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Operational results from near-line electronic composition measurements in non-aqueous fluids and early results of in-line testing

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Abstract

Ensuring that mud properties are appropriate for a particular well and that changes are noted and corrected quickly is critical while drilling. Following last year's AADE paper "A novel approach to the analysis of non-aqueous fluids for drilling" Salunda has developed an in-line prototype of the handheld device to determine the concentration of oil, solids and brine in non-aqueous fluids (NAF). This electronic device utilizes electrical measurement characteristics at radio frequencies in conjunction with a mud and oil density input to determine the mud properties based on API 13-B2 calculations.

The in-line prototype is designed to be submerged in drilling mud allowing for real-time measurement data to be captured *in-situ*. It is imperative that this data is accurately and consistently measured to allow engineers to quickly make informed decisions in order to achieve and maintain optimum drilling fluid performance.

In this paper we present operational results of the hand-held fluid analyzer to show accuracy and repeatability of electronic oil, brine and solids measurements, and share early results of real-time in-line measurements. The paper includes electronic measurement data gathered in controlled experiments; and during operations concurrently with retort and titration measurements.

Introduction

Drilling muds contain a number of components which are designed to carry out key functions during drilling; weighting solids are used to control the density of the fluid, bridging materials isolate drilling fluids from the formation via a filter cake and salts serve to aid well stabilization.

It is therefore critical that the mud properties are accurately and regularly monitored to ensure they are optimum for a particular well and that changes are identified quickly so that the correct additives and concentration of these additives can be made to ensure optimum performance.

Drilling mud composition and salinity has traditionally been measured via manual retort and titration processes which can present several potential issues, namely the speed and frequency in which these measurements can be made; a typical retort and titration measurement can take up over an hour to complete, meaning it can be slow to identify changes in mud properties.

API procedures serve to standardize the retort and titration process to ensure consistency across measurements and users, however this process is susceptible to inconsistencies due to differences in user interpretation, methods and instrumentation and there can be substantial errors in measurements.

Electronic oil, brine and solids measurements

A solid-state, hand-held instrument called capable of measuring the characteristic electromagnetic properties of non-aqueous drilling fluids and computing the concentration of oil, brine and solids has been developed.

Electronic mud measurements allow for the quick and frequent measurement of mud properties whilst ensuring consistency between measurement data, providing engineers with a consistent data set to work with and allowing changes in composition to be closely monitored and acted upon.

The technology has been in use for over 12 months; during which time data has been gathered comparing electronic measurements to manual retort and titration measurements; providing valuable insight into the effectiveness of using electronically generated composition measurements in operations. In addition, controlled experiments have been carried out on freshly formulated muds whose compositions are known. This paper presents two sets of data; operational measurement data collected via the hand-held drilling fluid analyzer gathered by a US-based solid handling equipment maker, and electronic measurements with controlled compositional perturbations made on freshly formulated lab muds in near-line and in-line configurations of the drilling fluids analyzer.

Measuring changes in drilling mud

Verification of a sensor's capabilities and compliance is critical for real-world applications and long term operational success. The fluid analyzers viability has been tested in a series of controlled laboratory experiments; checking its critical features and capabilities through laboratory testing against known samples and retort and titration to validate accuracy and performance acumen.

A mud sample, whose nominal composition was known, provided the starting point for testing. Recognized quantities of oil, fresh water, brine and bentonite were then added to replicate in-service operations and create a range of different muds with known compositions. Retort and titration based on API method 13 B-2 were undertaken at the start and end points to validate electronic measurements as different constituents were added to perturb the sample composition by known, fixed amounts.

Multiple retort, titration, density and electronic analyzer measurements were undertaken to identify the characteristics of the starting sample. The hand-held probe was used to measure the oil, water, solid and salinity content of the initial mud sample. The probe was set to 'variable salinity' mode and the mud density set to the density (pounds per gallon) based on the average of several mud density readings. The instrument was calibrated with a sample of 'DF-1' base oil before eight electronic repeat measurements were completed.

To produce a water-continuous solution for the salinity measurement, 20ml of mud was diluted with in a 205ml solution and blended for two minutes to ensure full dilution of the mud.

Table 1. Starting sample composition and salinity data based on electronic measurements.

