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Improvement of petrophysical evaluation in a gas bearing carbonate reservoir–A case in Persian Gulf

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ABSTRACT

Significant digenetic processes such as dolomitization, chemical dissolution, reprecipitation, fracturing, etc. create complex pore size distribution in carbonate reservoirs. Contrary to sandstones, the pore size distribution in carbonates is bimodal or trimodal. The existence of organic material increases the complexity, too. The dominant carbonate minerals are dolomite and calcite, commonly associated with a variable content of anhydrite. Anhydrite content negatively impacts the well log interpretation and complicates carbonates behavior compared to sandstones. In addition, the existence of gas affects the whole interpretation by underestimating porosity, due to low hydrogen index. Therefore, to have an accurate hydrocarbon in place estimation, we have to reduce the abovementioned problems in the interpretation.

This paper presents existing methods in evaluation of a gas bearing carbonate reservoir in Persian Gulf and tries to improve the evaluation using new logs. The initial evaluation is based on traditional logging tools such as Gamma Ray (GR), Resistivity Logs, Density, Neutron and Sonic. Since there exists only core porosity, we will validate the model by them. Porosity of the cores do not correspond to the calculated properties by the initial model.

To improve the characterization, dipole sonic imager and nuclear magnetic resonance (NMR) logs included in the model. Effective porosity (total porosity corrected by shale volume) obtained from NMR has a better impact on the initial model compared to shear wave velocity. If both of the parameters are added to the dataset simultaneously, the obtained porosity approaches to the laboratory measurements, especially in gas bearing intervals. The equations of porosity versus core porosity were calculated using the method of least square regression and higher values of R^2 were obtained. The average calculated porosity approaches to the average porosity of laboratory measurements.

1. Introduction

Carbonate reservoirs contain almost 50% of the world hydrocarbon reserves (Palaz and Marfurt, 1997). These reservoirs will be one of the main sources of future hydrocarbon production in the world. Carbonate sediments show a different behavior from sandstones and have a bimodal or trimodal pore size distribution. Furthermore, organic remains play a different role in the formation of these reservoirs (Folk, 1959). Significant diagenesis occurring through chemical dissolution, reprecipitation, dolomitization, fracturing etc., complicates the behavior of carbonate rocks (Blatt et al., 1972). Therefore, the shape and size of the pore network is likely to be heterogeneous and pore sizes may range from microns to meters (Palaz and Marfurt, 1997). Porosity distribution of carbonates is complex and has not been studied comprehensively. Primary and secondary porosities are not distinguished easily (Longman, 1981). Anhydrite inclusions made by evaporate precipitation may also be present in the environment of carbonate deposition. Most of the existing petrophysical interpretation methods are developed based on sandstones (siliciclastics) and seem inappropriate for carbonates. The application of these methods leads to erroneous interpretations of carbonates. Mahiout et al. (2014) studied the negative impacts of improper effects of anhydrite content in well log interpretation. He applied geochemical spectroscopy logging tool for determining the volume of anhydrite and improved the accuracy of the porosity and mineralogy in a complex gas bearing carbonate reservoir.

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Accurate reserves estimation depends on determining porosity and saturation as Peters (2006) indicates. Detailed mineralogical characterization of carbonates is necessary to determine accurate porosity of carbonates. In addition, when the carbonate reservoir contains gas, the evaluation becomes ambiguous using conventional porosity logs (Mahiout et al., 2014). Al-Shehhi et al. (2012) addressed the application of elemental spectroscopy, nuclear magnetic resonance (NMR) and dielectric measurements to improve petrophysical interpretation of a gas bearing carbonate formation and validated the results by laboratory measurements.

Petrophysical evaluation of a reservoir contains determining the properties such as porosity, water saturation, density, mineralogy and type of the pore fluid. Determination of these properties are necessary to estimate the hydrocarbon potential of a reservoir. Well logging tools do not measure the petrophysical properties of the formation directly. The logs measure different formation parameters that are then interpreted and translated to petrophysical properties. We can measure these properties by direct core analysis in the laboratory.

In this study, in addition to conventional set of logs, modern tools were ran in the studied reservoir. Dipole sonic Imager and NMR were applied to measure shear wave velocity and nuclear magnetic properties, respectively. The principles of these tools are presented in the following sections.

1.1. Sonic tools

Acoustic waves help the geoscientists to obtain petrophysical properties of rocks. According to the sources, two types of sonic tools are applied in wireline logging, monopole and dipole. A monopole source emits energy in any direction from the transmitter. A dipole source has the capability to emit energy in a specified direction (Haldorsen et al., 2004).

