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Development of a neural fuzzy system for advanced prediction of dew point pressure in gas condensate reservoirs

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ABSTRACT

Dew point pressure is one of the most critical quantities for characterizing a gas condensate reservoir. So, accurate determination of this property has been the main challenge in reservoir development and management. The experimental determination of dew point pressure in PVT cell is often difficult especially in case of lean retrograde gas condensate. Empirical correlations and some equations of state can be used to calculate reservoir fluid properties. Empirical correlations do not have ability to reliable duplicate the temperature behavior of constant composition fluids. Equations of state have convergence problem and need to be tuned against some experimental data. Complexity, non-linearity and vagueness are some reservoir parameter characteristic which can be propagated simply by intelligent system. With the advantage of fuzzy sets in knowledge representation and the high capacity of neural nets (NNs) in learning knowledge expressed in data, in this paper a neural fuzzy system(NFS) is proposed to predict dew point pressure of gas condensate reservoir. The model was developed using 110 measurements of dew point pressure. The performance of the model is compared against performance of some of the most accurate and general correlations for dew point pressure calculation. From the results of this study, it can be pointed out that this novel method is more accurate and reliable with the mean square error of 0.058%, 0.074% and 0.044% for training, validation and test processes, respectively.

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1. Introduction

Gas condensate reservoirs are valuable resources in providing energy. So, efficient production of these kinds of reserves is very important and crucial in petroleum industry. High rate gas production will decrease reservoir pressure below the dew point pressure (DPP). Consequently, liquid drop out around the well bore may reduce gas relative permeability and gas production rate. So, accurate determination of dew point pressure is considerable.

Constant Composition Expansion (CCE) and Constant Volume Depletion (CVD) are the most common tests in dew point pressure prediction. In CCE or pressure- volume test, a known amount of gas condensate is loaded into a visual PVT cell above the initial reservoir pressure. This usual PVT cell allows the visual observation of the condensation process that result from incrementally expanding the cell volume. An abrupt change of slope in a plot of relative volume versus pressure will determine the dew point pressure. Generally the dew point cannot be measured accurately by monitoring pressure–volume changes except in case of rich gas condensate samples which dew point is manifested by formation of a large amount of condensate. The depletion process is simulated by CVD, assuming immobility of dropped out condensate in porous media. The test consists of a series of expansion followed by expelling the excess gas at constant pressure in such a way that the cell volume remains constant at the end of each stage. The first droplet of condensate will be formed at the dew point pressure [1]. The experimental determination of DPP is expensive and time consuming and often not available.

During recent decades, various authors attempted to develop a general correlation for condensate fluid dew point estimation based on temperature, hydrocarbon composition and C_7^+ properties. Nemeth and Kennedy [2] developed a mathematical correlation relating the DDP of a hydrocarbon fluid and its composition, temperature and characteristics of the C_7^+ fraction. Multiple regressions were used to develop 11-coefficient correlation. They used 579 DPPs of 480 hydrocarbon system. The correlation covers a pressures range from 1270 to 10790 psi and temperature from 40 to 320 °F with an average deviation of 7.4%. (Elsharkawy [3] developed a 19-cofficient

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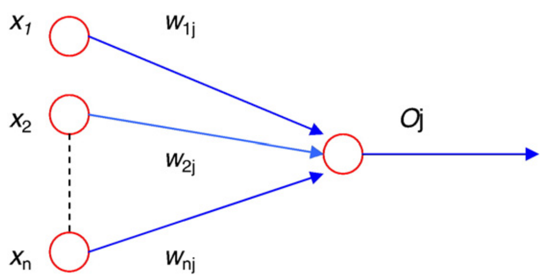

Fig. 1. A simple neuron.

mathematical correlation using 340 DPPs. The data includes 131 experimentally measured values and 209 collected from the literature and covers a pressure range from 1560 to 11830 psi and temperature range from 40 to 340 °F with an average absolute deviation of 7.68%.