Test Number	Oil %	Brine %	Corrected Solids %	Brine Salinity mg cl-/l brine
1	58.1	25.1	16.8	135,600
2	57.8	25.4	16.8	136,900
3	58	25.2	16.8	137,200
4	57.9	25.3	16.8	134,800
5	58	25.4	16.6	136,800
6	57.9	25.4	16.7	133,500
7	57.8	25.5	16.7	135,200
8	57.9	25.5	16.6	134,800
Average	**57.9**	**25.4**	**16.7**	**135,600**

A retort test, involving a 50ml oven, provided an % oil, water and solid volume as the starting point. 50ml of drilling mud was added to the retort vessel before it was placed in the heating chamber. A condenser was then attached to the tube emanating from the retort vessel to ensure the O ring seal was present and a tight connection achieved. A 50ml measuring cylinder was then placed under the exit spout of the condenser. Testing (one-hour heat-up/dwell cycle in total) occurred with the temperature set to 950°F (510°C) before vessel was cooled and the distillate analyzed – oil and water levels were recorded to nearest half division on the measuring cylinder and used to calculate the oil, water and solids % volume.

Table 2. Starting sample composition data based on retort.

Test Number	Oil %	Water %	Uncorrected Solids %
1	57	27	16
2	56	27	17
3	57	27	16
4	58	26	16
Average	**57**	**26.8**	**16.2**

Titration provided a salinity measurement for the starting sample. 100ml of deionized water and 50ml of propylene glycol propyl ether were mixed in a 250ml conical flask. One ml of drilling mud was added to the mixture, together with a few drops of dilute sulphuric acid to counteract lime in the mud sample and 1ml of potassium chromate indicator solution. 0.0282N silver nitrate solution was then added slowly from a burette until the mixture in the flask started to turn pink. A series of 1ml aliquots of silver nitrate solution were then added until the mixture changed from yellow to pink, with the flask swirled after each addition. The mud salinity (in mg Cl-ions/liter mud units) is determined as the number of ml of silver nitrate solution needed to produce the color change, multiplied by 1000.

Table 3. Starting sample salinity data based on titration.

Test Number	Ml AgNO3 Solution	Mud Salinity (mg CL-/l mud)
1	38	38,000
2	37	37,000
3	39	39,000
4	40	40,000
Average	**38.5**	**38,500**

A 250ml sample of the starting mud sample was weighed using digital scales to determine the density of mud.

Values for brine, corrected solids and brine salinity were calculated by combining the % oil, water and uncorrected solids from the retort measurements with the mud salinity measurements from the titration analysis. This enabled the average of the mud values to be compared directly with the average measurements provided by the hand-held anaylzer.

Table 4. Starting sample salinity and composition based on electronic, retort and titration measurements.

Test Number	Oil %	Brine %	Corrected Solids %	Brine Salinity (mg Cl- / l brine)
Retort/ Titration	57	28.3	14.7	136,200
Hand-held probe	57.9	25.4	16.7	135,600
Difference	0.9	-2.9	2	600

Perturbation Testing

Once the starting sample had been determined, it was perturbed by adding measured quantities of DF-1 base oil, water of different salinities and bentonite clay. This sample was measured incrementally using both electronic measurements and retort and titration methods.

In detail, the retort, titration and density measurements indicated that a 250ml sample of the starting mud contained 57% oil, 28.3% brine and 14.7% corrected solids. Brine salinity showed 136,200mg chloride ions/liter brine. The nominal perturbed mud compositions were then calculated using these values as the starting point. Follow-up electronic measurements were taken after each addition of oil, water, brine, barite and bentonite to compare with the calculated values. Retort and titration tests were also carried out after the final addition of oil, fresh water, brine and bentonite to provide a comparison to retort and titration.

The addition of DF-1 base oil increased the % oil while leaving the brine salinity unchanged. There was 57% oil content in the 250ml sample of mud, leaving the volume of the oil in the sample at 142.5ml. Oil was then added in 20ml increments until a total of 100ml had been introduced.

Table 5. Drilling fluid analyzer % oil measurements compared to retort and calculated % oil volume, when incrementally adding oil.

Added Oil (ml)	Expected Oil Volume (ml)	Expected Oil %	MudChecker Oil %
0	142.5	57	57.9
20	162.5	60.2	60.9
40	182.5	62.9	63.2
60	202.5	65.3	65.2
80	222.5	67.4	66.9
100	242.5	69.3	68.6

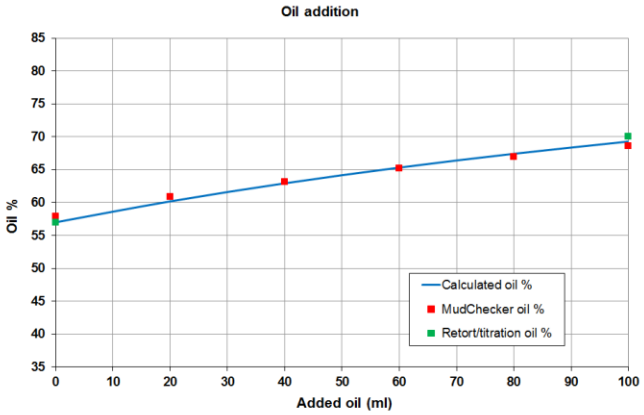

Figure 1. Drilling fluid analyzer % oil volumes compared to retort and calculated % oil volume, while adding oil in increments.

