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Forecasting density, oil formation volume factor and bubble point pressure of crude oil systems based on nonlinear system identification approach

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ABSTRACT

Accurate predictions of fluid properties, such as density, oil formation volume factor and bubble point pressure, are essentials for all reservoir engineering calculations. In this paper, an approach based on nonlinear system identification modeling; Nonlinear ARX (NARX) and Hammerstein-Wiener (HW) predictive model, is proposed for forecasting the pressure/volume/temperature (PVT) properties of crude oil systems. To this end, two datasets; one containing 168 PVT samples from different Iranian oil reservoirs and other a databank containing 755 data from various geographical locations, were employed to construct (i.e. train) and evaluate (i.e. test) the models. Simulation results demonstrate that the proposed NARX and HW models outperform previously employed methods including three types of artificial neural networks models (committee machine, multilayer perceptron and radial basis function), two types of ANFIS models (grid partition and fuzzy c-mean) and several empirical correlations with the smallest prediction error, and that they are reliable models for predicting the oil properties in reservoirs engineering among other soft computing approaches.

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1. Introduction

Obtaining properties of reservoir fluid has a very important application in reservoir engineering computation such as inflow performance calculations, well test analysis, numerical reservoir simulation, reserve estimates and material balance calculations (Osman et al., 2001). One essential necessity for all types of petroleum calculations is the PVT properties such as design of fluid handling equipment, reservoir volumetric estimates and determination of hydrocarbon flowing properties. Idyllically, in order to extract desired PVT properties, these properties must be acquired through laboratorial analysis of real measurements/samples collected from the oil wells location. Most often, though, these measurements are not fully available, because of one or more of these reasons: a) Samples collected are not reliable. b) Samples have not been taken because of cost saving. c) PVT analyses are not available when needed (Hemmati and Kharrat, 2007). As a result, many correlations models have been developed to relate these desired properties (e.g. density and bubble point pressure) to other measures which are relatively abundant and/or easier to measure (e.g. temperature, pressure and API gravity). The geological condition is considered important for the development of a correlation, since the chemical composition of crude oil varies from region to region (Al-Marhoun, 2004). Therefore, all calculations will depend on the precision of the correlations used for predicting the fluid properties (Osman et al., 2001).

During the past sixty years, the importance of developing and utilizing empirical correlations for PVT properties has been recognized by engineers. Consequently, much research has been conducted in this field and lead to the development of new empirical correlations. Katz (1942) published a graphical correlation for predicting oil formation volume factor (B_o) factor. Katz used U. S. mid-continent crude to develop his correlations. Al-Marhoun (1985, 2004) correlations consist of equations for estimating bubble point pressure (P_b), solution gas-oil ratio and B_o for Saudi Arabia oils. These correlations were developed using 75 bottom-hole samples from 62 reservoirs in Saudi Arabia. Petrosky and Farshad (1993) presented correlations for estimating P_b, solution gas oil ratio, B_o factor and oil compressibility for Gulf of Mexico oils. The correlations were developed with fluid samples taken from offshore Texas and Louisiana. Khan et al. (1987) used samples from 75 bottom-hole from 65 Saudi Arabia reservoirs and developed equations for estimating oil viscosity for Saudi Arabia oils at above and below the bubble point. Glaso (1980) presented

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Nomenclature

ANFIS	adaptive neural fuzzy interface system
ANN	artificial neural network
API	oil API gravity
B_o	oil formation volume factor
E_a	average absolute percent relative error
E_{max}	maximum absolute percent relative error
E_{min}	minimum absolute percent relative error
E_r	average percent relative error
FCM	fuzzy c-mean
GP	grid partition
HW	Hammerstein-wiener
M	membership function
NARX	nonlinear autoregressive exogenous
P	pressure (psia)
P_b	bubble point pressure
R^2	coefficient of determination
R_s	solution gas/oil (scf/stb)
T	temperature (°F)
γ_o	oil specific gravity
γ_g	gas specific gravity
ρ_o	density (g/cm^3)

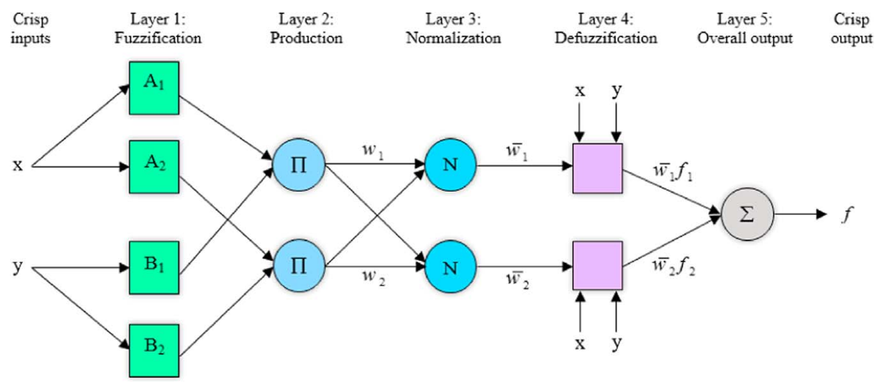

Fig. 1. ANFIS structure.

