NMR methods for determination of samples characteristics of oil-saturated rocks: Comparison with results of traditional studies

Diyashev R.N, Musin K.M, Yudintsev E.A.
TatNIPIneft inst., JSC Tatneft, Tatarstan, Russia

ABSTRACT

The (NMR) is one of express methods enabling to study structure and properties of porous media and fluids, saturating them. In recent time application of NMR methods for aims of petroleum geology experiences second birth, associated with development of NMR logging of wells in a strong field. The work shows feasibility of the method and estimates reliability of this method for determination of oil saturated rocks characteristics based on analysis of actual material accumulated for more than 2 decades in JSC “Tatneft” (more than 65 thousand analyzed samples).

INTRODUCTION

A physical basis of nuclear magnetic resonance method is influence of magnetic fields on behavior of atomic nucleus having an intrinsic magnetic moment. Most important among such elements are the nucleus C^{13} and, especially, H^{1}. Actually nuclear magnetic resonance method uses nucleus of hydrogen contained in water and oil, as probes, by quantity of which conclusions on porosity and content of fluids in samples are made, and mobility of fluids, wettability, permeability of porous matrix are evaluated by degree of interference of these nucleus and interstitial surface.

Works on application of nuclear magnetic resonance for the purposes of petroleum geology have begun in the former Soviet Union and other countries of the world at the end of 1960-s. The leader in the field of practical application of nuclear magnetic resonance for the purposes of petroleum geology was JSC "Tatneft", where nuclear magnetic resonance procedures for studying reservoir rock properties were included in usual practice.
Amplitude of a spin echo, as well as curves on times of spin-lattice relaxation (T1) and spin-spin relaxation (T2) are directly measured values in NMR-pulse procedures. All other characteristics are obtained by mathematical treating of the measured magnitudes on the basis of various theoretical models and (or) statistical dependences (Fig. 1).

**PROBLEMS, SOLVED BY NMR METHOD**

By now in JSC "Tatneft" the following procedures are tested and quite widely applied:

**Determination of porosity.** Distinctive feature of the method is the opportunity to determine porosity of core samples, not subjected to preliminary extraction (under condition of their 100% saturation with fluids).

**Determination of water saturation (oil-saturation).** For cores, taken on the basis of non-filtering drill fluid, the determination of water- or oil-saturation is possible. As the relaxation characteristics of some fractions of oil and water in a porous medium are very close, then, as against a situation with free volume, the simple separation of parts of water and oil is impossible. There is a series of procedures, tested in TatNIPIneft, which provide solution of this problem. Their idea lies in selective influence on magnitude of a relaxation time of one of phases. Such methods include congealing of samples, use of deuterated water or some other agents.

**Estimation of rock permeability** by fluid and gas is performed in accordance with chosen theoretical model on basis of relaxation time and porosity, or distribution of pores and pore channels by size.

**Index of free fluid.** By decomposition of relaxation curve into some components it is possible to
estimate portion of pore space occupied by movable fluid (oil or water).

**Residual or irreducible water saturation.** From analysis of relaxation curves for 100 % saturated samples there is an opportunity to determine residual (irreducible) water saturation.

**Residual oil saturation.** Residual oil saturation is determined using pulse- NMR method on amplitude of signal by direct process.

**Oils viscosity.** Estimation of oil viscosity, remaining in pore space of a core after its recovery to the surface is possible by means of corresponding empirical dependences based on data on relaxation times.

**The information on rock wettability.** Based on corresponding theoretical model through spin-lattice relaxation time the estimation of hydrophily or hydrophoby of rock interstitial surface is possible.

**The information on efficiency and mechanisms of physico-chemical methods of enhanced oil recovery (EOR).** The experience of JSC “Tatneft” demonstrates, that NMR is the effective means in study of influence of various physico-chemical methods of enhanced oil recovery[1]. Laboratory NMR studies are performed on standard (1 inch by diameter) cores using domestic NMR-relaxometers of "Echo" series, designed and made by Design Office "Radiophysics" in S-Petersburg State University. Working frequency of relaxometers - 20 MHz.

**OBJECTS OF STUDY.**

Main studies are carried out on core material from base terrigenous reservoirs of Devonian horizons (D1,D0) and carbonate reservoirs of Tournaisian horizon in Romashkino oil field.

Romashkino oil field, located in territory of Tatarstan Republic, Russia, was discovered in 1943. It is a giant field with the OOIP about 5.0 bln.t. In a sedimentary complex of the field there are more than 18 oil-gas-bearing deposits, in that number 12 are under commercial development. Most productive are formations of horizon D1, of Bobrik and Tournaisian stages, which from the very beginning are developed by water displacement of oil.

During the whole history in the field about 2.09 bln.t of oil has been produced. A maximum level of oil production in amount of 82 mln.t per year was achieved in 1970-1975.

Development of sandy-aleurolite reservoirs of multilayer horizon D1, as fractured-porous carbonate deposits of Tournaisian stage by waterflooding methods requires constant control and management of displacement process with the purpose of impropety oil recovery. Among methods of reservoirs studies NMR methods occupy a highly important place.

**ANALYSIS OF DETERMINATION OF RESERVOIR PARAMETERS OF FORMATIONS D1**

In total results of measuring 26195 samples are analysed, of which 13002 samples were studied by laboratory methods after extraction and 13193 samples – by NMR method in non-extracted state. In Table 1 averaged values on determination of porosity and content of residual water according to this sampling are given. Subsampling by lithotypes includes the samples, taken from reservoirs zone only.

