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New Approach for Determination of Bitumen and Water Contents in Tar Sands

S. Kryuchkov, K.Mirotchnik

NMR Plus Inc., Canada

V. Obidi

Emval Nigeria Ltd., Nigeria

A.Baishev

VNIINeft, Russia

ABSTRACT

A new interpretive algorithm has been developed for bitumen spectra analysis in tar sands. This algorithm utilizes Low Field NMR method for measurements. With the use of appropriate basic components spectra database the algorithm extracts information on bitumen contents, immovable and movable water saturations. The basic components spectra database can be built by analysis of spectra for similar types of rock or by analyzing representative set of samples from the field under study. Representative set of bitumen spectra in the bulk is also included into this database.

Application of methods of multivariate analysis made it possible to differentiate between samples coming from different geological formations without any a priori knowledge about these formations.

The algorithm has been tested by comparison with the results of direct measurements of bitumen/water contents carried out on an exam set of 30 samples. All the NMR

results are within the measurement uncertainty of the direct measurements.

Having an advantage of rapidity of processing with high reliability and accuracy this non- destructive NMR-based approach can be a vital alternative to standard direct measurements (solvent extraction) in situations, where the above-mentioned qualities of the method are crucial.

INTRODUCTION

The oil reserves presented by heavy oils and bitumen are accounted for roughly 6 trillions barrels, accumulated in oil bearing deposits around the world. The majority of these reserves are lumped in Canada, the Former Soviet Union, Venezuela and Nigeria[2].

The recent five years developments in NMR research offer number of methodological approaches and formal algorithms for laboratory and field NMR applications used for bitumen/water contents characterization in bulk volume (stable-emultions[2,3]) and in porous media (laboratory and in-situ measurements[4,5,6]).

The terms bitumen as used in those papers refers to hydrocarbons with viscosity values 1,000 cp –10,000 cp and higher at ambient temperature conditions (20^OC-30^OC).

The real NMR application for bitumen/water content determination in porous media can be affected by uncertainties related to hardware problems and problems related to application of the misinterpretive algorithms and software.

The experimental results demonstrate that NMR response from bitumen in porous media is similar to signals from capillary bound water[5,6]. The polar components from bitumen, asphaltenes first of all, can influence process of wettability alteration. The wettability alteration leads to un-proper usage of the popular interpretive models[7] and caused misinterpretation from conventional logs and NMR Logs[6]. The laboratory NMR experiments performed at different temperatures[5] demonstrate that ~95% of total amplitude of NMR signal recorded from bitumen is related to spectral bins presented in frame of $T_2 < 1$ms. Therefore impossibility to deliver whole NMR signal representing bitumen in porous media is caused by hardware limitation (long Time–to-Echo [TE] in MRIL tool) or can be affected by in-situ conditions. Investigation of bitumen content in totally invaded near-wellbore zone is usual for CMR tool application. This kind of situation leads some authors to conclusion about difficulties to quantify heavy hydrocarbons' content in porous media from NMR measurement alone[6]. The problem can be solved by application of NMR measurements to bitumen saturated porous media at two different temperatures (in-situ/ambient temperature and at elevated temperature[5]). This solution can be used as positive palliative particularly during thermal recovery projects. But this approach is time consuming and also can not be applied for interpretation of the routine NMR measurements performed at one ambient temperature (in-situ measurements with logging tools, well-site measurements on cuttings, some laboratory experimental programs etc.).

Possible advantage in proper bitumen content determination by one-run measurement can be reached by following:

- Development and application of the NMR hardware with short dead times (TE$\geq$0.1 ms) that can perform measurements at high Signal-to-Noise Ratio (S/N>100); during the industrially acceptable time domain (T$\leq$ 10 minutes);

- Development of the methodology providing proper description of physical relations between the NMR properties of bitumen and geological factors affecting bitumen properties in porous media (physical-chemical composition, distribution etc.)[8-10].

- Creation of a database (DBC) that accumulates representative set of NMR data describing NMR properties of bitumen in bulk and in porous media. Generalization of these data by tools developed in DBC environment.

- Development of sophisticated and effective formal algorithms implemented in cutting-

edge software that has to be developed as a part of industrial technology.

The last two years NMR Plus Inc., Canada was involved in development of this kind of technology. The development of some technological elements was partially supported by Industrial Research Assistance Program (IRAP), Canada.

In this paper, we report the results of software verification. This software was developed as a part of the technology and was specifically designed for bitumen/water content determination in tar sands.

BASIC SPECTRA

In general situation the spectrum of a sample is a set of N independent values, where N is the number of bins used in spectral analysis. Using cut-offs[7] is a typical approach to minimize the number of physically meaningful degrees of freedom. This approach works fine when physically different components of the sample contribute to different parts of the spectrum. It often happens that this latter assumption is not true and contribution of different physical components to the same spectral region is equally significant. The approach to analysis of such spectra must be more sophisticated.

