Calculation of Porosity by Combining the Nuclear Magnetic Resonance and Sonic Logs in Gas Bearing Reservoir at Sienna Field of WDDM Concession in Egypt

A.Z. Noah and T.F. Shazly

Faculty of Science and Engineering, American University in Cairo, Egypt

Egyptian Petroleum Research Institute, Cairo, Egypt

Abstract: The estimated porosity may be inaccurate when calculated from conventional logs (unless corrected for gas and shale effect) and also underestimated when derived from nuclear magnetic resonance (NMR) logs due to the effect of the lower hydrogen index of natural gas in gas-bearing sandstones. A technique of calculating porosity by combining the NMR log with the conventional interval transit time log is proposed and it is based on principle of NMR log and the results obtained from a physical rock volume model which constructed on the basis of interval transit time logs. For wells with the NMR log acquired from the MRIL-C tool, this technique is reliable for evaluating the effect of natural gas and obtaining accurate porosity in any borehole. The NMR porosity should be first corrected by using the deep lateral resistivity log in wells with NMR log acquired from the CMR-Plus tool and with collapsed borehole. Two field examples of tight gas sandstones, in the studied concession, illustrate that the porosity calculated by using this technique matches the core analyzed results very well. Another field example, in this paper, of conventional gas-bearing reservoir (Sienna Field), verifies that this technique is usable not only in tight gas sandstones, but also in any gas-bearing reservoirs. This study is applied on a well in Sienna Field which is located in the west delta deep marine concession (WDDM).

Key words: Egypt • Nuclear magnetic resonance • Porosity • Sonic log • WDDM concession

INTRODUCTION

Porosity is one of the most important input parameters in reservoir evaluation, so it is critical to accurately estimate this parameter in any reservoir especially in tight gas sandstones. Porosity can be calculated from conventional logs in oil-bearing or water saturated layers, but it may be overestimated or underestimated when calculated from logs (such as density log, neutron log and acoustic log) in gas-bearing formations because of the effects of the lower hydrogen index of natural gas. For the same reason, the porosity directly obtained from NMR logs may be underestimated too. In order to evaluate the effects of natural gas on the conventional and NMR logging results, it is essential to calculate porosity with greater precision, by integrating sonic with NMR logs. However, the curves of density and NMR logs, especially the NMR log acquired from the CMR-Plus tool, are distorted if the borehole is collapsed.

Oil and Gas in Egypt: The hydrocarbon reservoirs in Egypt are located in three main areas; the Gulf of Suez, the Western Desert and the Mediterranean Sea. Gas was lately discovered in the Mediterranean with economic quantities. Several major oil companies (Agip, BP Amoco, B. Gas, GÉOGE) have explored the Mediterranean and made good discoveries. The area of interest lies offshore in the West Delta Deep Marine concession. The study is applied on the interval (7614-8738 ft.) of Pliocene Formation of Sienna Field. Rashid Petroleum Company (JV comprising EGPC and BG Egypt/Edison International) has recently achieved good results in the Mediterranean West Delta Deep Marine (WDDM) concession. The gas discoveries in this highly prospective block used the 3D seismic data and the direct hydrocarbon indicators (DHIIs) such as bright spots, flat spots and AVO anomalies. The gas bearing formations has been discovered in the Pliocene sands. Recent exploration activity has focused on the Pliocene slope-channel
complex play with 6 exploration discovery wells drilled in WDDM within the last two years. These include the Scarab/Saffron, Simian, Sienna and Sapphire discoveries [1]. It is important to note that the success stories of exploration in the Western Desert summarize the application of advanced and updated technology.

**NMR Physics:** The physics of pulsed NMR has been known since 1950. It has been used extensively in industrial and medical applications. It is a complex and innovative new technology, but it is easy to understand. NMR logging works by forcing the Hydrogen nuclei of the formation fluids into a spin and then monitoring the rate and the way in which they recover stability [1, 2]. The Combining Magnetic Resonance (CMR)* tool is a pad-type tool that performs pulsed NMR measurements using Carr-Purcell-Meiboom- Gill (CPMG) pulse sequences. The spin–echo signals acquired during the measurement are derived from protons (i.e. Hydrogen nuclei) that process in the static magnetic field by a permanent magnet in the tool antenna [3]. A CPMG consists of two time intervals:

- An initial wait time (WT) during which the proton magnetization approaches its thermal equilibrium value in the static magnetic field.
- Echo collection period during which a set of Radio Frequency (RF) pulses generated by the tool antenna are used to generate the spin echoes.

