Combination of Nuclear Magnetic Resonance and Density Log for Evaluation of a Gas Reservoir in South of Iran

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Abstract
Conventional log based reservoir characterization of a gas reservoir in the Kangan and Dalan formations have recently been improved by the application of the nuclear magnetic resonance (NMR) log.
The problem of NMR measurements in gas reservoirs is that in Gas-bearing zones, total NMR porosities read much less than density-derived porosities.
Porosity derived from NMR alone suffers from the low hydrogen index of the gas and the long T1 polarization time of the gas when the data is acquired with insufficient wait time.
To provide a robust estimate of porosity, a method called Density-Magnetic Resonance (DMR) that combines density porosity and total NMR porosity was successfully applied to the 4 wells logged with NMR.
The DMR technique was able to produce a very good porosity estimation comparable to that measured on conventional cores. Improved porosity calculation lead to better core independent permeability estimation on the wells logged with NMR. Permeability derived from NMR was involved to an electrofacies modeling as an associated log to predict facies base permeability on 20 wells without NMR log.
To test the permeability prediction, estimated permeability was compared with core derived permeability on 5 cored wells to see how well, estimated permeability fitted the actual core permeability.

Key words
NMR, DMR, Porosity, Density, Signal amplitude, T2 distribution , T1 polarization

1-Introduction

Finding and producing oil and gas in an efficient manner to the economic benefit of a company requires a reservoir model to predict reservoir performance under different development scenarios, including supplemental recovery, and to aid in designing an appropriate reservoir management plan. Development of a realistic reservoir model needs to accurate geologic model prepared based on integrated reservoir characterization that can evaluate vertical and lateral variability of reservoir properties, estimate hydrocarbon pore volumes, or to simulate fluid flow for performance prediction.

The most important parameter resulting uncertainty in reservoir properties in gas reservoirs is that in gas-bearing zones, different logging tools such as density, neutron, sonic and NMR logs are affected by gas and read more or less porosities.

The potential of nuclear magnetic resonance (NMR) measurements to provide information on formation pore fluids and pore structure was first identified in the 1950s. The first NMR log was run in 1960 (Brown and Gamson, 1960) and measured the signal from protons processing in the Earth's magnetic field. Early NMR logging tools required the doping of the drilling mud with magnetite to kill the borehole signal. A prototype of the CMR tool was field tested in 1992 (Morris et al., 1993). The first commercial tool was introduced worldwide in 1994 (Morris et al., 1994). [1].

The recent introduction of total NMR porosity measurements into the well logging industry has provided many new formation evaluation techniques (Prammer *et al*., 1996; Freedman *et al*., 1997; Coates *et al*., 1997). A new NMR interpretation method for the evaluation of gas-bearing formations was proposed by Freedman (1997) and is referred to as the Density–Magnetic Resonance (DMR) method. [2].

The DMR method combines petrophysical response equations for total CMR porosity (TCMR) and formation bulk density measurements to derive new equations for gas-corrected total formation porosity.

In this study we used Freedman method to calculate DMR porosity and gas saturation.

2- Combination of density and magnetic resonance porosity in gas reservoirs

In fluid filled rocks, the volume of rock occupied by fluid is equal to porosity. Petrophysical NMR measurements utilize hydrogen proton spins to generate a signal. Because hydrogen is abundant in fluids, the magnitude of the NMR signal is proportional to the formation fluid volume.

When all the proton spins are aligned in the magnetic field, the NMR signal is proportional to the porosity of the rock.

The signal is a multi exponent decay curve and can be mathematically defined in multiple decay time constants. The multiple decay time constants are smoothed to provide a T2 relaxation distribution curve (figure 1). The area under the T2 curve is equal to the initial signal amplitude of the echo decay curve or porosity. Also T2 has been shown to be proportional to pore size [4].

The total CMR porosity (*TCMR*) in gas-bearing formations is defined by:

$$TCMR = \Phi S_{xog}(HI)_g GP + \Phi(1 - S_{xog})(HI)_f \qquad (1)$$

Where:

$TCMR$ is NMR total porosity, Φ is total formation porosity, S_{xog} is flushed zone gas saturation, GP is gas polarization function, $(HI)_g$ is hydrogen index of gas and $(HI)_f$ is hydrogen index of fluid.

