Special XYZ Techniques to Reduce Oil-Base Mud Contamination of Reservoir Fluid Samples

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ABSTRACT
It has long been understood that the proper characterization of reservoir behaviour is highly dependent on the acquisition of high-quality reservoir fluid samples. Until recently, this acquisition had to performed during a well test of a cased and perforated well, often at considerable expense to the operator. With the advent of the third generation of wire line formation testers, this acquisition can now be done during the open hole logging phase of a well. However, challenges remain, especially in the Niger Delta where the use of oil- base mud is commonplace. While the delivery of fully pressurized laboratory-quality samples is now becoming routine, the problem of ensuring these samples are not contaminated with oil base mud filtrate remains nontrivial. This paper will examine the use of special optical spectrometry as an aid to down hole sample analysis. We will investigate a spectrometry device that is sensitive to fluid colouration and show how this feature can be used to differentiate heavier, darker reservoir oils from lighter oil-base mud filtrates. We will investigate another spectrometry device that is sensitive to the Methane content of the sampled fluid and show its applicability in situations where there is little colour difference between reservoir oils and oil-base mud filtrate. Examples are given of a technique for down hole determination of sample contamination, and methods of optimising sample collection are discussed.
Keywords: oil base mud, characterization, reservoir behavior, logging, open hole, phase, down hole and mud filtrate

INTRODUCTION
The primary challenge in using wireline formation testers to acquire oil samples in wells drilled with oil base mud is the contamination of the sample by the mud filtrate. During the drilling process an unknown quantity of oil filtrate will invade that near well bore region. During sampling with a wireline formation tester an attempt is made to evacuate this region before sampling what is ideally the virgin reservoir fluid. It is the challenge of contamination monitoring to determine when the filtrate has been completely or mostly evacuated and the formation tester is pumping primarily reservoir fluid Optical spectroscopy has proven to be the most reliable method of differentiating reservoir oil from invaded filtrate oil.
Optical Spectroscopy
Figure 1 shows a schematic of the Optical Fluid Analyser (OFA) module of the Schlumberger MDT tool. As can be seen the OFA makes two different and independent measurements — a gas refraction measurement and an optical spectroscopy measurement. The optical spectroscopy measurement is the topic of this paper.
The OFA spectrometer is a ten channel device that measures the optical density of the fluid in the MDT flow line at ten different frequencies or wavelengths.

Figure 2 shows both the approximate location of the channels in the optical spectrum as well as how common reservoir fluids fit on this spectrum there are a few points to be noted. In the shorter wavelength (visible) portion of the spectrum there are significant differences in the spectral response of different oils. Intuitively this makes sense as, to the naked eye, oils can have a wide variety of colours, ranging from almost completely clear condensates through yellow and brown oils to black heavy oils. Further up the spectrum in the longer wavelengths it can be seen that the oils all have a fairly similar response, with a common peak at about 1725 nm — the so-called Oil Peak. This OD peak, well outside the visible spectrum, is a function of the resonant frequency of the C-H bond in hydrocarbon.

Optical Fluid Analyser Interpretation

Traditional OFA interpretation has relied on the difference in colour between mud filtrate and reservoir oil to allow differentiation between the two fluids and to predict contamination. It is assumed that in the majority of cases the mud filtrate will be of lighter colour than the reservoir oil and this usually holds true for black oil reservoirs. It would be expected, then, that as the near wellbore region is gradually evacuated using the Pump Out Module, that the optical density of the flow line fluid would start low and gradually build until it reached some stable level. Once this stable level is reached the engineer would infer that minimum contamination levels had been reached and therefore sample bottles could be opened.

Extensive work as been done in modeling this build up in optical density (Reference 8 and 9) and it has been found that this build up is an exponential of time raised to the power of /l2 such that:

$$OD = A - \frac{F}{(t^{5/12})}$$

Where A is the optical density of the reservoir oil that would be measured if contamination was zero. F is a fitting factor that allows the model to be fit anywhere along the buildup.

If we can assume that the differences in colouration are based solely on contamination, a reasonable assumption, then contamination level, can be calculated as:

$$C, = \frac{(A - (3D)}{} \quad '(2)$$

Where C, is the contamination at time t and OD, is the measured optical density at time t. With this equation it is possible to not only to determine contamination at present time, but by extrapolating the fit in Equation 1 it is possible to determine contamination at a future time. The more practical application is to invert this and solve for how long it will take to reach a desired level of contamination. Note that this interpretation can be done on any of the OFA channels but is most commonly done on those channels that are in the visible portion of the NIR spectrum.

