels do not adequately provide an understanding of the fluid anomalies, then the mud engineer continues on with additional fluid tests.

The RT fluid unit and system provides this data & values continuously as shown in the example below. This then is advantageous wrt periodic sampling and reporting.

To be noted is that the drilling fluid data gathering sequence of the RT fluid unit is:

1. Measuring the density of the drilling fluid in true real-time.
2. Monitoring and measuring the shear stress and shear rate of the fluid instantaneously and continuously – true real-time - at ambient temperature.
3. Converting that data to generically understood viscometer RPM values – 6 or 8 speed equivalent values each 5 seconds for 'near' real-time values at both ambient and API temperatures and plotting the values to provide trending values for analysis.
4. Apparent & Plastic Viscosity, and Yield Point values are simultaneously derived from the viscometer 600 & 300 RPM values.
5. Gel strengths – 10 second & 10 minute - are available automatically at 2-hour intervals as standard.

These primary drilling fluid properties are streamed to drilling analysis programs for the immediate and continuous update of those software packages. The RT fluid unit and system data services then enable the highest-level significant shear stress & shear rate values to be used for operations. This is rather than the second or third level values of viscometer RPM or Plastic Viscosity and Yield Point values.

The input of intermittent manual drilling fluid values to drilling analysis software then is improved substantially with the streamed fluids data. In addition, the fluid data available for input is from the highest sequential level – shear stress & shear rate – available for the optimization of drilling parameters.

The example below is one of many that were presented at an Operator's Drill-Well-On-Paper workshop. Note not only is the example descriptive for following fluid changes for a drilling operation but could also be used in conjunction with a Mud Program as a more visual awareness method.

Example:

Unit location:	Well returns
Density:	Constant
High shear:	Constant
Low shear:	Increasing

Assisting information:
Formation type; ROP; hole size & deviation; bit type; cuttings condition

Data communication and collaboration to benefit operations:
Driller; Operations Supervisor; Fluids supervisor; Operations team leader; Stakeholders; Solids control personnel.

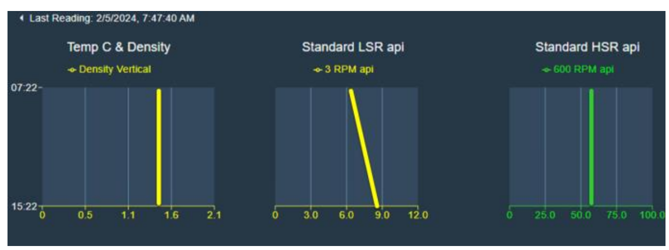


Figure 7 – a modified screen shot of the RT fluid unit shared data stream. The visualization of changing data value trends provides an early identification of drilling fluid and possibly wellbore anomalies. These trend curve screens can also have property boundaries or riverbanks associated with them that in turn function in conjunction with an alert/alarm warning should any of the properties deviate from those programmed.

Identifying drilling fluid anomalies from this example:

OBM oil based:

- Increase of low gravity solids concentration
- Gradual size reduction of particles in fluid, e.g. from degradation (grinding) in the wellbore, size degradation through the equipment especially centrifugal pumps, possibly from inadequate dilution. This can occur with the barite also.
- Poor hole cleaning with cuttings remaining in the well for excessive periods.
- Increasing water content
- Need for decanting centrifuge processing.

KCL water based:

- Increase of low gravity solids concentration
- Gradual size reduction of particles in fluid, e.g from degradation (grinding) in the wellbore, size degradation through the equipment especially centrifugal pumps, possibly from inadequate dilution. This can occur with the barite also.
- Poor hole cleaning with cuttings remaining in the well for excessive periods.
- Inadequate KCL concentration allowing clay solids to disperse into the fluid.
- Hole in fine shaker screen
- Need for decanting centrifuge processing.
- Excessive use of low viscosity polymers.
- Fluid flocculation e.g. in conjunction with cement contamination.