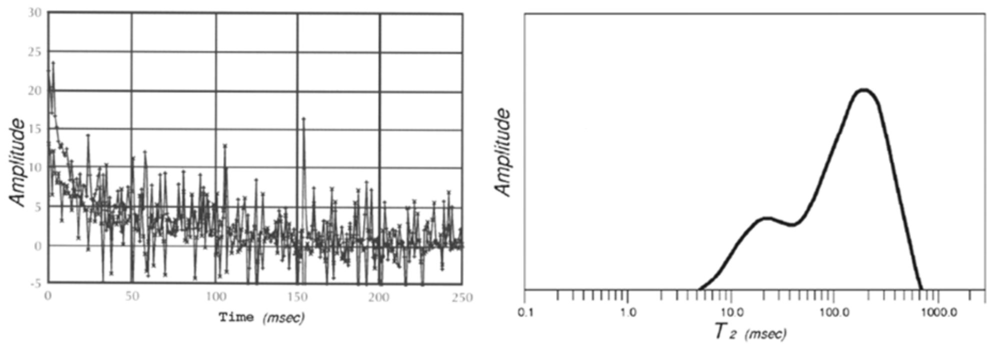

Figure 1 Example of measured echo train (left) and resulting T2 distribution (right).

The problem of NMR measurements in gas reservoirs is that in Gas-bearing zones, total NMR porosities read much less than density-derived porosities.
Porosity derived from NMR alone suffers from the low hydrogen index of the gas and the long T1 polarization time of the gas when the data is acquired with insufficient wait time.

Porosity can be calculated from bulk density because RHOB is the sum of the weighted components of the bulk density: fluid density, and the matrix density.

$$\Phi=\frac{\rho_{ma}-\rho_b}{\rho_{ma}-\rho_f} \qquad (2)$$

Measured formation bulk density in gas-bearing formations is defined by

$$\rho_b=\rho_{ma}(1-\Phi)+\rho_f\Phi(1-S_{xog})+\rho_g\Phi S_{xog} \qquad (3)$$

Where:

Φ is total formation porosity , ρ_b is bulk density, ρ_{ma} is matrix density, ρ_f is fluid density, ρ_g is Gas density and S_{xog} is flushed zone gas saturation.

The response equations 1 and 3 describe a two-fluid model of a porous formation that consists of a rock matrix and a pore space filled with a liquid and a gas phase.

The equations for DMRP and gas saturation are derived from the simultaneous solution of the equations 1 and 3 for the formation bulk density and NMR measurements [2].

$$\Phi = \frac{\left(\frac{\rho_{b-}\rho_{ma}}{\rho_f - \rho_{ma}}\right)\times\left(1-\frac{(HI)_g \times GP}{(HI)_f}\right)+\frac{(\rho_f - \rho_g)\times TCMR}{(\rho_{ma}-\rho_f)\times(HI)_f}}{\left(1-\frac{(HI)_g \times GP}{(HI)_f}\right)+\frac{(\rho_f - \rho_g)}{(\rho_{ma}-\rho_f)}} \qquad (4)$$

$$S_{xog} = \frac{\frac{\rho_{b-}\rho_{ma}}{\rho_f - \rho_{ma}} - \frac{TCMR}{(HI)_f}}{\frac{\rho_{b-}\rho_{ma}}{\rho_f - \rho_{ma}}\times\left(\frac{(HI)_g \times GP}{(HI)_f}\right)+\left(\frac{\rho_f - \rho_g}{\rho_{ma}-\rho_f}\times\frac{TCMR}{(HI)_f}\right)} \qquad (5)$$

Where Φ is called DMRP.

3- Formation evaluation of the reservoir

The DMRP calculation method is applied in one of Iranian huge gas reservoir, which is recently logged with CMR tool. The Kangan and Dalan formations in this reservoir in south of Iran are two of the most important reservoirs in the world. These formations are composed of limestone, dolomite, anhydrite and shale. This reservoir is subdivided into four individual zone and all four zones produce gas.

The heterogeneous carbonate reservoir has undergone post depositional diagenesis, which have had an impact on reservoir characteristics. Calcite cementation and dissolution, dolomitisation and particularly precipitation of anhydrite cements and shales have destroyed porosity and affect the permeability in the reservoir.