The above noted algorithm is implemented in the MDT welisite acquisition software using a program called 0CM (Oil Base Contamination Monitor). With this software the Field Engineer is able to specify the beginning and end of the fitting interval as well as specify a target level of sample contamination, An example of the real time weilsite output from this software is shown in Figure 4.

Contamination Determination from the Non-visible Spectrum

The previous technique to quantify sample contamination has relied on two key points:

1.   There is a significant colour difference between the reservoir fluid and the   filtrate.
2.   The reservoir fluid is darker than the filtrate

In many instances the above criteria are well met. However, in many light hydrocarbon developments such as condensates or volatile oils, the reservoir oil can be lighter than, or very similar to, the filtrate oil. In this case an alternate method is required in order to differentiate the fluids.

Figure 3 is a close-up of the spectral response around the oil peak. There are three curves plotted: dead oil, pure CH4 Methane and live crude oil. As can be seen, a peak that is a function solely of methane joins the traditional oil peak at 1725 nm. This difference is due to the fact that CH4 is the only hydrocarbon molecule that has a single Carbon atom and therefore has no Carbon-Carbon bond.

It is a reasonable to state that, for the purposes of oil differentiation, the filtrate will behave as dead oil that is the filtrate will have no (or very little) Methane content.

The reservoir oil will have some, higher, concentration of Methane. This assumption will be dependent on the elapsed time from the invasion process and on the propensity of the Methane to diffuse from the virgin to the invaded zone. This assumption is a key factor that will allow the determination of contamination from Methane content much as was done in the visible spectrum.

Live Fluid Analyser

The ability to measure the Methane peak has been implemented in another MDT module, the Live Fluid Analyser (LFA). The LFA shares many characteristics of the OFA with the addition of a channel at 1650 nm, sensitive to the Methane peak discussed above. For contamination purposes, this channel is treated much like the channel in the visible spectrum of the OFA. An increase in OD is assumed to occur as the filtrate is evacuated. In the case of the Methane channel this increase is due to the gradual increase in gas content in the flow line as the relative concentration of reservoir fluid rises with respect to the filtrate.

It has been shown that the change in OD of the Methane channel also follows the same $t^{5/12}$ build-up that is seen in the color bases channels so the same software algorithms can be applied.

Scattering Corrections

The fluids pumped by the pump-out module are rarely completely free of mud solids or formation sand. These solids will scatter the incident light from the OFA spectrometer and will therefore cause noise on the optical density data. This noise can be of such a magnitude that it will obscure the effects of the build-up. It is noted that this noise due to scattering is mostly wavelength independent so the amount of scattering will be constant across adjacent OFA channels. The scattering in one channel can therefore be easily removed by subtracting the data from a nearby channel. The OCM implementation of this is to subtract from any given channel the data from a channel that is two channels down. All build-ups presented in OCM are scattering corrected.

Comparison with Laboratory Contaminations

The litmus test of success for the contamination measurements discussed is their comparison to laboratory measurements made on the subsequently acquired samples. In comparing LFA and OFA derived contaminations with laboratory contaminations a number of caveats must be noted. The primary caveat is that for the two most common forms of-laboratory contamination monitoring, Gel Permeation Chromatography and Gas Chromatography the contamination is determined from a sample flashed to ambient and is percent contamination by weight. OFA and LFA contaminations are determined down hole on fluid at reservoir conditions and are assumed to be per cent volume contaminations,

When an MDT sample is taken to the lab a small amount, usually less than 5cc, is flashed off and the contamination is measured in the remaining liquid at ambient conditions. If the gas content is high then there can be a considerable difference in the contamination determinations. This is best illustrated with an example:

Assume a sample with GEC or GC contamination measured at 14.0%. Also assume that the subsequent PVT analysis determined that gas specific gravity is 0.8, oil specific gravity is 0.75 and solution GOR is 2000 scf/bbl.

If the lab analysis requires a flash-off of a 5 cc sample = 0.000031 bbl. Therefore 2000 scf/bbl x 0.000031 bbl 0.062 scf of gas is liberated and lost,

At ambient this gas has mass = 0.0763 lb/scf x 0.75 x 0.062 scf= 0.003548 lbs = 1.61 lgrams.