The visualization benefits of fluid property trends then provide a more readily understandable basis for the stakeholders to ask questions from. This aspect is intended for a broader fluids property control awareness with the ultimate objective of optimizing wellbore conditions under operations. It is the high-resolution digital reporting of the drilling fluid characteristics and their distribution that enables this facility.

Case histories are shared below to substantiate the claims.

The following case histories and examples are provided to substantiate the significance and benefits of functioning from digital fluids data platforms.

Case 1: Elevating the drilling fluids engineer to fluids manager or administrator.

The IMS RT fluid unit systems have enabled the role of the drilling fluids engineer to be elevated to that of fluids manager or administrator. This change is possible as the RT fluid unit systems over-ride the engineer’s core functions of measuring and controlling density, rheology & gel strengths by streaming real-time and remotely measuring values to all stakeholders. Typically, these core characteristics are enough to indicate 80% of the changing conditions of a drilling fluid and their relationship to drilling conditions.

The points below elaborate on this subject:

1. Position elevated from mud engineer to fluids manager/fluids administrator.
2. Fundamental & time-consuming tasks of density, rheology, gels removed - and improved with real-time trending values to lift primary analysis tasks.
3. Able to widen the mud engineer/manager scope by cross training to include cement, solids control, and waste management tasks (total fluids manager).
4. Enables continuous overview of fluid operations for multiple operations simultaneously - and the competent control of these operations with the support of well-defined procedures, and with the possible assistance of a 'floating fluids engineer' that can travel from a central control station to problem sites to remediate issues.
5. Fluids data streamed to all stakeholders - enabling the fluids manager to communicate to others for additional possibly helpful information.
6. Continuous real-time data trends enable 'fluids manager's' notes to be added digitally for later reference.
7. For land operations, e.g. in the USA, the mud manager and drill team will be able to hold a constant overview of operations instead of once a day or intermittent site visits only.
8. With real-time values at hand for all, the mud engineer (fluids manager/administrator) has been able to communicate with stakeholders more informatively, the elevated position has become more significant and integral then for the operations team.
9. Because of the improved fluids overview, the fluids manager will be able to focus more on optimization, logistics, environment (work and discharges).
10. The elevated position of the fluids manager has enabled a more transparent and documented condition for ongoing planning meetings for new wells, projects.

Case 2: RT fluid unit operations – equipment & software performance.

The RT fluids unit provider has intentionally constructed the automized fluids measuring equipment and software programmes for the varying harsh conditions that the systems may be subject to. The range includes extreme temperature conditions, cold and desert environments, logistics, transportation & installation challenges, and remote communication networks.

The ISO 9001 and ESG standards are fundamental in the quality control standards the provider adheres to.

The points below endorse the IMS performance position:

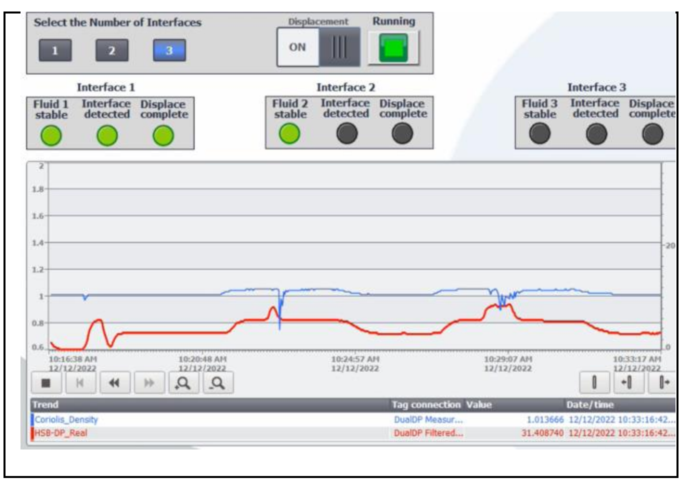
1. The RT fluid unit and accessories are constructed with stainless steel and can be adapted to any site for installation convenience; the unit one moving/rotating component only; the system is gravity fed from the fluid supply source – charge pump manifold, fluid tanks, returns tanks or flow divider; the construction is EX rated.
2. The open-pipe system eliminates plugging & clogging; a upstream strainer mitigates equipment damage – and can be cleaned within 5 minutes. No unit flushing required.

