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A State-of-the-Art Permeability Modeling Using Fuzzy Logic in a Heterogeneous Carbonate (An Iranian Carbonate Reservoir Case Study)

M. R. Ghafoori, M. Roostaeian, and V. A. Sajjadian, Arvandan Oil & Gas Company (AOGC), National Iranian Oil Company (NIOC)

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Abstract

Permeability is one of the crucial parameters in dynamic reservoir modeling and simulation. Direct measurement of permeability through coring and wireline formation testing is expensive and sometimes fail to achieve. In recent years, different methodologies have been introduced to the petroleum geosciences/engineering descipline to predict permeability from openhole logs.

In this case study, the permeability models for two wells with core data were built using the following methods: permeability-effective porosity relationship, FZI, multilinear regression, and fuzzy logic. The last two uses the raw openhole logs data including density, neutron, sonic, and gamma ray. These models then were used to predict the permeability in the third well. Core data was used to cross-check the result for these wells. Along with the openhole logs, image logs permeability including coarse and high resolution is available to investigate the model.

The models result shows that the fuzzy logic yields a better result compared to other methods as fuzzy logic model could almost reproduce the whole range of the available core permeabilities but the permeability of the other models is in a narrower range compared to core permeability. Furthermore, the fuzzy logic model result is in harmony with the log derived permeability and could be used for permeability prediction fieldwide.

Introduction

Permeability is the ability of the rock in transmitting fluids through pore spaces in the rock. This means that non-porous rocks have no permeability. Permeability controls the directional movement and the flow rate of the reservoir fluids.

Acquisition of permeability is a important key in 3D reservoir modeling as well as in determining the well completion strategy. One of the challenges in characterizing and evaluating the reservoir quality is permeability estimation. That is because the permeability can not be measured directly for the reservoir rock with except of using core plugs and wireline formation testing as direct measurements. But, direct measuring methods are expensive, time-consuming and investigating only small scale of the reservoir which needs to be scaled up.

Permeability of the rock depends on its effective porosity; accordingly, it is affected by the grain size, grain shape, grain size distribution, grain packing, and the degree of consolidation and cementation. Also, the type of clay or cementing material between grains affects permeability [1].

Due to variation in depositional environment and diagenetic processes in forming of carbonate rocks, several porosity types coexist in carbonates simultaneously. So, carbonates are microscopically heterogeneous. Having different types of porosity with complex pore size distributions result in wide permeability variations for the same total porosity and making difficult to predict the permeability of carbonate rocks [1].

Because permeability is related more to the sorting and pore throat size rather than pore size, permeability prediction becomes more difficult to be evaluated by logging tools. Also, estimating permeability from well logs is encountered with the problem of scale. On average, well logs have a vertical resolution of two feet with compared to the two inches of core plugs [2].

Several methods for permeability prediction have been developed. The oldest method is based on relationship between porosity and permeability. This relationship is qualitative and is not directly or indirectly quantitative in any way. It is possible to have very high porosity without having any permeability at all, as in the case of pumice stone, clays, and shales. Conversely, high permeability with a low porosity is also possible, for example in micro-fractured carbonates [1].

Permeability in carbonate formations is not only related to porosity, but it also depends on grain size, sorting, pore throat sizes, the size of inter-granular pore space, the amount of unconsolidated vugs (fractures and solution cavities), and the presence or absence of connected vugs as discussed by Craze and Lucia [3, 4, 5].

In order to find an accurate correlation between the porosity and permeability, it must be taken into account a large number of physical factors that characterize a porous medium, including irreducible fluid saturation, specific surface