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# A novel approach to the analysis of non-aqueous fluids for drilling

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## Abstract

An instrument has been developed based on the measurement of multiple electrical characteristics at radio-frequencies to determine the concentration of oil, brine and solids in non-aqueous fluids (NAF). This instrument, the MudChecker, was developed by Salunda Limited (Oxfordshire, United Kingdom) and measures the oil, brine and solids content of an oil-based mud (OBM). In an additional mode of operation, MudChecker can also measure the salinity of the brine within the mud. As with retort measurements, density information for the base-oil fluid, high-gravity solids, low-gravity solids, and the drilling mud are "inputs" required by the instrument to generate results based on the API 13-B2 calculations.

The instrument is a hand-held, solid-state device that requires very little space to conduct the test. In contrast to the distillation procedure of a retort, NAF samples can now be quickly analyzed without heating or otherwise altering the temperature of the fluid. Use of the instrument yields time savings, cost savings, eliminates potential HSE hazards, and gives more repeatable results than the retort and chemical titration procedures commonly used. This paper explains how the instrument is used and gives some comparative data generated in side-by-side trials against manually recorded retort data and chemical titration data. Data for "new-build" muds, "lab muds" and field muds from OBM drilling operations is presented, including from recent performance improvements.

## Introduction

Oil and gas field drilling fluids perform a number of critical functions, and their composition must be closely monitored and analyzed throughout drilling operations. The muds used to undertake these actions are produced from either aqueous or oil-based suspensions, enabling important functions to be undertaken during the oil and gas extraction process. While generally easier to maintain in terms of formulation and maintenance, oil-based muds generally are more expensive to manufacture.

There are components that are common to all muds: a mineral to control the weight or density of the mud, a bridging solid to encourage the formation of a filter cake within the well, and wetting and thickening agents to tailor the rheology of the mud. Salts also feature in both types of fluid, providing an aid to well stabilization – for oil based muds, these salts are contained in aqueous emulsion droplets. Drilling fluids perform a number of other functions in addition to limiting the potential escape of oil and gas. They ensure that the well remains clear of any debris by expediently moving the drill bit cuttings quickly to the surface as well as preventing rock dispersion. They also stop invasive fluids and solids from seeping back into the rock formation. Muds stabilize the well during the drilling process, limiting the potential for any collateral damage to the production zone. Controlling mud fluid parameters is important to achieve proper drilling performance and requires that properties are measured with sufficient accuracy - optimum drilling fluid performance is strongly dependent on knowing the formation properties so that correct selections of additives can be made. Likewise, it is important to know if solids that are separated at the shakers are drill cuttings, or pieces of rock.

Today, measurements of drilling fluid composition and salinity are made using retort and chemical titration procedures. This process can be slow, taking several hours to clean, fill and heat the retort cup to around 950°F in order to distill the components of the mud. In parallel the engineer may perform a chemical titration for the chloride ions in the salts dissolved in the mud. Measurements are made by eye of the oil and water levels in a distillation cylinder, and of a color change in the titration products in a flask. The time required for these methods limits the frequency of these tests. Accuracy and precision of results is dependent on user experience, operator skill, equipment cleanliness, and the manual reading of levels and color changes in glassware. Indeed, accuracy is frequently not reproducible from retort to retort and operator to operator due to differences in equipment and interpretation of measurement methods (e.g. determining the exact position of the oil/water interface in the measuring cylinder when waxy emulsifiers are present). Procedures can vary from user to user.

## MudChecker

MudChecker was developed by Salunda Limited; an Oxford (England) based Instrumentation Company established to exploit technology from Oxford University. The aim is to provide a much quicker and more repeatable means of detecting a drilling fluid composition than performing retort and chemical titration tests: a more objective measurement with less room for operator bias. The MudChecker tests take as little as three minutes to perform, so the frequency of mud checks can increase. The capability of monitoring the trend in drilling fluid composition could be of particular value when drilling difficult sections, limestone, horizontal wells and salt domes, or during underbalanced or managed pressure drilling (MPD) offshore or in deep-water.