3. Rotating component - pump - may require changing at 3000 -5000 hours; pump change is a 2-hour task for 2 pre-trained rig persons.
4. Pump on unit 1 replaced at 4965 hours where the formations drilled were 50% sandstone; mud density up to 11.7 ppg (1.40 SG).
5. Software is updated and calibrated remotely; software calibration is required approximately each 3 months.
6. Continuous IMS overview of performance from its HQ offices in Norway to enable proactive maintenance.
7. Over 104465 hours operation history enables the correct spares to be available onsite for quick repair/replacement.
8. Multiple installations have accrued over 104465 hours operations time meaning experience is available for optimizing and troubleshooting to maintain 99+% uptime.
9. IMS compliance for continued ISO certification stimulates proactive equipment & software maintenance.

Case 3: Fluid displacement & interface identification.

A benefit of real-time drilling fluids property recognition is that fluid interfaces can be detected at the earliest enabling the new fluid to be isolated and thereby removing the contamination potential. The displacement system is programmed to recognize a change in fluids at the 15% interface or contamination point. As a well will have been circulated clean prior to pumping a slug, wash train or specialised pill through it, the well will be free of cuttings and debris enabling the RT fluid unit to be connected to the flowline or divider immediately after the bell nipple. In this way the new fluid interface is identified at the earliest opportunity for separation or isolation as deemed necessary.

The advantage gained from the displacement identification system is that unnecessary fluid correction treatments can be avoided or at least minimized, and that fluid waste streams can be significantly reduced.



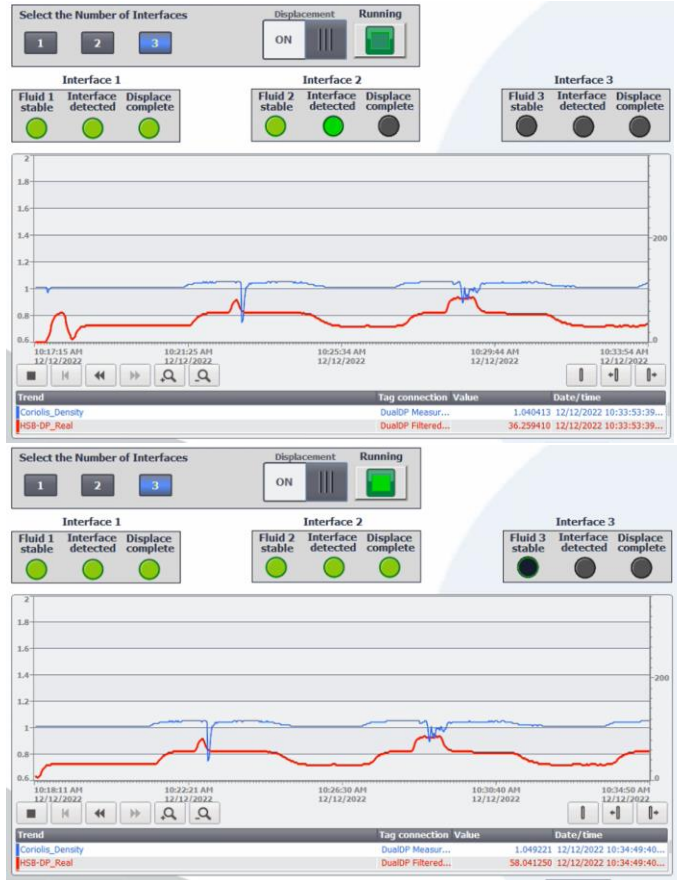


Figure 8 – these 3 HMI screen shots show the density and rheology trend changes of fluid #2 over to fluid #3. The change is indicated by the progressive buttons in the Interface 2 window The density and rheology changes respond accordingly.