As a possible step in direction of such sophistication we suggest to use correlation of contributions from one physical component of a sample to different parts of the spectrum. One of the simplest ways to introduce this assumption is to represent contribution of a given physical component of a sample by a fixed spectral distribution function. Thus, an increase of contribution of this physical component into one part of the spectrum will lead to proportional contribution of this same component to other parts of the spectrum. We will call those functions basic functions. If $\varphi_k(\tau_i)$ is the k-th basic function we assume that it is normalized: $\sum_{i=1}^{N} \varphi_k(\tau_i) = 1$. Here τ_i is the characteristic time of the i-th spectral bin.

The challenging part here is to introduce spectra for physical components in such a way that we do not loose flexibility in representing complex sample spectra, on the one hand, and we achieve substantial reduction in the number of degrees of freedom in spectrum representation, on the other hand.

In the case of bitumen sands the spectrum of bitumen in bulk is the first candidate to be included into the set of basic functions. In our study, four different types of bitumen with different spectra were found based on information accumulated in DBC (56 NMR spectra obtained from bitumen samples in bulk). Additional bitumen spectrum was included into the set of basic functions based on spectra of bitumen in samples. The samples were collected from 8 bitumen-saturated deposits. Corresponding five basic functions are presented in Fig.1 below.
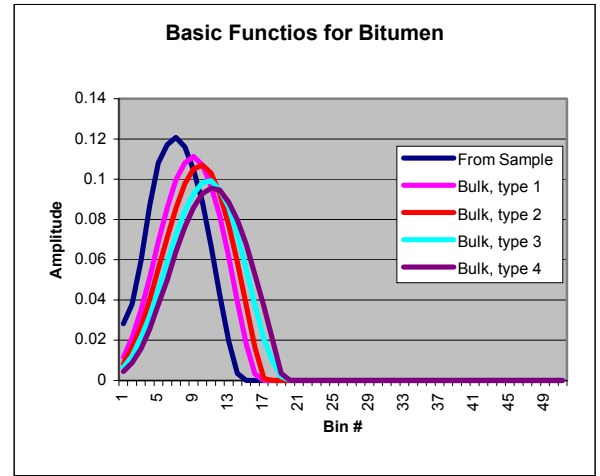

Fig.1 Basic functions for bitumen.

Basic functions representing different states of water in porous medium are presented in Fig.2 below.
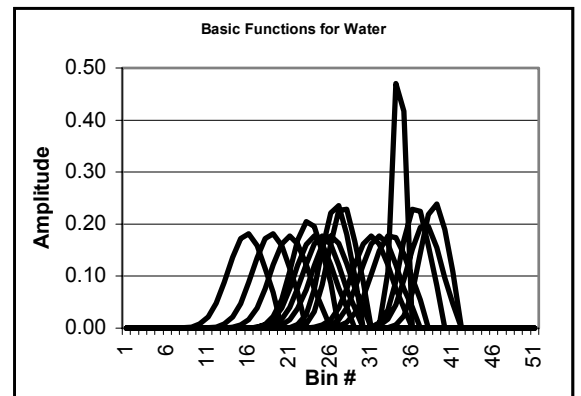

Fig. 2. Basic functions for water.

These functions have been singled out from the teaching set of spectra. These spectra were delivered from 140 tar sand samples collected around the world (from 8 bitumen bearing formations). The approach was to make it possible to capture all the local maximums observed in the spectra. In the set of basic functions representing water we considered the first 9 functions (with the positions of maximums less then 20 ms) as representing residual (non-movable) water. In a sense, this is similar to approach with the cut-off times. The rest of water basic functions were representing contribution from movable water.

DECOMPOSITION PROCEDURE

We are looking for representation of the observed signal $f(\tau_i)$ in the form $f(\tau_i) = \sum_{k=1}^{M} a_k \varphi_k(\tau_i) + r_i$, where M is the number of the basic functions used and are trying to minimize r_i in a standard least mean square sense. There has to be a standard physical limitation on solution that all $a_k \geq 0$. This limitation is what leads to different algorithms of solving this least-squares problem with limitation of positive coefficients. We've taken an iterative approach, when functions are added to the set of functions used at current step. An algorithm for adding functions is as follows. We find absolute maximum of the function and choose a basic function with a maximum closest to the maximum of the function to fit. After fitting the function with the current (limited) set of basic functions we analyze the residual function in a similar way: find maximum, choose appropriate additional basic function and try to fit the function with this bigger set of basic functions. If the function goes into the sum with negative coefficient it is excluded from basic functions set for this sample. This process continues until the residual function is less then the noise level or we are exhausted of basic functions.

REAL LIFE EXAMPLE

Interpretation technique was verified based on exam set of samples without any preliminary tuning of applied algorithm. The spectra delivered from 30 bitumen sand samples representing two different geological formations were analyzed (Nigeria, Russia). Spectra were analyzed with the aid of the above-described algorithm. An example of spectral analysis for Sample #29 from our exam set is presented below in Fig.3.
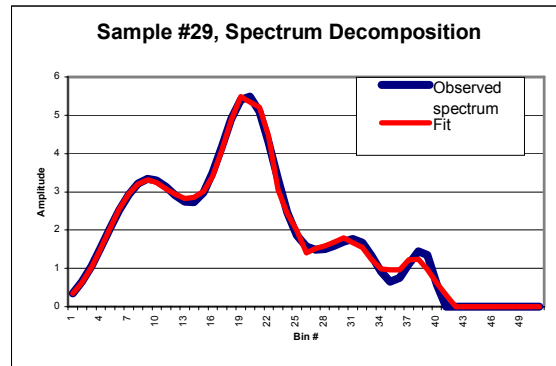

Fig.3. Spectrum decomposition for sample #29.