The device has intrinsically low power consumption and has batteries that are rechargeable using a USB cable. It is electrically safe and generates no fumes, heat or odors. It utilizes software to analyze and display results on any connected laptop, PC, or tablet. Results are recorded electronically with a time stamp, and may be recalled or exported for subsequent analysis and trending.


**Figure 1 - MudChecker performing a measurement on an oil-based mud sample. Approximately 250ml of mud is needed for each full test (including the salinity measurement), but only 20ml of the mud is consumed in the test.**

Similarly, MudChecker can be used to make quick measurements of total percentage solids content in samples taken from the inlet and outlet of solids handling equipment to determine if they are operating within specifications or require maintenance. By plotting a trend from frequent spot measurements, the efficiency of solids management equipment may be optimized by adjusting parameters such as shaker speed, flow rate or screen size until the total solids at the outlet falls below acceptable levels, enabling the base-oil and weighting material consumption to be minimized. Using the MudChecker to optimize efficient operation of a shaker may also reduce or eliminate the need for additional solids management equipment such as centrifuges or hydro-cyclones on the well site, resulting in substantial cost savings.

## Operation

There are two different modes of operation for MudChecker. In the first mode, it measures the volume percentages of oil, brine and solids, but the brine salinity is taken to be a known value. The MudChecker unit is first connected to a PC via a USB cable. The supplied PC software then communicates with the MudChecker and allows certain test parameters to be set including the density values of the mud components, and the brine salinity unit to be used in the tests. The brine salinity can be specified in volume units such as mg of chloride ions per liter of brine, or weight units such as mg of chloride ions per kg of brine (ppm). The unit may be unplugged from the PC while the tests take place.

The actual mud density and brine salinity can be input directly into MudChecker via the display and four keys on the front panel. The metal probe is then dipped into the mud sample as shown in Figure 1. It is very important that the probe is completely filled with the mud, and so a narrow slot is machined along the length of the outer probe cylinder. This enables the operator to visually check that the probe is filling with mud as it is slowly dipped into the container. After three minutes, the measurement is complete and the unit "beeps" to indicate that it can be removed from the mud.

If the unit is still connected to the PC via the USB cable, the composition calculation is immediately performed and the results displayed on both the PC and on the MudChecker screen (in an abbreviated form). If the unit is disconnected from the PC, the results are displayed as soon as the connection is restored. It is not necessary to connect to the PC immediately after each test; a series of tests can be performed then all of the results are generated as soon as the connection is restored. Each test result has a unique number and the values are stored within the unit, available for recall at a later date. The PC can produce a spreadsheet data file for each test that can be printed out to document the test results.

In the second mode, MudChecker measures the volume percentages of oil, brine and solids and also determines the salinity of the brine in the mud. The test starts in the same way as the first operating mode, but an additional test is performed on a sample of the mud that has been blended with a controlled amount of a supplied surfactant solution. 20ml of the mud is added to 205ml of the surfactant in a blender cup, and the mixture blended for a couple of minutes at a high blend speed. When the initial test in the undiluted mud has finished, the outer shield of the probe is removed and the central rod cleaned. A second, larger diameter probe shield is then attached to the unit and the probe dipped into the diluted mud sample for the second test. After one minute, the measurement is complete and the unit "beeps" to indicate that it can be removed from the mud.

## Repeatability

To test the repeatability of the MudChecker measurements, a typical oil-based drilling mud was repeatedly tested over a period of several days. The results of eight tests on this mud sample are shown in Table 1 (with the volume percentages rounded to the nearest 0.1% and the salinity values rounded to the nearest 100 mg $Cl^-$ / liter brine).