A number of 17 wells were selected for this study. Selected wells were drilled with water-base mud and penetrated a massive gas reservoir. Conventional cores were cut over the zones of interest on 5 wells and full set logs were carried out for all 17 wells. The CMR _Plus tool was logged at 270 m/hr using a 2.1 sec wait time in two wells. A petrophysical database was constructed that incorporates wire-line logs, NMR, core and layer data.

The gas-corrected porosity (DMRP) in the wells with NMR log provides an accurate formation total porosity that can be used to improve gas reserve estimates.

Figures 2 and 3 show the full set logs, T2 distribution of NMR and interpretation results in one of selected wells. A strong gas effect on the neutron and density logs is evident from the large separation between RHOB and NPHI as shown in track 4 above gas water contact (figure 2).

NMR porosity (TCMR), Density porosity (PHIT_DEN) and DMRP logs are compared with core derived porosity in track 8. This comparison shows good match between calculated DMRP and core porosity. Also Track 9 shows that core permeability and NMR permeability are in good agreement.

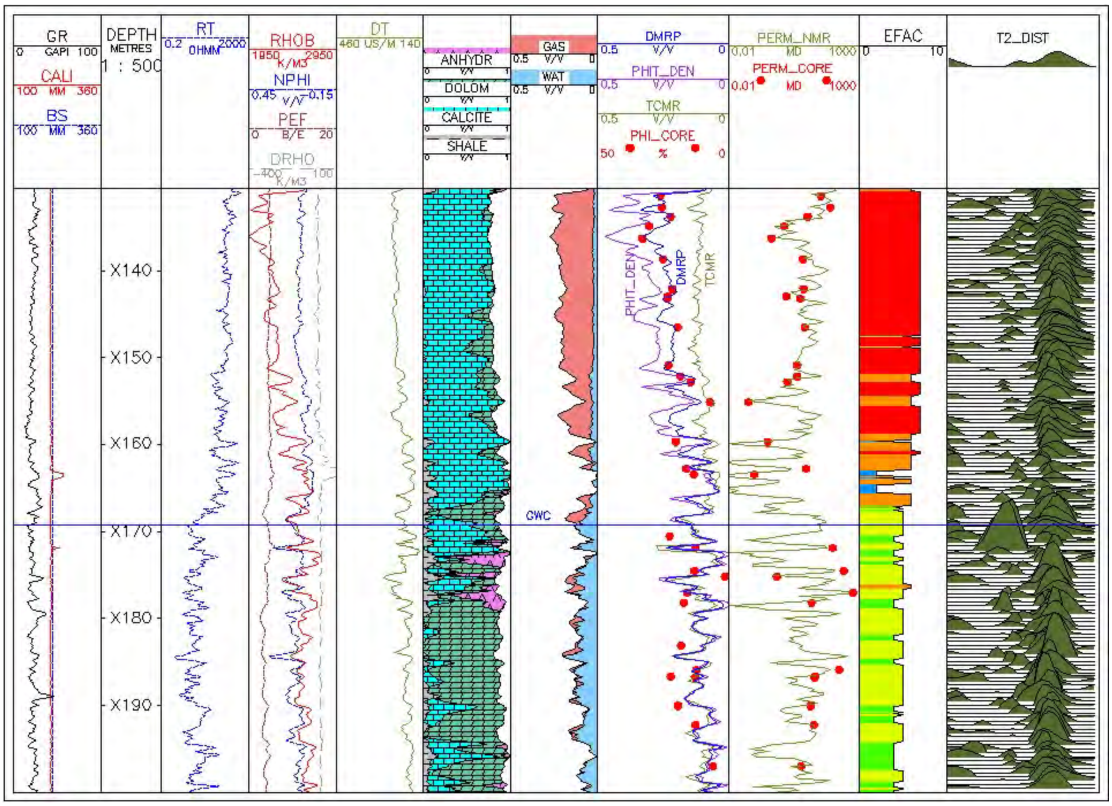

Figure 2 full set logs, T2 distribution of NMR and interpretation results in well A