Oil content measurements taken via the hand-held probe correlate extremely closely to the calculated content volumes; Oil content measurements are within 1% of the calculated content volumes at all measurement increments. This is a good demonstration of the device's ability to accurately track changes in oil composition over time. It should be noted that the elevated temperatures used during retort to distill oil and water leads to some loss of oil distillate, which may explain some differences in results.

The addition of fresh water and brine to the mud sample will increase the water % volume of the same and change the brine salinity. The 250ml sample of mud has a brine percentage of 28.3% and a brine salinity of 136200 mg chloride ions/litre brine. The actual volume of brine in the sample is therefore 70.8ml. Fresh water and brine were then added in 10ml increments until a total of 50ml had been added to measure the effect on the water % volumes and the brine salinity.

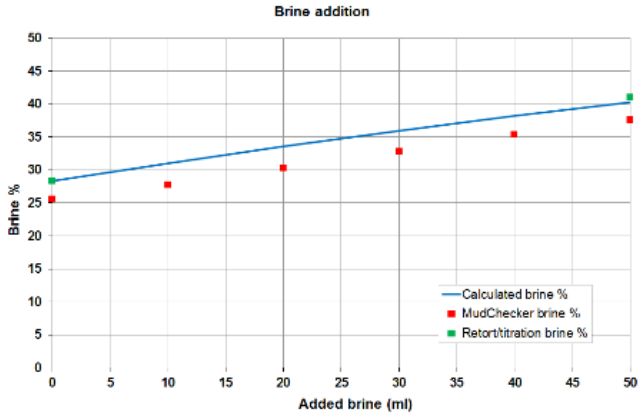

Figure 2. Drilling fluid analyzer % brine volumes compared to retort and calculated % brine volume, while adding brine in increments.

Additions of both fresh water and brine showed that the hand-held drilling fluid analyzer was extremely accurate at tracking increases in water concentration in drilling mud.

Large increases in water concentration can provide an early indicator for the potential of wellbore collapse, or of a kick. The speed with which measurements can be taken via the hand-held probe means operators are able to quickly and accurately detect increases in water and act to prevent such dangers.

Table 6. Expected salinity & electronic salinity measurements when incrementally adding fresh water

Added Water (ml)	Salinity Expected	Electronic Salinity Measurement (Cl- / l brine)
0	136,200	140,600
10	119,300	125,600
20	106,200	111,800
30	95,600	99,800
40	87,000	94,000
50	798,00	845,000

In addition to tracking the composition of the drilling fluid, measurements were also taken to validate the devices ability to accurately track changes in salinity levels. Salinity measurements were accurate to within 25,000 mg cl-/litre brine proving the device to be extremely effective at trending changes in chloride content.

Bentonite clay added to the mud sample increased the % solids, while brine salinity remained unchanged. The 250ml sample of mud had a solids percentage of 14.7% - the actual volume of solids was 36.8ml. The addition of clay in 5g steps occurred until 25g total had been introduced, bringing clay density to 2.6g/ml.

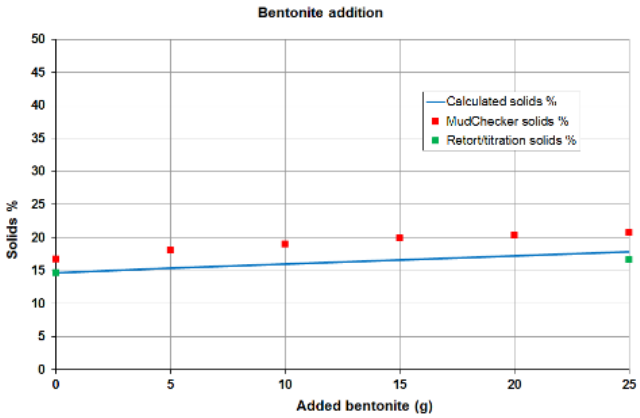

Figure 3. Drilling fluid analyzer % solids volumes compared with retort & calculated % solids volume while adding bentonite in increments.