The tool antenna has a uniform response over its 6 inches length, which accounts for the high vertical resolution of the CMR measurements. The CMR response has a blind zone of approximately 1/2 inch, which provides immunity to mud cake and moderate bore hole rigidity effects. The measured integrated radial response of the CMR tool shows that 90% of the signal is derived from within 1.2 inches of the bore hole wall [3, 4]. The CMR perform the following measurements:

- Total NMR hydrogen signal amplitude, which is used to derive the total porosity.
- The distribution of the NMR hydrogen relaxation, which is used to derive the pore size distribution.

**NMR Porosity:** The fact that NMR porosity depends only on the fluids content of the formation, unlike density and neutron porosity, which is influenced by both fluids and surrounding rocks, makes NMR measurements much more capable than conventional logs to furnish clay corrected, nonproductive and productive porosities. The strength of the NMR signal is proportional to the number of hydrogen atoms in NMR tool-dependent rock volume. In zones containing light hydrocarbon, where the hydrogen index is less than unity, NMR porosity will typically underestimate true porosity in proportion to the hydrogen index. In this formation, there is a separation between density and neutron porosity, which indicates light hydrocarbon [5]. For oil and water, NMR results can be expressed as the percentage of fluid volume to the rock volume. The number of hydrogen atoms in gas depends strongly on temperature and pressure. Hence, it is important to estimate the pressure and temperature accurately to account for their effect on NMR results in natural gas reservoirs [6-8]. In the literature, there has been some confusion in defining and using the results of NMR porosity data. To clear out this confusion; Fig. 1 shows the standard rock porosity model. MSIG denotes the total water content porosity. MPH is the total porosity from NMR (fluid fractions of the rock excluding solids fluids). Fig. 2 exhibits uploaded data through interactive petrophysics software.

![Fig. 1: Shows step of interactive petrophysics software.](image)
The target interval investigated is a gas bearing sandstones. The density log is seriously affected by the borehole, because more than 95% of the boreholes have collapsed due to the under compaction. The NMR logs (Fig. 3), in 82% of wells, were acquired with the MRIL-C tool and good measured results were obtained. In other 9.5% of wells, NMR logs were acquired with the CMR-Plus tool. Therefore, the density logs in 82% of wells and NMR logs in 9.5% wells were distorted and the relationships between the density and the core porosity and between the NMR porosity obtained from the CMR-Plus tool and the core porosity are unsound. Figs 4 and 5 illustrate a cross plot between core porosity and both of NMR and acoustic porosity. To avoid the effect
Porosity Estimation in Gas-bearing Formation: Method of Calculating Porosity from NMR Log: Based on the principle of NMR logging, the equation of calculating porosity from NMR log can be expressed as follows [1, 9]:

\[
\text{CMRP} = \Phi \cdot S_e \cdot H_l + \Phi \cdot H_I (1 - S_e) = \Phi [S_e \cdot H_l \cdot P_e + H_I (1 - S_e)]
\]  

(1)

where: \( P_e = 1 - \exp \left( \frac{-T_w}{T_{w,lg}} \right) \)

CMRP is the NMR porosity (in%), that can be acquired from NMR log directly; \( \Phi \) is the formation’s porosity (in%); \( S_e \) is the gas saturation in fraction; \( H_l \) is the hydrogen index of natural gas, \( H_I \) is hydrogen index of pore fluid (the units are fractions); \( P_e \) is the polarization factor; \( T_w \) is the polarization time, \( T_{w,lg} \) is the longitudinal relaxation time of natural gas (the units are microseconds). For fully water-saturated rocks, \( H_I \) is taken to be 1.0 and Equation (1) can be rewritten as [9, 10]:

\[
\text{CMRP}/\Phi = 1 - S_e (1 - I_e \cdot P_e)
\]  

(2)

The porosity must be calculated first to obtain information about \( S_e \).

Method of Calculating Porosity from an Interval Transit Time Log: The sonic log is commonly used to calculate the porosity of formations; however the velocity of elastic waves through a given lithology is a function of porosity. Wyllie proposed a simple mixing equation to describe this behavior and called it the time average
equation. It can be written in terms of velocity or \( \Delta t \) [1]. Based on the principle of the volume physical model of gas-bearing sandstone, the response equation of interval transit time log can be expressed as [11, 12]:

\[
\Delta t = \Delta t_{\text{mat}} (1 - \Phi) + \Delta t_{\text{w}} \Phi (1 - S_p) + \Delta t_{\text{g}} \Phi S_p
\]

(3)

where: \( \Delta t \) is the log measured interval transit time, \( \Delta t_{\text{mat}} \) is the interval transit time of rock matrix, \( \Delta t_{\text{w}} \) is the interval transit time of water, \( \Delta t_{\text{g}} \) is the interval transit time of natural gas (the units are \( \mu s/m \)).