**Table 1 - The results of 8 MudChecker tests on a typical oil-based mud sample.**

| Test number | Oil % | Brine % | Corr. Solids% | Mud salinity (mg $Cl^-$/ l mud) | Brine salinity (mg $Cl^-$/ l brine) |
|---|---|---|---|---|---|
| 1 | 58.1 | 25.1 | 16.8 | 34,000 | 135,600 |
| 2 | 57.8 | 25.4 | 16.8 | 34,800 | 136,900 |
| 3 | 58.0 | 25.2 | 16.8 | 34,600 | 137,200 |
| 4 | 57.9 | 25.3 | 16.8 | 34,100 | 134,800 |
| 5 | 58.0 | 25.4 | 16.6 | 34,800 | 136,800 |
| 6 | 57.9 | 25.4 | 16.7 | 33,900 | 133,500 |
| 7 | 57.8 | 25.5 | 16.7 | 34,500 | 135,200 |
| 8 | 57.9 | 25.5 | 16.6 | 34,400 | 134,800 |
| Average | 57.9 | 25.4 | 16.7 | 34,400 | 135,600 |

## Test results

Prototype MudChecker units were supplied to laboratories at a major oil and gas operator and a drilling fluids company (Newpark Drilling Fluids, Inc.). Over a period of several months, a large variety of drilling muds passed through these laboratories and their compositions were analyzed using the standard retort and chemical titration procedures to determine the volume percentages of oil, water, brine and solids (both uncorrected and corrected for salt), together with the mud salinity. For many of these muds, MudChecker measurements were also made to provide a direct comparison with the retort and chemical titration data. The devices were used in full measurement mode, determining the mud salinity as well as the composition percentages.


**Figure 2: MudChecker requires much less space than the apparatus required for a retort and chemical titration measurement.**

Approximately half of the mud tests were performed on "new-build" or "lab muds" with the remaining half relating to field muds that had been used for drilling. Half of the tests were performed on muds with synthetic base oils, with the remaining half using diesel. The mud densities covered a wide range from 9.40 ppg (1.13 g/ml) to 17.16 ppg (2.06 g/ml). In all, the results from 71 different mud tests were collected. Some muds were tested more than once at different times in order to test the reproducibility of both the MudChecker and the retort measurements.

Figure 3 shows the results obtained on the 71 tests for the oil volume percentages of the mud samples. The values obtained from the retort tests are plotted on the X axis, and the values reported by MudChecker are plotted on the Y axis. The straight line is a least-squares fitted line that is pinned to go through the origin. The tests performed by the two mud laboratories have different symbols.

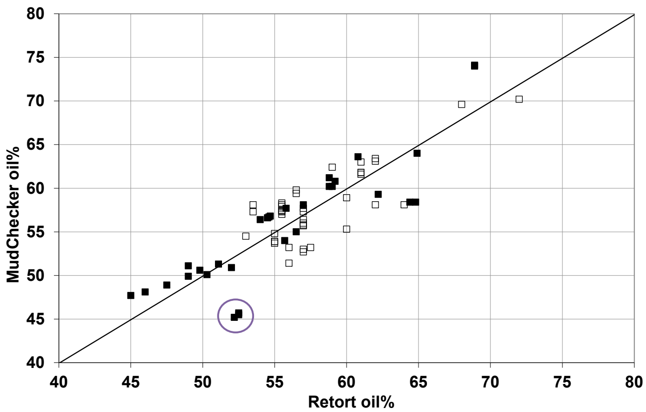


**Figure 3: The volume percentages of oil in the mud samples.**

The oil percentage values in the mud samples cover a very wide spread between 45% and 72%, and the MudChecker oil percentage values are in reasonable agreement with the retort percentage values; the fitted line has a slope that is extremely close to 1.0. Three test points in Figure 3 have been highlighted by a circle. These points lie well below the fitted line and will be considered in further discussions below.

Figure 4 shows the results obtained for the volume percentages of water (without any dissolved salts). This quantity is directly linked to the volume of water transferred to the measuring cylinder when the mud sample is processed in the retort, and so provides a simple comparison with the retort data. In full measurement mode, MudChecker calculates both the brine volume percentages and the water volume percentages, the latter to enable the mud engineer to directly compare retort data. The water percentage values in the mud samples cover a wide spread between 7% and 34%, and the MudChecker water percentage values are in reasonable agreement with the retort percentage values; the fitted line again has a slope that is extremely close to 1.0. The three mud tests previously highlighted in Figure 3 have also been highlighted in Figure 4. It should be noted that these results were obtained using MudChecker prototypes and without calibration of the units for the base oil in the muds. Calibration functionality is now available as standard, and has been found to increase accuracy (See table 2).