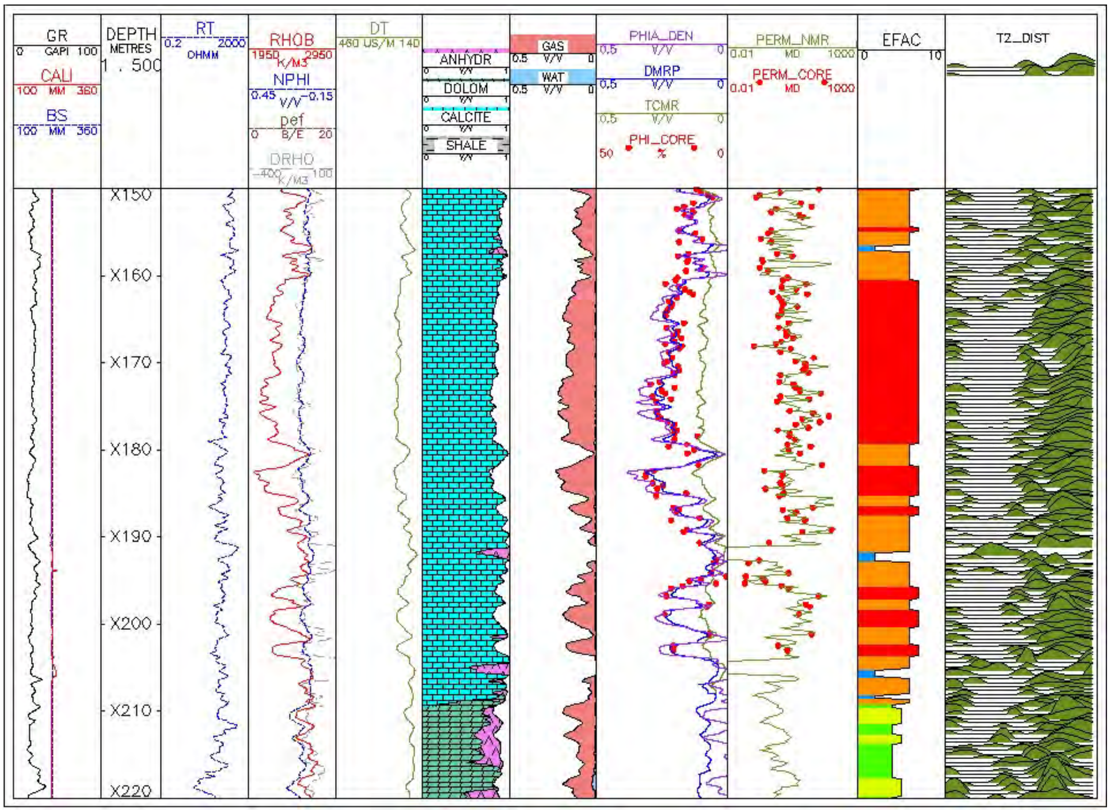

Figure 3 full set logs, T2 distribution of NMR and interpretation results in well B

In addition to evaluation of porosity and permeability, combination of resulted porosity and permeability with log and core data helps define three dimensional reservoir facies models that describe the distribution of porosity, permeability and capillary pressure in more detail.
An efficient way to perform a facies analysis is to setup a classification model that partitions the log data into sets of log responses that characterize facies and allow the facies to be distinguished from others. In a later stage of the survey, the model is propagated over the other wells of the same field.
In this study MRGC method (Multi-Resolution Graph-Based Clustering) was used to identify electrofacies in the wells. Continuous NMR permeability was imported to the models as an associated log to predict permeability over the entire field simultaneously.
To test the permeability prediction, the techniques were calibrated in 2 NMR wells and blind tested in two cored wells to see how well estimated permeability fitted the actual core permeability.
As indicated in figure 4 (A & B), there is good match between NMR facies base predicted permeability and core measurements. Also presented histograms (C & D) show that predicted permeability and NMR permeability in two predicted electrofacies in well A are in good agreement.