This type of fit has been achieved with only 7 basic functions: one for bitumen type 1 and other 6 for different types of water. NMR-determined content of bitumen and water were S_w=10.7% and S_b=7.2%. Direct extraction measurements gave S_w=10.8% and S_b=7.1% for the same sample.

Graphs below (see Fig.4, 5) show how determination of water and bitumen content by NMR is correlated to results of determination of these values by direct extraction method. With the notion that both NMR and direct measurements contribute to uncertainty of the result the observed correlation of data from both methods can be considered quite strong.
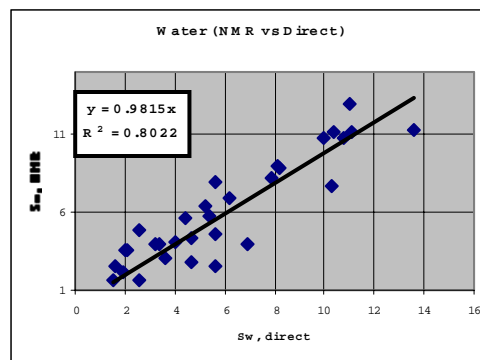

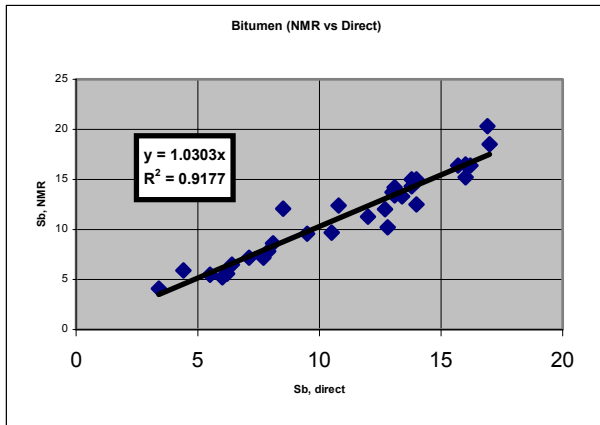Fig.4. NMR-determined water vs. directly measured water content.

Fig.5. NMR-determined bitumen vs. directly measured bitumen content.

MULTIVARIAT ANALYSIS OF DATA

It was known that the samples came from different geological formation. So, there was a problem of finding out what NMR parameter could give indication of the origin of the sample. To find such parameters a multivariate analysis[11] has been performed on the results of bitumen and water determination in the sample set at hand.

First, we decided to represent each sample by three values: bitumen saturation S_b, irreducible water saturation S_{wirr}, and by movable water S_{wm}. With standard multivariate analysis procedures[11] we singled out 3 principal components representing variations of the above values in the set. It turned out that the third component was the indicator we were looking for. The graph below shows the value of this third principal component for 30 samples. The first 17 samples of the set, obviously, belong to one group as the other 13 belong to a different group. Geological analysis of the samples confirmed that this discrimination of samples is indeed right.

The color on histogram of Fig.6 represents the data characterized of different geological formation. It is clearly seen that the value of principal coordinate A3 is a good indicator for distinguishing the data obtained from those two formations. The mixing of colors can be seen only on the border between the data presenting different formations.
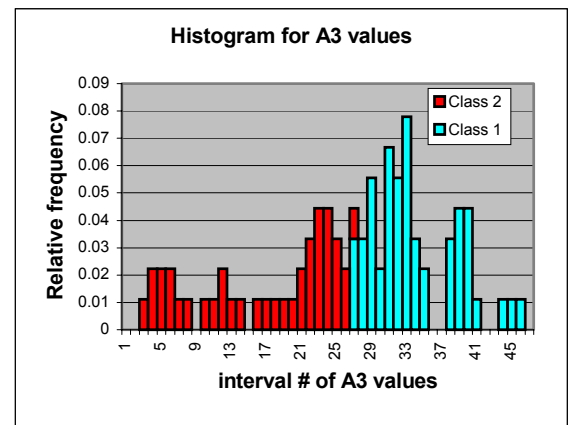

Fig.6. Histogram for principal variable A3 values

As it was mentioned above, the solutions presented in Figures 4-6, were reached without any preliminary tuning of the algorithm. The results can be significantly improved based on preliminary tuning of algorithm with usage of the specific representative teaching set of samples, collected from investigated deposits.

CONCLUSIONS

1. The original algorithm for determination of the bitumen/water contents in tar sand was developed and positively tested. The algorithm can be applied for interpretation of NMR signal obtained from bitumen- saturated samples at AS IS conditions. The NMR measurements can be performed as one-run procedure at ambient temperature.

2. The final results from algorithm application can be improved with preliminary algorithm tuning based on teaching set of samples collected from investigated deposits.

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