As shown in table, discrepancies of average statistical values of rock porosity when measured by laboratory method and by method of impulse NMR do not exceed one absolute percent in sampling on any lithotype or types of oil saturated rocks. Totally for all main lithotypes of rocks in reservoirs zone the average statistical values of porosity made 0.03 % abs. It is obvious, that such differences of obtained values lie within the limits of errors of used methods and are not caused by peculiarities of samples preparation and measuring methods. Indirectly such close values of porosity say about statistical equivalence of given samples.

Table 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Lithotype</th>
<th>Determination of porosity, %</th>
<th>Residual water saturation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Extract. (lab.) value/number of samples</td>
<td>Non-extract. (NMR) value/number of samples</td>
</tr>
<tr>
<td>5.</td>
<td>Clayey aleurolites</td>
<td>18.6/108</td>
<td>17.86/133</td>
</tr>
<tr>
<td></td>
<td>TOTAL for lithotype</td>
<td>20.35/10750</td>
<td>20.32/10123</td>
</tr>
</tbody>
</table>

A somewhat different picture is received in analysis of obtained values of residual water saturation. The discrepancies between obtained values vary by samples for different lithotypes of rocks between 1.1% abs. and 4.13 % abs. Discrepancies in this case have pronounced systematic character. The average statistical values, obtained by impulse NMR method on non-extracted cores, in all cases appear lower, than the values obtained using method of saturating on extracted cores. On the average for all main lithotypes of rocks the discrepancy in obtained values makes 2.9 % abs.

Thus, the above mentioned absolute discrepancies in determination of residual water content on
extracted and non-extracted rocks of formations of horizon D1 lead correspondingly to differences of being determined values of their oil saturation from 1.4 to 5% relat. for different lithotypes and 3.44% relat. – totally for all main lithotypes.

**ANALYSIS OF DETERMINATION OF RESERVOIR PARAMETERS OF TOURNAISIAN STAGE**

In total results of measuring 39246 samples are analysed, of which 18028 samples were studied by laboratory methods after extraction and 21218 samples – by NMR method. The studied samples were presented mainly limestones of different types. In table 2 the averaged values on determination of porosity and content of residual water according to this sample are given. In sampling by separate lithotypes the samples, taken only from layers, interpreted as reservoir, have been used.

Table 2.
Results of estimation of reservoir properties for Tournaisian samples

<table>
<thead>
<tr>
<th>Item</th>
<th>Lithotype or type of oil saturation</th>
<th>Determination of porosity, %</th>
<th>Residual water saturation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Extract. (lab.) value/number of samples</td>
<td>Non-extract. (NMR) value/number of samples</td>
</tr>
<tr>
<td>1.</td>
<td>Limestones</td>
<td>11.7/3134</td>
<td>11.9/5037</td>
</tr>
<tr>
<td>2.</td>
<td>Organogenic-detrital limestones</td>
<td>12.7/3857</td>
<td>12.2/2886</td>
</tr>
<tr>
<td>3.</td>
<td>Clot-detrital limestones</td>
<td>11.3/559</td>
<td>11.1/265</td>
</tr>
<tr>
<td>TOTAL</td>
<td>for lithotype</td>
<td>12.2/7550</td>
<td>12.0/8188</td>
</tr>
</tbody>
</table>

In spite of significant difference of studied sample types (terrigenous and carbonate rocks), as in case of formation D1, the discrepancy of average statistical values of porosity obtained by different methods, has not appeared great and does not exceed 0.5 % abs. Totally for main lithotypes of rocks the discrepancy of average porosity values of extracted and non-extracted rocks made 0.2% abs.

Nevertheless, though the results of comparison of porosity values point to statistical equivalence of samples, the discrepancy between values of residual water saturation turned to be sufficiently high and, as for formation D1, has pronounced systematic character. For various widely presented lithotypes of rocks it varies from 3.8 to 8.8 % abs., averaging 4.5 % abs. for lithotypes. As a result we can say that difference in average value of residual water content being 4.5% leads to difference in oil saturation of 7.6% relat. The average statistical values of residual water content according to results of laboratory determination on extracted cores are always higher, than values determined using method of impulse.
NMR on non-extracted samples.

Similar picture is observed also in statistical averaging of residual water content in Tournaisian rocks by porosity intervals irrespective of rocks lithotype (Fig.2). In fact, practically over the whole spectrum of porosity the residual water content, being determined on extracted rocks by centrifugation method, is higher than that, determined by NMR method on non-extracted samples of rocks.

The main reason for differences in residual water content seems to be not in different methods of investigation (centrifuging and NMR), but in influence of rocks extracting on physico-chemical properties of interstitial surface of rocks.

CONCLUSIONS

Statistical analysis, performed on collections, containing tens of thousands samples, has shown that discrepancies in determination of porosity by NMR method and method of saturation make on the average 0.1 % for terrigenous rocks of formation D1 and 0.2 % for Tournaisian carbonate rocks. In measurement of residual water saturation (initial oil saturation) the influence of extraction is notable for samples of formation D1 (absolute deviation in determination of initial oil saturation up to 4.13 %, relative - up to 5 %), and is even more significant for Tournaisian limestones (absolute deviation up to 8.8 %, relative - up to 15 %). It is obvious that further laborious methodical work in this direction is required.

Substantial increase of validity of results, obtained using NMR method, can be achieved by implementation in practice of multipulse NMR procedures, allowing to increase the number of
experimental points in relaxation curves while decreasing measurement time by one order of magnitude.