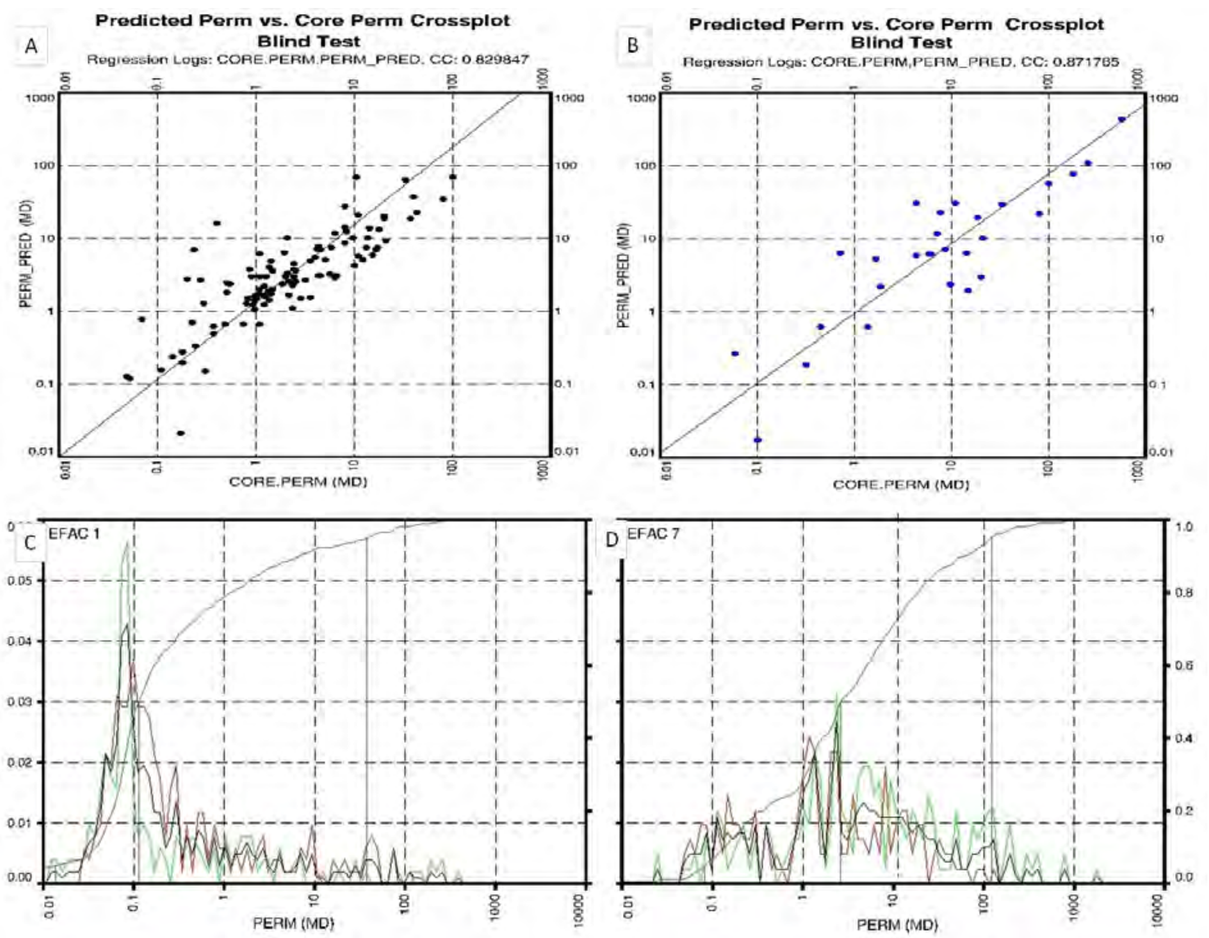

Figure 4 A& B: Comparison between predicted permeability and core measurements in two cored wells, C & D: histograms comparison between NMR permeability and predicted permeability in two predicted electrofacies in well A

4- Conclusions

Combining density log and NMR measurements improves the petrophysical evaluation of gas-bearing formations giving the total porosity corrected for gas effect and the flushed zone water and gas saturation. The DMR technique is able to produce a very good porosity estimate comparable to that estimated from the density-neutron logs and to porosity measurements on conventional core. Improved porosity calculation should lead to better core independent permeability estimation on the wells logged with NMR.

Seventeen wells from the field were evaluated for electrofacies using MRGC method. A NMR and facies base continuous permeability curve was also estimated over the wells that can be used as a direct input to the geological models. Electrofacies can also use as a heterogeneity modeler when sound rock types and flow units are not available.

5- Acknowledgments

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