1.1.1. Monopole source

When a monopole sources is located in the center of the borehole, it emits energy in every direction. A spherical wave travels from the mud to the borehole wall. Three new waves will be generated when the wavefront meets the wall. A mud wave will be reflected, and P-wave and S-wave will be generated in the interface. If the angle of refraction wave exceeds the critical angle, it will generate a headwave on the interface. Each point on this headwave will be a new wave source. This is concluded from Huygens principle. The first arrival recorded in the receiver is known as the P-wave arrival. This is the basic sonic logging measurement. The next recording in the receiver will be the S-wave arrival. The behavior of the refracted S-wave is similar to the P-wave. The last arrivals of a monopole source are surface waves (Haldorsen et al., 2004). Stoneley waves are slightly dispersive, so their velocity depends on the frequency. The permeability of a formation might be estimated from low frequency Stoneley waves (Scholte, 1948).

1.1.2. Dipole source

If the shear wave velocity is lower than the mud wave velocity, no refraction will occur. Therefore, no S-wave will be detected. This formation is called slow formation. In these types of formations, the monopole sources are not applied. A dipole source is designed to generate two orthogonal flexural waves along the tool. The particle motion in flexural wave is similar to S-waves (Haldorsen et al., 2004). Flexural waves have a dispersive nature like Stoneley waves. At zero frequency, flexural wave slowness is the true formation shear slowness. Therefore, using the dispersion analysis, the shear wave slowness can be obtained from flexural slowness (Sinha and Zeroug, 1999). In addition, dipole sources have higher resolutions.

Wang and Szata (1999) showed that V_p/V_s is a powerful tool for predicting lithologies of carbonate rocks. They applied a dipole sonic log to measure the velocity ratios of more than 95 carbonate core samples. They inferred that carbonate lithologies could be identified at the exploration stage if a measure of velocity ratio can be made in advance of drilling. Therefore, we expect a positive impact of including shear wave velocity on petrophysical evaluation of the case study by improving lithology.

1.2. Nuclear magnetic resonance (NMR)

NMR logging is based on the response of nuclei when it is exposed to a magnetic field. An external magnetic field changes the direction of the existing magnetism in the atomic nucleus. Measurable signals will be produced during this interaction. NMR measurements are based on the response of the nucleus of hydrogen atom. Hydrogen can be found in both water and hydrocarbon and has a relatively large magnetic status. Hydrogen protons relax in three different mechanisms: surface, bulk fluid and diffusion (Coates et al., 1997).

In NMR logging, the porosity measurement contains no data from the matrix and is independent from lithology. Therefore, the response is different from the conventional logging tools (Vinegar, 1986). Different valuable information about the fluids in the rock and the pores that contain these fluids can be obtained from NMR logging.

An NMR logging tool measures the density of hydrogen nuclei in reservoir fluids, directly as Miller et al. (1990) state. Since the density of the hydrogen nuclei of water is known, the NMR data can be easily converted to water-filled porosity without any knowledge of the matrix. In addition, NMR logging tool can determine the quantities of different fluids and some of its properties such as viscosity (Morriss et al., 1994).

From the difference between the NMR behavior of the fluid in a reservoir rock and in bulk form, one can obtain pore size data. Therefore, estimation of pore distribution can help in determining petrophysical properties of a reservoir rock such as permeability as well as capillary pressure (Prammer, 1994). An NMR tool can see all of the fluids in the pore space leading to total porosity. Therefore, using the pore size distribution, one can obtain the effective porosity (Prammer et al., 1996).

Mai and Kantzas (2002) studied the application of low field NMR in porosity distribution of carbonate reservoirs. Interpretation of NMR spectra determined the primary and secondary porosity of large collection of cores from Alberta and Saskatchewan. Al-Bulushi et al. (2013) combined dielectric and 3D NMR data to better characterize a carbonate reservoir in North Oman.

In this study, the interpretation of NMR spectra led to determination of effective porosity (total porosity corrected by shale volume) and was added to the petrophysical model as a new observation in a gas bearing carbonate reservoir.

2. Geological setting

The existing case study is a gas field in Persian Gulf. The field is a carbonate which was deposited in a shallow marine environment during a general regional marine transgression that began in the middle of Permian and lasted until Triassic. The studied formation has been formed in Permian period and is 195 m thick. The average top of the formation is 3100 m below mean sea level.

The formation consists of limestone interbeded with dolomite, with thin streaks of dolomitic limestone in the middle.