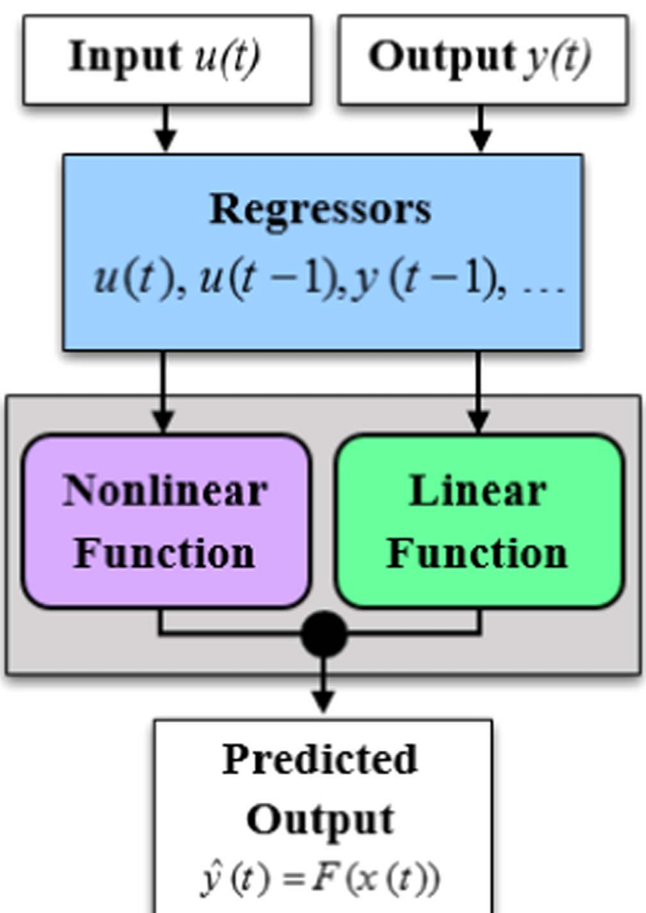

Fig. 2. Structure of NARX model.

correlations for estimating P_b, solution gas-oil ratio and B_o for North Sea oils. In other studies such as Hanafy et al. (1997), Egyptian crude oil were used to estimate correlations for P_b, solution gas-oil ratio, B_o, oil compressibility, oil density and oil viscosity. Also Standing (1962), using 105 experimental data points on 22 different oil-gas mixtures from California reservoirs, proposed correlations for estimating P_b, solution gas-oil ratio and B_o for California oils. In another study, Vazquez and Beggs (1980), using analyses of 600 laboratory PVT from fields all over the world, correlations for solution gas-oil ratio, B_o and oil compressibility were presented.

The main problem of these correlations is that they are not adequately accurate, since they are usually based on specific regions of oil fields. Therefore, researchers turned to soft computing methods for a greater accuracy, faster, and easier way of predicting important properties from available PVT parameters. Another popular means of obtaining reservoir properties is the method of Artificial Neural Networks (ANNs). Many researchers have investigated that ANNs are able to solve the PVT correlation problems in the petroleum industry (Shokir et al., 2004). Therefore, in recent years researchers have utilized ANNs to predict more accurate PVT correlations (Osman and Al-Marhoun, 2005; Asadisaghandi and Tahmasebi, 2011; Alimadadi et al., 2011; Abedini et al., 2012; Talebi et al., 2014). Obviously recurrent neural networks like ANN, because of their intrinsic nonlinearity and computational simplicity, are natural candidates to approximate a given model for a predictive purpose such as oil system properties. However, system identification approach as one of the widely employed method for prediction purposes; including such convenient model forms for prediction purposes like the Nonlinear AutoRegressive with exogenous inputs (NARX) model and Hammerstein-Wiener (HW) model has not been employed before, to the authors' knowledge, for crude oil properties forecasting. This study propose an approach, i. e. NARX and HW modeling for predicting reservoir-fluid PVT properties such as density, B_o and P_b with high accuracy.

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