Using 146 PVT analyses informs of western Venezuela (Anaco) fields, Marruffo et al. [4], developed correlations to determine the dew point pressure and C_7^+ content of gas condensate reservoirs. Mathematical recombination and mass balance were used as consistent tests to validate PVT test results. Statistical analysis of the variables was done focusing on multiple no linear regressions. This suggested correlation was more accurate than Nemeth and Kennedy correlation. Moreover, this new one allowed improving the characterization and exploitation plans of gas condensate reservoirs without PVT information. In 1996, Carison and Cawston [5] investigated the influence of hydrogen sulphide on dew point pressure. According to their researches, as H_2S content increases, the volume of liquid drop out decreases. Potsch and Braeuer [6], proposed a novel graphical method for determining the dew point pressure as a back up for visual readings of the total volume (gas and liquid) during a constant composition expansion and the Z-factor. The dew point is determined from a plot of the number of moles in the cell versus pressure. Graphical intersecting the straight line in the one phase region with the curve in the two phase region yields the dew point pressure. Although this method does not require a window or through- window cell, but high accuracy single Z-factor calculation routine is required. Although empirical correlations are simple yet accurate in some extent, but they have not been able to reliably duplicate the temperature behavior of constant composition fluids [7]. Being developed based on specific data set; most empirical correlations have not good generalization.

Using equations of state to calculate DPP is another method. However, convergence problem and proper characterization of the heptanes plus (C_7^+) fraction requirement are the most difficulties [1,3].

The complexity, fuzziness and uncertainty existent in addition to non-linear behavior of most reservoir parameters require a powerful tool to overcome these challenges. In recent years, intelligent techniques such as artificial neural network (ANN), fuzzy logic (FL), genetic algorithms (GA) have had noticeable part in reservoir engineering applications.

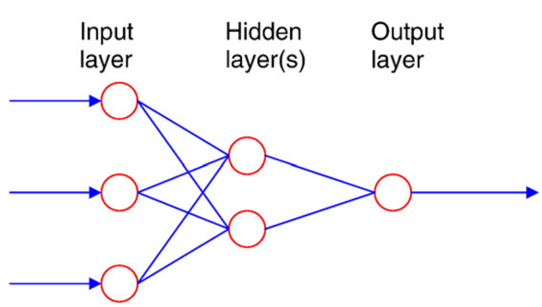

Fig. 2. Basic structure of multi-layer feed-forward neural network model.

Table 1
Properties of gas condensate samples used in this study

	Minimum	Maximum
DPP(psia)	2532	11,830
Reservoir temperature (°F)	40	362
Mw C_7^+	106	358
Composition mole fraction		
C_1	0.58	0.96
C_2	0.0010	0.1415
C_3	0.0006	0.0835
iC_4	0.0000	0.0179
nC_4	0.0000	0.0403
iC_5	0.0000	0.0436
nC_5	0.0000	0.0241
C_6	0.0001	0.0308
C_7^+	0.0003	0.1232
H_2S	0.0000	0.0311
CO_2	0.0000	0.0927
N_2	0.0000	0.1171

Nowadays, neural fuzzy systems have become more versatile approach to the problem of reservoir fluid properties prediction. Combination of the explicit knowledge representation of fuzzy logic with the learning power of neural nets can be more useful. This study is aimed at the following objectives:

1. Propose novel, simple yet accurate fuzzy neural system to estimate DPP.
2. Testing the performance of the model and compare the results with the performance of the most accurate correlations for DPP prediction (Nemeth and Kennedy prediction [2]; Elsharkawy [3]).

2. Fuzzy logic

Fuzzy logic was initiated in 1965, by Lotfi A. Zadeh, the father of fuzzy logic, at university of California. Basically, fuzzy logic is a multi-valued logic that allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low, etc. Notions like rather tall or very fast can be formulated mathematically and processed by computers, in order to apply a more human-like way of thinking in programming of computers [8].

There is an inherent vagueness present in our natural language when we describe phenomena that do not have abrupt boundaries. Fuzzy sets are mathematical objects modeling this impreciseness. Fuzzy set theory provides mathematical tool for carrying out approximate reasoning processes when available information is uncertain, incomplete or vague [9]. Fuzzy logic convert complex problem into simpler problems using approximate reasoning. The system is described by fuzzy rules and membership functions using human type language and linguistic variables [10].

A fuzzy set is a collection of ordered pairs $A=\{x,\mu(x)\}$ that describes the relationship between an uncertain quantity x and a membership function $\mu(x)$, where $\mu(x)$ is number between 0 and 1. Fuzzy model formulate the information on an intensity scale [11]. A fuzzy model determines the relationships between the inputs and outputs of a

Table 2
Characteristics of fuzzy model

Parameter	Operator
«and»	Prod
Implication	TSK: min
Aggregation	Max
Defuzzification	Wtaver

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