



Original article

Prediction of reservoir brine properties using radial basis function (RBF) neural network

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ABSTRACT

Aquifers, which play a prominent role as an effective tool to recover hydrocarbon from reservoirs, assist the production of hydrocarbon in various ways. In so-called water flooding methods, the pressure of the reservoir is intensified by the injection of water into the formation, increasing the capacity of the reservoir to allow for more hydrocarbon extraction. Some studies have indicated that oil recovery can be increased by modifying the salinity of the injected brine in water flooding methods. Furthermore, various characteristics of brines are required for different calculations used within the petroleum industry. Consequently, it is of great significance to acquire the exact information about PVT properties of brine extracted from reservoirs. The properties of brine that are of great importance are density, enthalpy, and vapor pressure. In this study, radial basis function neural networks assisted with genetic algorithm were utilized to predict the mentioned properties. The root mean squared error of 0.270810, 0.455726, and 1.264687 were obtained for reservoir brine density, enthalpy, and vapor pressure, respectively. The predicted values obtained by the proposed models were in great agreement with experimental values. In addition, a comparison between the proposed model in this study and a previously proposed model revealed the superiority of the proposed GA-RBF model.

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1. Introduction

Aquifers, which are rocks containing water, surround the majority of hydrocarbon reservoirs. The effect of the aquifer on reservoirs depends on the extent of the aquifer and the permeability of the rock. If these parameters are high enough, the

aquifer has a greater impact on the reservoir [1]. Aquifers, which play a prominent role as an effective tool to recover hydrocarbon from reservoirs, assist the hydrocarbon production in various ways such as: peripheral water drive, edge water drive, and bottom water drive [2]. In so-called water flooding methods, the pressure of the reservoir is intensified by the injection of water into the formation, increasing the capacity of the reservoir to allow for more hydrocarbon extraction [1,3]. In the aforementioned methods to recover hydrocarbon, brine would also be produced in addition to hydrocarbon [4]. Brine production increases when the reservoir pressure drops [5]. In some cases even if the most modern field management techniques are employed, produced fluid from the reservoir may comprise of 90% brine in volume [6]. Salty wet crude, recovered from the reservoir, lacks a good quality and causes some problems impeding hydrocarbon production. The brine production can have some adverse effects on the efficiency of hydrocarbon

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production and can affect the extent of depletion. In some cases, wells should be closed in due to inadequate treatment facilities [4]. In addition to mentioned problems, some studies have indicated that oil recovery can be increased by modifying the salinity of the injected brine in water flooding methods [7]. Furthermore, various characteristics of brines are required for different calculations used within the petroleum industry [8,9]. Consequently, it is of great significance to acquire the exact information about PVT properties of brine extracted from reservoirs.

In recent years, various properties of brines such as density, vapor pressure, and enthalpy have gained attention and several studies have been conducted regarding these characteristics. Two methods have been utilized by different studies to find accurate knowledge about different parameters relating to brine: (1) experimental studies (2) studies to present estimative models. However, laboratory approaches are costly and time consuming. Accordingly, if the experimental equipment is not available, the latter method is employed [10]. There have been several reports presented regarding brine density, which is considered as a crucial factor in many areas such as fluid inclusion studies, simulating fluid flow, and enhanced oil recovery. In experimental scope, Ghafri et al. [11] measured the density of NaCl (aq) at temperatures between 283 and 472 K and pressures up to 68.5 MPa and molality of 1.06, 3.16, and 6 mol/kg. Kumar [12] reported the density of SrCl₂ (aq) for a temperature range of (50–200) °C at 20.27 bar pressure up to a concentration of 2.7 mol/kg. Moreover, there are other experimental studies about density in literature [13–17]. Concerning predictive models, Hass [18] used the empirical Masson's rule to develop a model to predict the density of vapor-saturated NaCl (aq). This model is capable of density prediction in the range of (75–325) °C and up to a saturation of 7.3 molal. Phillips et al. [18] presented another model for density of brine, which is applicable for temperature range of (10–350) °C, molality range of (0.25–5) mol/kg, and pressures up to 50 MPa. This model can predict the laboratory data with a maximum deviation of $\pm 2\%$. Concerning enthalpy, Busey et al. [19] used a calorimeter to find the enthalpies of NaCl (aq) for dilute solutions. They carried out this experiment for concentrations of (0.1–5) mol/kg and at temperatures from (323–673) K. Comparing the results of the experiment with existing data in the literature, they indicated that the calorimeter can measure enthalpy accurately, which can be applied to find thermodynamic characteristics. Silvester and Pitzer [8] analyzed the thermodynamic parameters for NaCl (aq) and developed equations to predict them for the temperature range of (298.15–573.15) K and molality range of (0–6) mol/kg. They also provided a table for values of thermodynamic parameters including enthalpy. Mayrath and Wood [20] measured the enthalpy of NaCl (aq) for molality in range of (0.1–6) mol/kg and temperature range of (348–476) K. They applied the result to calculate the other parameters. This study also showed that flow calorimeter has the ability to measure the thermodynamic characteristics at high temperatures in a quick and accurate way. Mayrath and Wood [21] also utilized flow calorimeter to measure the enthalpy of the different aqueous solutions. Concerning vapor pressure, Gibbard et al. [22] reported the vapor pressures of NaCl (aq) at a temperature range of (298–373) K and molality range of (1–6.1) mol/kg. Using the measured data, enthalpy, and freezing-point data, they computed parameters of the modified Debye-Huckel-power-series. They compared the results of this equation