Drilling fluid analyzer measurements taken after the addition of bentonite provides a good demonstration of the device's ability to accurately measure changes in solids composition. The experiment showed that the hand-held probe tracked the addition of Bentonite closely, with its results correlating closely with the expected/calculated oil composition to within a 2.5 % deviation from the expected volumes. Solids and brine also tracked closely to the expected concentrations.

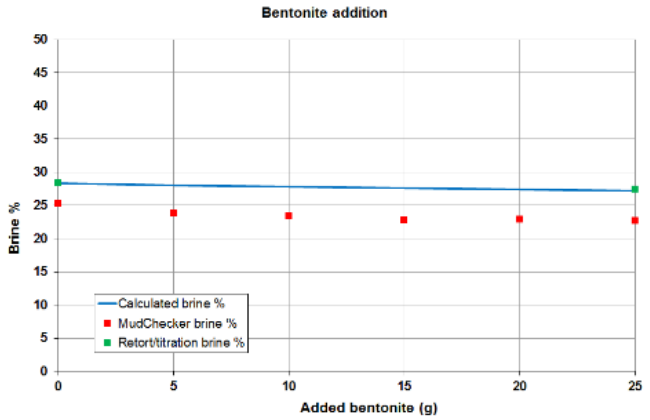

Figure 4. Drilling fluid analyzer % brine volumes compared with retort & calculated % brine volumes, while adding bentonite.

Perturbation of the sample by fixed amounts clearly showed that there a good correlation between the expected content, retort measurements and hand-held analyzer measurements.

The hand-held probe measurements carried out on the starting sample proved the device's effectiveness in providing repeatable results when compared to retort testing with measurements on the same sample being within 0.4 % range.

The tests validate the hand-held drilling fluid analyzers capability for rapid and consistent analysis of drilling mud with the device proving to be good at trending the composition of oil-based drilling fluids. The measurement results correlated closely with the actual composition and demonstrated the analyzer's capacity across all samples to deliver tests accurately and precisely.

Operational/Field Results

Solids handling equipment is often routinely tested to ensure efficiency. Measuring the composition of drilling fluids at different points in the mud ecosystem commonly forms part of the maintenance process. This example looks at electronic measurements taken by a maker of solids handling equipment concurrently with retort measurements over a 39-day period.

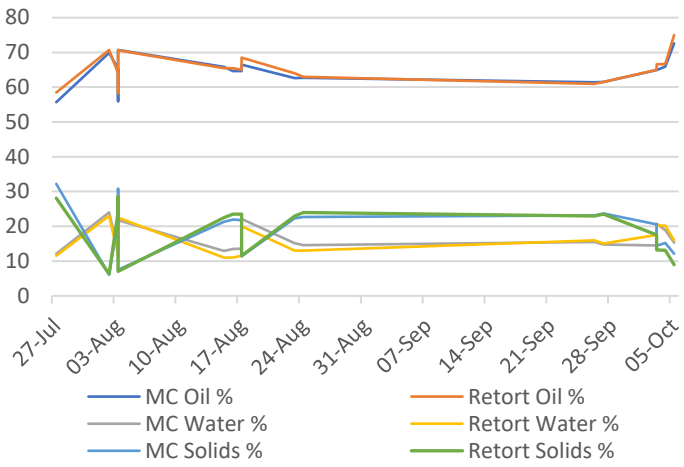

Figure 5. The volume percentages of oil, water & solids in the mud samples recorded via retort & the drilling fluid analyzer

The data included in this sample contains 17 test records that were carried out on field muds that range from oil concentrations of 58.5% to 75%.

The max drilling fluid analyzer error over the test period was +4.1% which occurred on the initial test carried out on the 27th of July. The mean average of error across the oil, water & solids is -0.8, +0.6 and +0.5% respectively. This example proved the devices feasibility to accurately track the composition of field muds with varying properties and percentage compositions.

