NEW INSIGHTS INTO IN-SITU MEASUREMENTS OF OIL SAND SAMPLES

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ABSTRACT

Low field NMR is a promising technology for performing measurements of oil, water and solids content in oil sand samples. Algorithms have previously been developed for separating the signals from bitumen and clay-bound water in oil sand samples, and in-situ oil and water predictions have been successfully made for a large database of oil sand ore and froth samples. In this work, we present measurements of a case study containing both high and low quality samples. Fluid content predictions are similar for this different field study, and NMR spectra properties can also be used to infer the quality of the ore. Additionally, NMR spectra are also obtained for middlings samples, and NMR applications in processing plants are identified. The NMR algorithm could be used in NMR logging tools, or for laboratory or online measurements of discrete samples, leading to improved reservoir understanding and process control.

CASE STUDY #1: IN-SITU SATURATION AND OIL SAND QUALITY

Oil sands consist of unconsolidated sand/clay mixtures, containing bitumen and water in the pore spaces between the solid grains. In order to determine *in-situ* oil and water saturations, a methodology is required to separate the oil and water signals, and these signals then have to be related to mass. A de-convolution method had been developed previously [Kantzas *et al*., 2005; Bryan *et al*., 2005] for numerically separating the oil and water peaks in porous media. This methodology was applied to this new set of data, which was obtained from a different reservoir. This set of data contained 18 samples, in which NMR data, Dean-Stark and particle size distribution (PSD) information were collected.

Once the appropriate amplitudes have been determined, they still have to be related to mass. For water this is straight-forward: the NMR amplitude per unit mass of water is a constant in any machine. For bitumen, the NMR amplitude per unit mass can be inferred from the oil relaxation time, T_{2gm} [Kantzas *et al*., 2005; Bryan *et al*., 2005]. In this case study, bulk oils were extracted from all 18 samples, and the oil RHI was determined empirically as a non-linear function of T_{2gm}. For a single field, the relationship between these parameters is well-defined. From the oil T_{2gm}, the oil amplitude can be related to oil mass, and both oil and water saturations can be determined.

De-convolution of "normal" oil sand samples

According to the classification established in previous work, "normal" samples have the characteristics as shown in Figure 1 and Figure 2. These samples have a well-defined, fast-relaxing peak that relaxes fully under 10 ms. This first peak contains the contribution of viscous bitumen and surface bound water. In this study, since bulk oil had also been extracted from the oil sand ores, the de-convolution algorithm was tested by comparing the T_{2gm} of the de-convoluted oil to that of the extracted bulk oil. In order for the de-convolution to be truly accurate, the oil T_{2gm} must match the bulk value, and the oil and water predictions must match Dean-Stark (DS) values.

The results of this study demonstrate that the de-convolution does not work consistently in all samples. In Figure 1, the oil T_{2gm} matches well with the bulk oil value, and when the de-convoluted water was compared to DS water content, the match was very close. Unfortunately, the same was not true for the sample shown in Figure 2. In Figure 2, the oil T_{2gm} still matches well with the value of bulk oil, however NMR predicts roughly twice the water content as DS. In order to properly match the water content, more amplitude would have to be attributed to the bitumen, which would lead to over-estimation in the bitumen T_{2gm} values. The de-convolution generally works well for samples with well-defined peaks, but at this time it is not clear why it sometimes does not, as in Figure 2.

De-convolution of "odd" samples

Not all samples in the field case study tested had properties similar to Figures 1 and 2. The remaining samples, labeled as "odd", have significantly different properties. They all lack signal at very early time and the first peak tends to be fairly narrow. Additionally, two separate, fast-relaxing peaks may be present under 10 ms. When the same de-convolution algorithm was applied, these peak characteristics lead to a larger oil T_{2gm}, compared to the bulk oil values. Figure 3 shows an example of two such samples; it can be seen that the de-convoluted oil spectrum cannot be made to match its bulk oil spectrum.

When the oil T_{2gm} is too high, using the RHI correlation to convert oil amplitude into mass would be problematic. High T_{2gm} values will generally lead to over-estimations in oil RHI, thus the oil content predicted may be low. When comparing the water matches of these "odd" spectra, the results were also not conclusive. Some spectra had water matches that were significantly high, indicating that the oil signal should be taken as a larger portion of the spectrum, which would lead to further errors in the oil T_{2gm} and RHI values. Other samples, however, had water matches that were too low, when compared to DS.

