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Synthesis of capillary pressure curves from post-stack seismic data with the use of intelligent estimators: A case study from the Iranian part of the South Pars gas field, Persian Gulf Basin

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A B S T R A C T

Capillary pressure curves are important data for reservoir rock typing, analyzing pore throat distribution, determining height above free water level, and reservoir simulation. Laboratory experiments provide accurate data, however they are expensive, time-consuming and discontinuous through the reservoir intervals. The current study focuses on synthesizing artificial capillary pressure (Pc) curves from seismic attributes with the use of artificial intelligent systems including Artificial Neural Networks (ANNs), Fuzzy logic (FL) and Adaptive Neuro-Fuzzy Inference Systems (ANFISs). The synthetic capillary pressure curves were achieved by estimating pressure values at six mercury saturation points. These points correspond to mercury filled pore volumes of core samples (Hg-saturation) at 5%, 20%, 35%, 65%, 80%, and 90% saturations. To predict the synthetic Pc curve at each saturation point, various FL, ANFIS and ANN models were constructed. The varying neural network models differ in their training algorithm. Based on the performance function, the most accurately functioning models were selected as the final solvers to do the prediction process at each of the above-mentioned mercury saturation points. The constructed models were then tested at six depth points of the studied well which were already unforeseen by the models. The results show that the Fuzzy logic and neuro-fuzzy models were not capable of making reliable estimations, while the predictions from the ANN models were satisfyingly trustworthy. The obtained results showed a good agreement between the laboratory derived and synthetic capillary pressure curves. Finally, a 3D seismic cube was captured for which the required attributes were extracted and the capillary pressure cube was estimated by using the developed models. In the next step, the synthesized Pc cube was compared with the seismic cube and an acceptable correspondence was observed.

1. Introduction

Reservoir rocks are the porous and permeable media that hold commercial amounts of hydrocarbons. These media contain the immiscible fluids of water, oil and gas in an equilibrium which is caused by the capillary forces. Capillary pressure (Pc) as the pressure difference between these phases has a significant role in controlling the oil flow. Capillary pressure curves are one of the important tools in studying hydrocarbon reservoirs. As a parameter measured directly from core plugs, Pc curves currently provide reliable information about pore fluid saturation of oil/gas/water, lateral and vertical variations of permeability and dynamic properties of reservoirs. These curves can help in identifying reservoir compartmentalization, deciding about reservoir management or drilling prospects and monitoring injected fluids (Lumley et al., 2003). Besides, comparing a theoretical water saturation profile which is based on the capillary pressure measurements with a routine petrophysical saturation profile can offer a collection of diverse reservoir characterizations including positions of transition zones, hydrocarbon/water contacts (even if they are below the total depth of the well), and hydraulic units (Holmes, 2002). Considering all these vital information coupled with the much further knowledge achievable from Pc measurements, one can certainly claim that understanding the reservoir behavior demands a deep comprehension of major wettability behavior of the porous media. However, the availability of all the aforementioned precious and inspiring tools is challenged by core data scarcity and subsequent analysis costs. For the time being, the acquirement of capillary pressure values is based on experimental procedures for the most part. Nevertheless, the huge costs and sufferings of taking core samples accompanied by the difficulty and expensiveness of making measurements introduce such practical intelligent techniques. Hence, there has always been a considerable desire aimed towards the acquirement of these values with rather indirect methods. Numerous studies have

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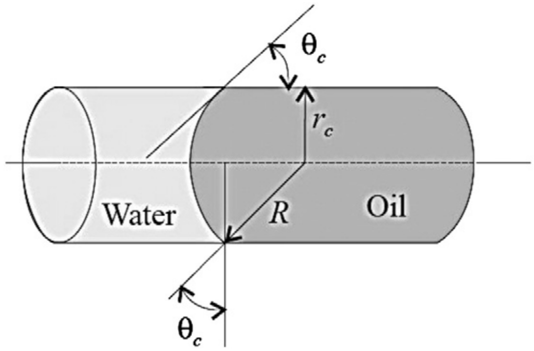

Fig. 1. Rock pore assumed as a cylindrical tube to derive capillary pressure equation (Ursin and Zolotukhin, 1997).