Figure 5 shows the results obtained for the volume percentages of solids (including any soluble salts). Again, this quantity is directly deduced from the volumes of oil and water transferred to the measuring cylinder when the mud sample is processed in the retort. MudChecker calculates both the corrected solids volume percentages (without any soluble salts) and the uncorrected solids volume percentages with the soluble salts, the latter to enable the mud engineer to directly compare with retort results.

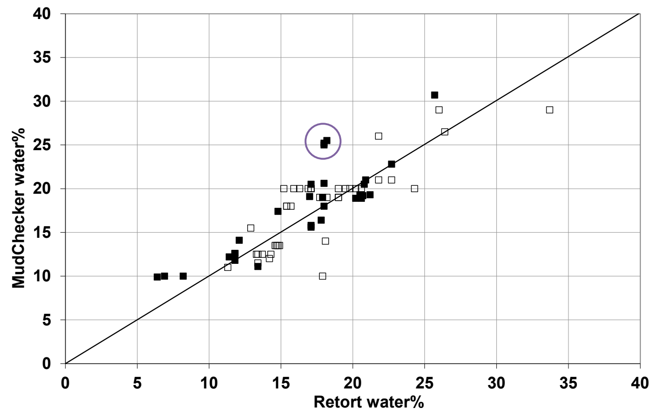


**Figure 4 - The volume percentages of water in the mud samples.**

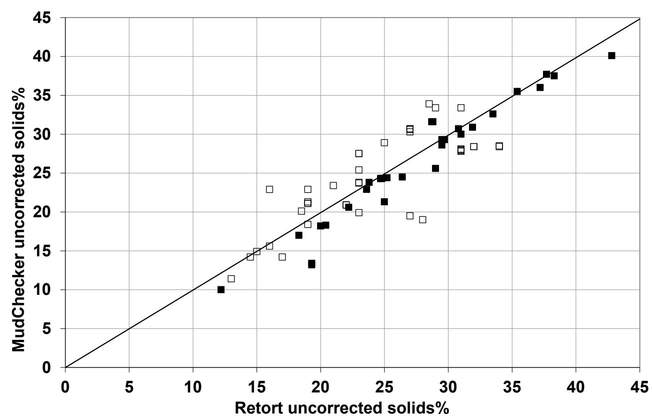


**Figure 5 - The volume percentages of solids (including soluble salts) in the mud samples.**

The uncorrected solids percentage values in the mud samples cover a wide spread between 12% and 43%, reflecting the wide range of mud densities in these mud samples. The MudChecker uncorrected solids percentage values are in reasonable agreement with the retort percentage values with the fitted line having a slope that is extremely close to 1.0.

Figure 6 shows the results obtained for the mud salinity, expressed as the number of mg of chloride ions per liter of whole mud. This quantity is directly related to the volume of silver nitrate solution used when a fixed volume of mud (commonly 1 ml) is titrated for chloride ions in the presence of a potassium chromate indicator. MudChecker also calculates and reports the brine salinity in a variety of common salinity units. Volume-based units are the number of mg of chloride ions or the number of mg of $CaCl_2$ per liter of brine; weight-based units are the number of mg of chloride ions per kg of brine (i.e. ppm $CaCl_2$) or weight-percentage of $CaCl_2$.