Fluid Content Predictions

For both the "normal" and "odd" spectra, the same de-convolution algorithm was applied, and oil and water signals were converted into fluid masses. Saturation was determined as the fluid mass, as a percentage of the total sample mass. The overall predictions for all samples are shown below in Figure 4. The average error in the water predictions is 1.2

saturation units, with a standard deviation in the error of 0.8 saturation units. For the oil predictions, the average error is 1.8 saturation units, with a standard deviation in the error of 1.2 units. On average, therefore, the error bar for the NMR predictions is around ± 2 saturation units for the water, and 3 saturation units for the oil content. This is marginally larger than what was seen in previous work [Bryan *et al*., 2005], however the data set considered in this study is significantly smaller, therefore it can be concluded that in this field case study, the NMR predictions are within a similar range of accuracy to other work. This is encouraging, since it means that the same analysis procedure can be applied in different reservoirs to yield similar quality of predictions.

Upon reviewing the PSD data, it was found that the "odd" samples have a higher fraction of clay, silt and very fine sand. In general, these samples correspond to sands that contain greater than 10% by weight of these fine particles. In cases where the sand is preferably water-wet, these samples contain a higher fraction of water existing in these very fine pores and relaxing extremely fast, thus overlapping extensively with the oil signal. This higher degree of overlap seems to be responsible for the different spectra properties.

Corrections could be made to the oil T_{2gm} values of the odd samples, leading to improvements in the oil RHI values. However, this led to insignificant improvements in oil content, over the range of RHI values in this reservoir case study. These results demonstrate that the problem in the predictions lies in the de-convolution method. Errors are also similar for both the oil and water, which is further evidence that any further improvements must come from the de-convolution part of this approach, or from improved signal acquisition, which is a machine hardware problem. Within the current limits of accuracy, however, NMR estimates of in-situ saturation can be made.

CASE STUDY #2: MEASUREMENTS ON MIDDLING SAMPLES

In oil sands mining applications, bitumen is recovered from the oil sand ore using the froth hot water floatation process [Clark, 1944]. In this process, hot water and air are circulated through the oil sand, generating a mixture of oil, water and solids known as a froth. Primary froths, which contain a high percentage of bitumen, have been the focus of previous NMR studies [Kantzas *et al*., 2005; Bryan *et al*., 2005]. Middlings are waste product from primary frothing operations; these middlings are often further processed to recover more of the bitumen.

In this case study, 16 middlings samples were obtained from laboratory BEU jar testing procedures, which are assumed to be representative of the shear conditions present in plant frothing operations. NMR spectra were measured for all samples, and compared to DS measurements of fluid content. A primary quantity of interest in these middlings is the bitumen content, which can affect the process control of the treatment of these middlings. The challenge of this NMR application is the proper acquisition and quantification of a small amount of bitumen.

NMR has been shown to be able to measure oil and water content in mixtures of bitumen, water and solids, but the structure of middlings is considerably different from other samples. Figure 5 shows an spectrum obtained from one of these middlings. Middlings are characterized by having a very small bitumen signal (under 10 ms), a contribution from surface bound water and a contribution from bulk water. Determination of bitumen content when only small quantities of bitumen are present requires a measurement with an accurate acquired signal. De-convolution is not required in these samples, due to the low bitumen content present. In the approach taken in this work, bitumen was taken to be the signal under 10 ms. In order to convert this amplitude to mass, a constant amplitude strength was used, which is roughly half the amplitude strength of water.

Figure 6 shows the comparison between NMR bitumen and water content, and fluid content obtained from DS extraction. The water match is very good for samples containing significant water signal. Especially for very low bitumen content, there are some discrepancies between the measured bitumen content values and the NMR estimations. This indicates that the NMR tool used in this study has a lower limit of the bitumen content that can be measured accurately, for samples with higher bitumen content, however, there is a clear correlation between the NMR and DS values.

OVERALL DISCUSSION AND IMPLICATIONS

The difficulty with NMR predictions in oil sands is that accurate signal de-convolution is key to determining the *in-situ* fluid saturations. Without a consistent error in the predictions, however, it is not trivial to develop improvements to the de-convolution method. Additionally, if the desired application for this technology is determination of oil and water content using NMR logging tools instead of bench-top instruments, the spectra obtained in the laboratory must first be related to the spectra obtained from logging tools, before more complex de-convolutions can be proposed. If the accuracy demonstrated could be determined using logging tools, however, this will still be extremely beneficial to companies in the initial characterization of their field. Even if this technology is applied for discrete core samples as a bench-top tool, as in applications of monitoring ore quality in mining operations, the level of accuracy demonstrated is still valuable. NMR can differentiate between high and low bitumen content ores, and the spectra properties can also be used to infer the fine solids fraction, which is related to ore processibility.