The flashed oil sample of 5 cc at 0.8 specific gravity weighs 4 grams. 14% contamination means there is 0.56 grams of contaminant and correcting that back to the total original mass gives 0.56 grams 1 5.612 grams = 9.98% contamination.

The above example indicates that laboratory analysis will usually indicate a higher contamination level than the downhole methods employed by the LFA / OFA. Also, the difference between the downhole methods and the laboratory methods will increase as GOR increases. It should be noted that the above calculations assume that there is no contaminant lost when the gas is flashed off— a GOR oils where the contaminant may migrate into the gas phase or vice versa. Niger Delta Examples

Example 1
The 0CM output plot in Figure 4 was done on a point where two samples were taken. MDT pressure gradient was 0.34 psi/ft indicating a Black Oil. This is also supported by the channel I Optical Density of approximately 2.4. In an oil this dark it would be expected to get a build-up on both the colour and the Methane channels. This is indeed the case and both build-ups are of high quality which indicates a high degree of reliability in the data.
Both bottles were filled at the end of the pump sequence and the bottles calculated contaminations of 6.0% and 7.5% respectively — which corresponds well with the predicted contaminations of 6.5%

Example 2
This 0CM plot in Figure 5 was done on a zone where MDT pressure gradient was 0.21 psi/ft indicating a lighter, volatile oil. In light oils such as this there can be a problem fitting a build-up to the colour based optical density channels. Such is the case here. The colour curves are unable to fit a build-up and there is only a build-up from the Methane curve.
Laboratory analysis of the sample acquired at the end of this pump sequence indicated a weight % contamination of 5%. This is compared to the 1.0% contamination level seen by the LFA and indeed should be higher as explained previously by the weight to volume conversion. Full PVT analysis of this sample remains outstanding so it is not possible to do the calculation to bring the laboratory weight % contamination back to a LFA volume % contamination.

Example 3
This OCM plot is taken from a reservoir with MDT pressure gradient of 0.24 psi/ft indicating a lighter volatile oil. There was sufficient colour contrast in this zone to derive a build-up on the colour channel as well as a build-up on the Methane channel. It should also be noted here that the build-up was able to fit over the event seen at approx 1600 seconds. This event was caused by plugging of the pump-out module that was cleared by halting the pump sequence and pumping from the borehole instead of the reservoir. Even with this glitch in the pump sequence the OCM was able to fit over the larger time frame and make contamination predications.
Laboratory analysis of the two samples acquired at the end of this pump sequence indicated a weight % contamination of 5% and 6% respectively. This is compared to the 9% volume contamination level seen by the Methane/ colour average curve seen in the plot.

Example 4
This OCM plot is taken from a reservoir with MDT pressure gradient of 0.30 psi/ft. It can be seen that the software was unable to fit a build-up curve to the raw data and therefore the software is unable to calculate a contamination. However, laboratory analysis of the oil base filtrate contamination found contaminations levels that were too small to measure (below 2.0%). It is thought that the particular characteristics of this zone (permeability, zone thickness, etc) allowed the filtrate to clean up very quickly and the build-up was lost in early time and obscured by solids arrival.

RECOMMENDATIONS
In order to maximise the chances of obtaining the best possible downhole contamination analysis, the following points should be noted.
• Pump speed should be kept at a constant speed so that the time based curve   being fit to the raw data is directly correlateable to volume pumped
• Build-up calculations should be done on as many channels as possible and   agreement   between channels can be taken as a sign of the robustness of the   measurement.
• A zone that exhibits no build-up with a subsequently flat OD vs Time curve can be assumed to have cleaned up very early and consideration can be given to   opening the sample chambers.
• With darker reservoir oils the colour based analysis will often be sufficient to   determine
contamination, however it sh.u4d be noted that the addition of a Methane based contamination will allow for a more robust determination of contamination and subsequently higher confidence in the data.

CONCLUSIONS

It has been shown that optical spectroscopy provides quantitative information for predicting sample contamination. Both the colour based curves and the methane base curves have been investigated and shown to responds to varying levels of filtrate in the pumped fluids. The colour based curves have proven to be adequate for reservoirs where there is sufficient colour contrast between the filtrate and the reservoir oil. In very light oils, the use of the Methane based contamination predictions is required.

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