Displacement service advantages

Identifying, controlling and minimizing the fluid interfaces has significant benefits to overall operations.

Section	Contaminated Volume m3	Cost WBM/OBM NOK	Disposal Events
17 ½" IMS	3.5	14K / 52K	
12 ¼" IMS	2	8K / 16K	
8 ½" IMS	1	4K / 8K	
Total	6.5	26K / 76K	Onboard storage; cranes for hoses; transportation to shore; tank cleaning; hoses; storage onshore; transportation for disposal; disposal; energy consumption in the process
17 ½" Conventional	21	84K / 168K	
12 ¼" Conventional	12	48K / 96K	
8 ½" Conventional	6	24K / 48K	
Total	49	156K / 312K	Onboard storage; cranes for hoses; transportation to shore; tank cleaning; hoses; storage onshore; transportation for disposal; disposal; energy consumption in the process. NOTE: Each event is 7.5 times that of the IMS Displacement process.
Comments	7.5 times the volume for handling	Higher cost conventional WBM 6 / OBM 4.1	Events will be impacted by volume

Figure 9 – the generic potential operational and economical savings is presented in this table. The values in the table are for Norwegian offshore operations.

Case 4: Capability to reduce interval sections of a well

An international Operator credits the use of the RT fluid unit and its live fluids properties data stream applied in conjunction with a drilling analysis system for the avoidance of needing to side track critical wells in the Barents Sea, Norway, 2017. The combined use of these two true real-time facilities, that is the RT fluid characteristics combined with transient wellbore analysis and advisory software provided superior wellbore control and operations conditions successfully. The extreme drilling nature of the geological conditions would have resulted in the Operator needing to re-drill the respective intervals at an estimated cost of US$ 11 million. This was avoided.

The Barents Sea region geological formation sequences are challenging in that they can be comprised of alternating low/high pressure zones, vugular conditions, with consequential lost circulation and with unstable wellbore characteristics. These sequences are apparent at all depths with the result that wellbore integrity can be comprised.

This case history is from a statement the Operator published in their internal magazine. The estimated savings have been derived from earlier experiences where side tracking has been necessary through the unstable formations.

Figure 10 – the diagram and text has been extracted from an internal Equinor magazine.

Case 5: Early detection of pump pressure anomaly

While drilling, the driller observed a 174 psi (12 bar) reduction in pump suction pressure.

Based on standard procedures, the toolpusher immediately discussed the issue with the ARTE (Advanced Real-Time Engineer) and mud engineer to gain an understanding of the situation.

Initially the toolpusher assumed that the situation was owing to a drill pipe washout. However, the ARTE informed him of a steady but rapid fluid increase in the active pits.

The RT fluid unit data indicated a coincidental reduction in rheology and density, and it was inferred that there could be an addition of water into the active system. Note: The RT fluid unit was connected to the active suction tank.

This gain did not set off any pit level alarms at this early stage partly because it was associated with continuing mud losses to the well.

Additions of water into the active suction tank was identified and stopped after approximately 13 barrels (2 m^3) of water had been added to the 340 barrels (55m^3) tanks – see the operations logging chart below.

The minor water addition to the active system caused the rheology of the drilling fluid to be reduced with the eventual consequence of reducing the pump pressure.

The immediate indication of the falling rheology as measured by the real time RT fluid unit could be seen 10 minutes prior to the reduction in the pump pressure.

Had this contaminated mud entered the well, it would have caused a potentially hazardous loss of Equivalent Circulating Density (ECD).