investigated the possibility of obtaining Pc values with the use of soft computing methods. Among these studies, Artificial Intelligence is currently playing a leading role. The most popular intelligent approaches include Fuzzy logic (FL), Artificial Neural Networks (ANNs), Adaptive Neuro-Fuzzy Inference Systems (ANFISs), Genetic Algorithms (GAs) and the hybrid systems. The current research makes use of Fuzzy logic (FL), neural network (NN) and neuro-fuzzy (NF) techniques to obtain synthetic capillary pressure curves from the post-stack seismic attributes. It is worth mentioning that even though numerous studies have discussed obtaining rock properties from seismic attributes by using neural networks, there has never been an attempt to simulate capillary pressure measurements from seismic attributes. Furthermore, the present research takes a look at implementing intelligent techniques other than NN (i.e. FL and ANFIS) in simulating capillary pressure curves. The idea behind this attempt lies in the fact that in case of having more than one appropriately functioning estimator, the results could be combined into a single response in a committee machine structure and a superior outcome would be obtained. Altunbay et al. (2001) studied gaining capillary pressure from NMR logs and its implications on field economics. AlMustafa and AlZahrani (2001) detected geopressure by using neural classification of seismic attributes. Glorioso et al. (2003) derived capillary pressure and water saturation from NMR transversal relaxation time. Lumley et al. (2003) investigated the estimation of reservoir pressure and saturation by crossplot inversion of 4D seismic attributes. Chopra et al. (2004) studied multi-attribute seismic analyses to determine nonlinear relationships in well logs. Schultz et al. (1994) carried out the seismic-guided estimation of log properties. The present study suggests synthesizing artificial capillary pressure curves from seismic attributes with the use of artificial intelligent estimators.

The study area is located in the Iranian part of the South Pars gas field in the Persian Gulf Basin. The Kangan and Dalan formations are the gas bearing reservoirs of the field. These carbonate reservoirs are respectively from lower Triassic and upper Permian era and mainly consist of dolomite, anhydrite, limestone and shale.

2. Statement of theory and basic definitions

2.1. Capillary pressure

Capillary pressure may be defined as the difference between the non-wetting and wetting phases across a curved area. Diverse experimental approaches like mercury injection and centrifuge method exist to obtain Pc values. Assuming rock pores as cylindrical tubes and oil and water as non-wetting and wetting phases respectively (Fig. 1) the capillary pressure is obtained by the following equation (Ursin and Zolotukhin, 1997):

$$\mathrm{Pc} = \frac{2\sigma_{ow}\cos\theta_c}{r_c} \tag{1}$$

where Pc is the capillary pressure, σ_{ow} is the surface tension parameter, θ_c is the contact angle in the oil–water–solid interface and r_c is the capillary radius.

In the mercury injection technique, the non-wetting phase (Hg) is injected into the core during the test. This fluid displaces the wetting phase and the saturation of both fluids change throughout the test (Honarpour et al., 1986). An approximate pore size distribution of rocks can be obtained from capillary pressure curves as it is reflected by the 1/r factor in the equation. Although the determination of the pore throat size distribution of rocks based on capillary pressure curves is only an approximation, the distribution is an important parameter for analyses of many fluid transport properties of porous media (Donaldson and Tiab, 2004). Capillary pressure curves are also used for calculating relative permeability. Even though this method is not usually the preferred one, it is useful for obtaining gas–oil or gas–water relative permeability when rock samples are too small for flow tests but large enough for mercury injection. The technique is also useful in rock which has such low permeability that flow tests are impractical and for instances where capillary pressure data have been measured but a sample of the rock is not available for measuring relative permeability (Honarpour et al., 1986).

The Pc curves used in developing the models of the present study were obtained by applying the mercury injection technique on the core samples cut from the reservoir horizons in one of the wells of South Pars gas field.

2.2. Seismic attributes

Seismic attributes are the mathematical representations of characteristics of the geological formations within the earth. They are referred to as any kind of quantitative measurement of a specific seismic property. Since the introduction of seismic attributes in the early 1960s which

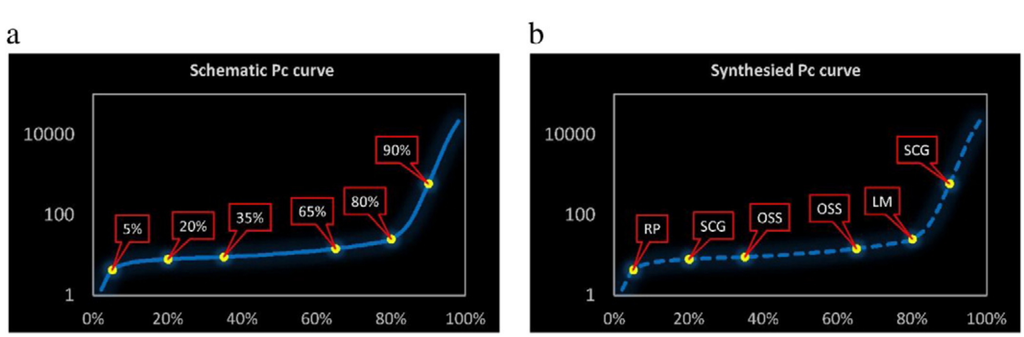

Fig. 2. (a) Procedure of estimating Pc curves, (b) the optimal training algorithms for estimating Pc values at each saturation point.