Table 7. Drilling fluid analyzer level of error in composition measurements compared to retort

Date	Oil Error	Water Error	Solids Error
27-Jul	-2.8	0.6	4.1
02-Aug	-0.8	1	-0.2
03-Aug	1.3	0.9	-2.2
03-Aug	-2.3	1.7	2.3
03-Aug	0.1	-0.7	0.5
15-Aug	0.3	1.9	-1.2
16-Aug	-0.9	2.5	-1.6
17-Aug	-0.4	2.1	-1.7
17-Aug	-2	2.1	-0.1
23-Aug	-1.4	2.1	-0.7
24-Aug	-0.3	1.6	-1.3
26-Sep	0.4	-0.5	0.1
27-Sep	0	-0.2	0.2
03-Oct	-0.1	-3	3.1
03-Oct	-1.7	0.5	1.2
04-Oct	-0.8	-1.3	2.1
05-Oct	-2.4	-0.7	3.1
Average	**-0.8**	**0.6**	**0.5**

In-line capability testing and early results

Radio frequency sensor technology has been utilized to trial an in-line, battery-powered prototype that tracks the oil, water & solid composition. The device is intended to be partially submerged in mud samples and provide real-time oil, water, solid composition measurements, recorded in accompanying software.

Figure 6. Drilling fluid in-line analyzer prototype

The instrument has been calibrated and is suitable for use with all oil and synthetic based drilling muds. The accompanying software allows the user to input the density value (i.e. the mud weight), salinity and the oil density, and uses these values to calculate the full results based on the measurements.

A computer interfaces with the device via a USB cable to access and process measurements. The software functionality allows users to enter parameters used in the calculation (such as mud density, oil density and salinity), customize output parameters and graphs, log results, view results and download previous records.

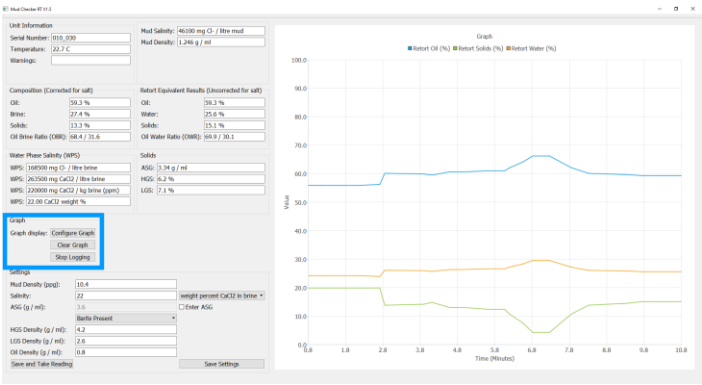

Figure 7. In-line drilling fluid analyzer prototype software displaying oil, water and solids composition

Table 8. In-line drilling fluid analyzer log data sample, displaying the devices repeatable results

Time	Retort Oil (%)	Retort Water (%)	Retort Solids (%)	Oil Water Ratio (OWR)
14:16:46	59.2	7.4	33.4	88.9 / 11.1
14:17:50	59.2	7.4	33.4	88.9 / 11.1
14:17:54	59.2	7.4	33.4	88.9 / 11.1
14:17:58	59.2	7.4	33.4	88.9 / 11.1
14:19:02	59.2	7.4	33.4	88.9 / 11.1
14:20:07	59.2	7.4	33.4	88.9 / 11.1
14:21:13	59.2	7.4	33.4	88.9 / 11.1
14:21:38	59.2	7.4	33.4	88.9 / 11.1
14:21:41	59.2	7.4	33.4	88.9 / 11.1
14:22:46	59.3	7.3	33.4	89.1 / 10.9
14:23:44	59.3	7.3	33.4	89.1 / 10.9
14:23:47	59.3	7.3	33.4	89.1 / 10.9
14:24:27	59.3	7.3	33.4	89.1 / 10.9
14:24:30	59.3	7.3	33.4	89.1 / 10.9
14:25:34	59.3	7.3	33.4	89.1 / 10.9
14:25:45	59.3	7.3	33.4	89.1 / 10.9
14:25:48	59.3	7.3	33.4	89.1 / 10.9
14:26:53	59.3	7.3	33.4	89.1 / 10.9
14:27:58	59.3	7.3	33.4	89.1 / 10.9
14:29:03	59.3	7.3	33.4	89.1 / 10.9
14:30:07	59.3	7.3	33.4	89.1 / 10.9

Conclusions

The results reported in this paper present electronic measurements as a viable alternative to retort & titration for measuring the composition and salinity of oil-based & synthetic-based drilling *muds*. Electronic composition & salinity measurements provide users with a consistent data set that is ideal for trending and adjusting drilling fluid properties.

The electronic technique has been extensively tested against both field and laboratory muds and results have been shown to correlate well with both perturbation of samples by known quantities of material, and with measurements based on traditional retort and titration techniques.

The speed in which measurements can be carried out via this method allow for more frequent mud checks and, using an in-line prototype, provide real time data for mud composition.

Nomenclature

NAF = *Non-Aqueous Fluids*