At present, Wyllie’s average time equation is always used for porosity calculation from interval transit time log and it can be written as [13, 14]:

\[
\Phi_i = \frac{\Delta t - \Delta t_{\text{mat}}}{\Delta t_{\text{w}} - \Delta t_{\text{mat}}}
\]

(4)

where: \( \Phi_i \) is the porosity estimated from the acoustic log in fraction; \( \Delta t_i \) is the interval transit time of pore fluid.

Equation (5) illustrates that \( S_p \) and \( \Delta t_i \) are two important input parameters in calculating porosity from the interval transit time log. However, the determination of \( S_p \) relies on porosity. It is difficult to calculate porosity from the conventional interval transit time logs alone [15]:

\[
\frac{\Phi_c}{\Phi} = 1 + S_p \left[ \frac{\Delta t - \Delta t_{\text{mat}}}{\Delta t_{\text{w}} - \Delta t_{\text{mat}}} \right]
\]

(5)

Method of Calculating Porosity by Integrating Conventional Interval Transit Time with NMR Logs: Due to the effect of the lower hydrogen index of natural gas in gas-bearing sandstones, proceeding from the basic principle of NMR log and the results obtained from a physical rock volume model constructed on the basis of interval transit time logs, a technique of calculating porosity by combining the NMR log with the conventional interval transit time log is proposed. For wells with the NMR log acquired from the MRIL-C tool, this technique is reliable for evaluating the effect of natural gas and obtaining accurate porosity in any borehole. This technique is also suitable for collapsed borehole [16]. Two values of \( x \) and \( y \) were assumed [1], where:

\[
X = \left[ \frac{\Delta t - \Delta t_{\text{mat}}}{\Delta t_{\text{w}} - \Delta t_{\text{mat}}} \right] \text{ and } Y = 1 - \left( H_i \times P_e \right)
\]

By substituting the two parameters, \( X \) and \( Y \), into Equations (5) and (2) separately, we obtain the following two expressions:

\[
\Phi_i = \Phi_c + CMRP \times (X \times Y) \times (X + Y)
\]

(8)

Then from equations (6 and 7) the following equation is obtained

\[
\Phi = (Y/(X+Y)) \times \Phi_c + CMRP \times (X \times Y) \times (X + Y)
\]

(9)

By assuming that \( A = y/(x+y) \) and \( B = X \times Y \) the following equation is deduced:

\[
\Phi = A \times \Phi_c + B \times CMRP
\]

(9)

where \( A + B = 1 \)

The advantage of this technique is that porosity can be estimated without the parameters \( S_p \), HI, and \( P_e \). Fig. 6 shows that there is a good relation between core porosities and the estimated porosity from NMR combined tool. The values of \( A \) and \( B \) can be ensured by

Fig. 6: Cross plot of \((\Phi_c/CMP)\) Vs \((\Phi_c/CMP)\).
deriving them from core samples and well logging data. Generally, core porosities are considered to be the accurate porosity of the formation. By substituting core porosities into Equation (9) and dividing by CMRP on both sides, we obtain the following expression [1]:

\[ \frac{\Phi_i}{\text{CMRP}} = A \left( \frac{\Phi_i}{\text{CMRP}} \right) + B \] (10)

If \( \frac{\Phi_i}{\text{CMRP}} \) is plotted in the horizontal axis and \( \frac{\Phi_i}{\text{CMRP}} \) in the vertical axis, the linear regression method is used and the values of A and B were determined as follow:

\[ \Phi = 0.6449 \Phi_i + 0.0936 \text{CMRP} \]

**CONCLUSION**

Nuclear Magnetic Resonance Imaging has emerged as the leading technological break-through, which is providing difficult-to-interpret zones with the outstanding results. Unlike other conventional tools, the NMR measurements are largely based on the fluid and the pore space characteristics. This makes it possible to see the fluids and pores more obviously which are not seen on other conventional logs like Density, Neutron and Sonic. This paper shows that combined NMR wire line tools with the sonic log are considered to be the most accurate technique compared to other conventional logging tools. Through analysis, it is a fact that NMR tools are more accurate and more applicable than other conventional tools. NMR tools overcome lots of obstacles that face conventional logs. They also can be integrated with other tools with phenomenon accuracy. NMR physics are explored and explained in details. Inter Petrophysics© by Schlumberger is the software used in interpretation. Several software applications are done on this paper. Moreover, applying the NMR interpretations on the studied well with all the needed data and logs for it is discussed in detail in the present work. Finally, we conclude by stating the unique privileges of using the NMR technology for well logging and how useful it is in enhancing the oil industry in general. Then the porosity can be precisely estimated by combining interval transit time with NMR logs in any gas-bearing formations by using the technique proposed in this study. Before this technique is applied, a certain number of core samples should be drilled for routine analysis to determine the parameters of A and B.

**REFERENCES**