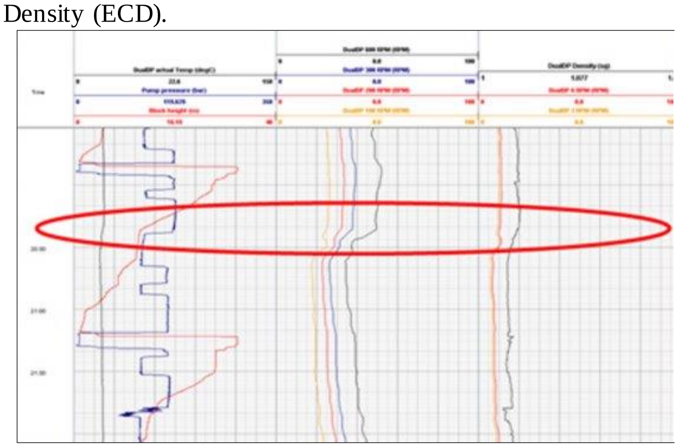


Figure 11 – the snapshot above is from the real-time drilling operations screen showing the sharp change in density and rheology values relative to drilling activities. The density and rheology values are from the RT fluid unit, where the suction was from the active suction tank.

Conclusions

The extensive experience of the provider and collaboration with most of the drilling industry's suppliers has shown that the following conclusions are apparent.

1. The reliable digitalization of drilling fluid characteristics is possible, and robust measuring & monitoring equipment ensures that the high-resolution fluid data values provided are repeatable and consistent.
2. Digitalization of the characteristics immediately ensures that the data values can be communicated to selected stakeholders for their attention and review.
3. Real-time digitalization of the fluid's characteristics – especially the significant density and rheology properties –

enable the data values to be incorporated and compliment other drilling analysis systems simultaneously and continuously. This also ensures non-conforming fluid spikes are captured and attended to.

4. Digitalized fluid values can be streamed from the highest level possible – shear stress & shear rate – rather than from the lower derived Plastic Viscosity and Yield Point level.
5. Digitalised data values can be displayed more visually than the traditional manual fluids engineer's values.
6. Digitalised data values can be associated with out-of-boundary and riverbank alarm systems for improved control, recognition and reaction.
7. The real-time property values can support additional facilities such as displacement and interface identification programs.
8. The real-time and historic fluid characteristics and associated data streams can be re-called and shown on desktop or smart device screens upon request.
9. A universal data format – in this case OPC UA - is most appropriate owing to its applicability and useability by the drilling analysis systems of all external providers.
10. Measuring and monitoring of the fluid's characteristics can be achieved without additional onsite personnel.

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Nomenclature

OPC UA	*Open Platform Communications United Architecture*
PSI	*Pounds per square inch*
API	*American Petroleum Institute*
SI	*International Systems of units*
^0F; ^0C	*Temperature Fahrenheit; Centigrade*
HMI	*Human Machine Interface*
IOT	*Internet of Things (software integration & collaboration)*
FV	*Funnel Viscosity*
RPM	*Revolutions per Minute*
ROP	*Rate of Penetration*
OBM	*Oil Based Mud, aka Non-Aqueous Drilling Fluid*
KCl	*Potassium Chloride – drilling fluid*
PPG	*Pounds per Gallon - density*
SG	*Specific Gravity - density*
M^3	*Cubic Meters – volume, equivalent to 6.29 barrels*
ECD	*Equivalent Circulating Density*

References

1. Rachid El Boubsi, Jan Atle Andresen, Geertjan van Og, Huisman; Knut S. Bjørkevoll, Roar Nybo, SINTEF Petroleum; Jan Ove Brevik, Statoil; Gerhard Nygaard, Cybernetic Drilling Technologies; George G. Smith, Intelligent Mud Solutions AS, 2017. SPE-185929 "DEMO2000 – Drilling Process Control."
2. Markus Doschek, Donia Wamani, OMV; Henrik Sveinall, Reagan James, Intelligent Mud Solutions; Roland Faschingbauer, Sirius-ES IADC Conference Abu Dhabi December 2021 - CASE HISTORY: A description of the technical experiences, benefits and challenges of a real-time drilling fluids monitoring system when integrated into a drilling campaign.
3. Roar A. Fjellheim, Computas AS; Reidar B. Bratvold, University of Stavanger; Mike C. Herbert, ConocoPhillips Norge AS, 2008. SPE 111876 "CODIO - Collaborative Decision Making in Integrated Operations."