The middlings case study demonstrates that NMR spectra can differentiate between so-called “base case” samples that are representative of expected middlings, and between samples that are known to be higher in bitumen content. Therefore, an exciting new application of low field NMR technology is that of a qualitative measurement technique, for providing fast indications that the bitumen content has increased above those of base values in the middlings. NMR can therefore be used as a bench-top tool for these tests, and the interpretation algorithms are straight-forward and easy to implement.

REFERENCES

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Clark, K.A., "Hot-Water Separation of Alberta Bituminous Sand", *Can. Inst. Min. & Metall. Trans.*, **47**, 257 – 274, 1944.

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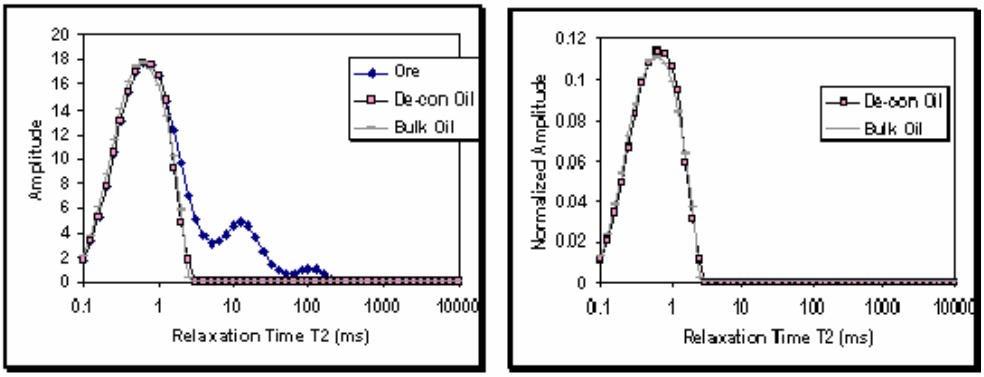
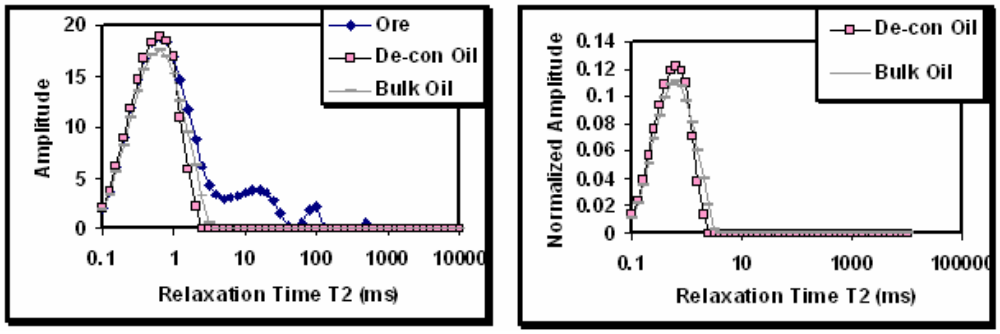


(a) (b)

Figure 1. De-convoluted oil signal from the original ore spectrum (a) and comparison of de-convoluted oil to bulk oil (b) – sample with a good water match



(a) (b)

Figure 2. De-convoluted oil signal from the original ore spectrum (a) and comparison of de-convoluted oil to bulk oil (b) – sample with a poor water match.