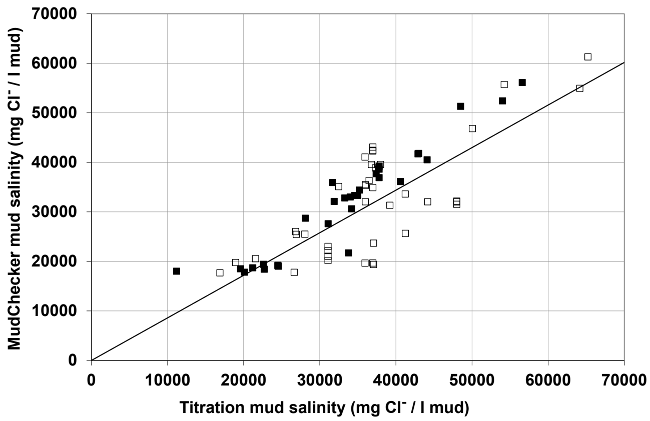


**Figure 6 - The mud salinity values (in mg chloride ions per liter of whole mud).**

The fitted line in Figure 6 has a slope that is noticeable smaller than 1.0, indicating that the mud salinity values deduced from the mud titration measurements are systematically higher than the values reported by MudChecker. This discrepancy is under investigation, but one possibility is that mud engineers might tend to overshoot the correct end point on the silver nitrate solution due to the difficultly of determining the change from yellow to pink in an often murky-brown diluted mud solution.

The three mud tests highlighted by the circles in Figures 3 and 4 relate to the repeated testing at different dates of the same mud sample. This sample stood out from the others since it consistently gave an oil percentage that was too low (by 7 percent), and a water percentage that was too high (by 7 percent) compared to the retort values. A sample of this mud was therefore acquired by Salunda, and investigated to see what was causing the unusual results.

It is now believed that this sample has a particularly high clay or shale content compared to the other samples, and the properties of the clay were affecting the accuracy of the MudChecker measurement. Tests with samples blended with different amounts of bentonite clay confirmed the effect. Enhancements were made to the MudChecker and new measurement technology was found to better characterize the solids present and improve the accuracy of the results.

The effect of these improvements is shown in Table 2 which shows the composition percentages for this mud sample obtained using the prototype and production versions of the MudChecker respectively. The "prototype" values are the averages of the three mud tests highlighted by the circles in Figures 3 and 4 above, while the "product" values are the averages of three MudChecker tests performed on this mud in the Salunda laboratory using the latest technology. Before the enhancements were implemented, the MudChecker values for the oil and water percentages differed from the retort values by 7%. After the enhancement, the MudChecker and retort values agree to within 1%. In addition, the MudChecker was calibrated for the base oil.

**Table 2 – The MudChecker results on the sample with high clay/shale before and after the calculation algorithm was changed to allow the detection of clay.**

| Test | Oil % | Water % | Uncorr. Solids % | Mud salinity (mg $Cl^-$/ l mud) |
|---|---|---|---|---|
| Retort/ Titration (ave.) | 52.4 | 18.0 | 29.6 | 37,800 |
| MudChecker Prototype (Ave.) | 45.5 | 25.2 | 29.3 | 38,200 |
| MudChecker Product (ave.) | 52.6 | 18.4 | 29.0 | 32,800 |

## Conclusions

The work described in this paper represents a new novel approach to the analysis of the composition of oil-based and other NAF muds. MudChecker is a hand-held, solid-state measuring device that is simply dipped into the mud sample to provide values for the volume percentages of oil, water and solids in the mud, together with the mud salinity. This paper explains how the instrument is used and gives some comparative data generated in side-by-side trials against manually recorded retort data and chemical titration data. Data for "new-build" muds, "lab muds" and field muds from OBM drilling operations is considered. A large set of more than seventy samples was tested at more than one laboratory by several users using different units over a period of several months. A variety of muds was tested with a wide range of mud weights, compositions and base oils. Field muds and fresh muds were analyzed using prototype MudChecker units. A good correlation with retort and titration was shown. Recent improvements to the MudChecker measurement technology have resulted in improvements in accuracy including better characterization of solids and calibration of the unit for a base oil is now possible. These improvements were demonstrated when samples, which previously when measured using prototype units differed from the retort values by up to 7%, were re-tested using the latest MudChecker technology and shown to agree with retort values within 1%.

## Acknowledgments

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## Nomenclature

*NAF* = *Non-aqueous fluid*
*OBM* = *Oil-based mud*
*ppg* = *pounds per gallon*