with the experimental data and found good agreement between them. Gibbard and Scatchard [23] conducted a similar investigation to Gibbard et al. [22] to measure the vapor pressure of LiCl (aq). Using the data, they presented a 25-parameter quantic equation and the results of the equation were consist with the experimental data. Liu and Lindsay [24] utilized laboratory approaches to find the vapor pressure of NaCl (aq) and water, and osmotic coefficients in the concentration range of 4 mol/kg to saturation and temperature range of (75–300) °C. Using the results of the experiments, they developed a group of equations expressing the free energies of NaCl (aq) over a wide range of temperatures and concentrations. Recently, Bahadori et al. [25] proposed an Arrhenius type function to prognosticate the characteristics of reservoir brine including density, vapor pressure, and enthalpy at a concentration range of (5–25)% salt content by mass and for temperatures above 30 °C. This model has eliminated some of the complexities of mathematics and allows petroleum engineers to calculate brine characteristics with fewer calculations than the previous models.

It is evident from preceding explanations that researchers have attempted to provide precise knowledge about the PVT properties of brine in order to apply them in computation with other important parameters. However, most of the studies use experimental or thermodynamic models that require a lot of time and calculations. In recent years, soft computing approaches such as Support Vector Machines (SVMs), Fuzzy Logic (FL), Genetic Algorithms (Gas), and Artificial Neural Networks (ANNs) have been adopted by different researchers in various parts of the petroleum industry to eliminate such difficulties because of their great capacity for analysis and modeling of complex subjects [26–31]. Regarding the use of these models in the prediction of brine PVT properties, Arabloo et al. [2] proposed a model employing the least squares support vector machine technique to estimate liquid saturation vapor pressure, density and enthalpy of formation water. They showed that the results of this model are in good agreement with experimental data.

Although the presented models using different methods to study the brine characteristics are valuable, further studies are needed to provide a more straightforward and accurate estimation of brine properties. To achieve this goal, artificial neural network has been applied in this communication. This study aims to develop three different intelligent models to predict the reservoir brine properties including density, enthalpy, and vapor pressure at vapor saturation pressure. After the development of the models, their accuracy will be investigated. Moreover, the results will be compared with Bahadori et al. [25] and Arabloo et al. [2].

2. Details of intelligent model

Artificial neural networks (ANNs), considered as a branch of artificial intelligence, have the capacity to learn, store and recall information if a suitable database is provided [32]. ANNs, incorporating a set of interconnected nodes, are computational models. Complex relationships can be modeled employing ANNs [33]. Ability for processing a huge data bank and capability to generalize the relationships between various variables are the main merits of neural networks. In addition to the aforementioned advantages of ANNs, there are some prominent problems with such approaches such as: noticeable computation stress, and probability to over-fitting [34,35].

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