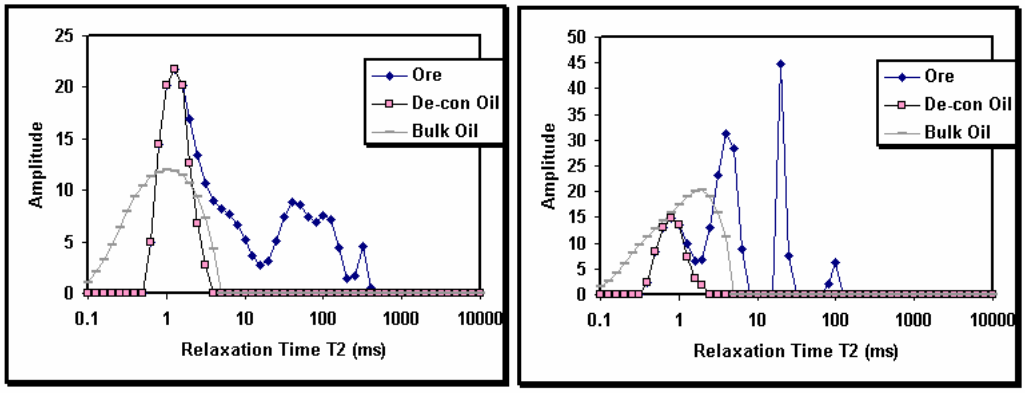
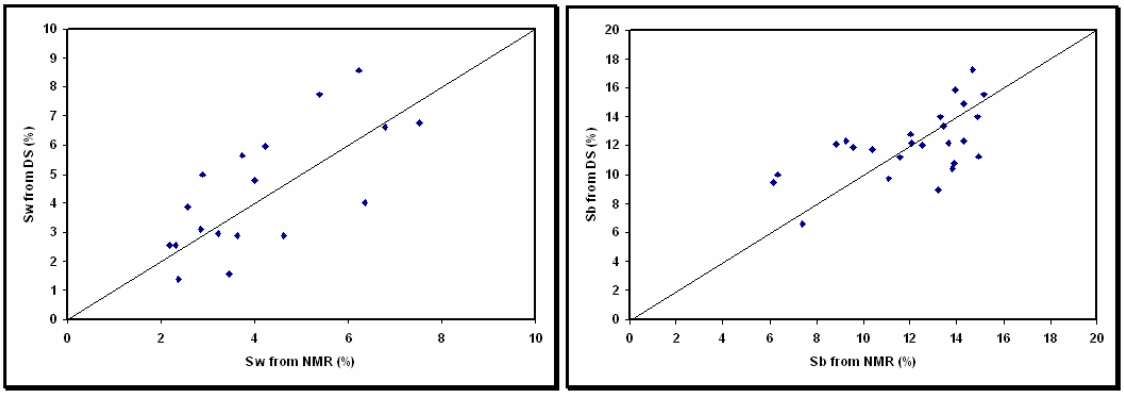


Figure 3. Spectra where the NMR signal begins at later values of T_2.



(a) (b)

Figure 4. NMR water content (a) and oil content (b), compared to DS measured values

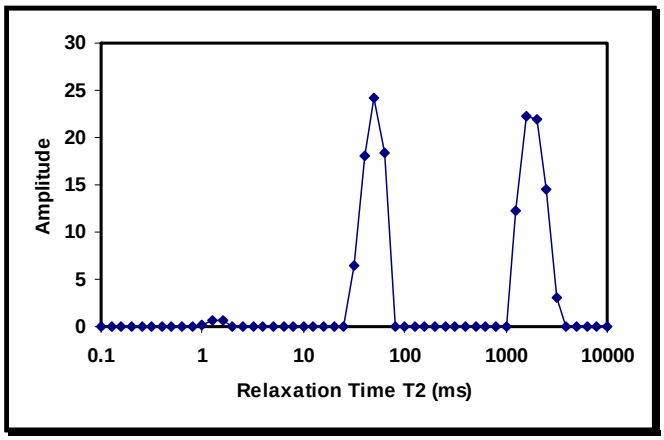
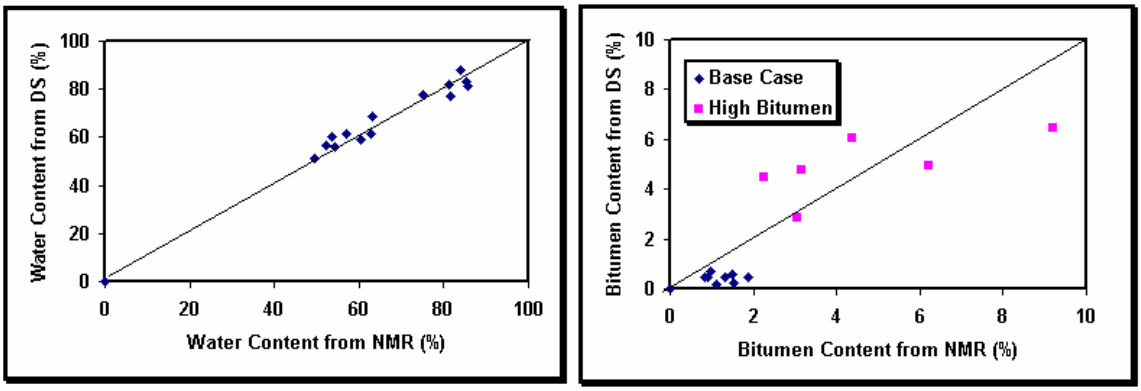


Figure 5. NMR spectrum of middlings skimmed from a laboratory BEU jar test.



(a) (b)

Figure 6. NMR predictions of water (a) and oil (b) content in middlings samples, compared to DS values.