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Comparison of scaling equation with neural network model for prediction of asphaltene precipitation

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ABSTRACT

The precipitation and deposition of crude oil polar fractions such as asphaltenes in petroleum reservoirs reduce considerably the rock permeability and the oil recovery. Therefore, it is of great importance to determine "how much" the asphaltenes precipitate as a function of pressure, temperature and liquid phase composition. Extensive new experimental data for the amount of asphaltene precipitated in an Iranian crude oil has been determined with various solvents at different temperatures and dilution ratios. All experiments were carried out at atmospheric pressure. The experimental data obtained in this study were used to examine the scaling equations proposed by Rassamdana et al. and Hu et al. We introduced a modified version of their proposed scaling equation. Our observation showed that the results obtained from the present scaling equation are more satisfactory. Furthermore, an Artificial Neural Network (ANN) model was also designed and applied to predict the amount of asphaltene precipitation at a given operating condition. The predicted results of asphaltene precipitation from ANN model was also compared with the results of Rassamdana et al., Hu et al. and our proposed scaling equations. It was observed that there is more acceptable quantitative and qualitative agreement between experimental data and predicted amount of asphaltene precipitation through using ANN model and this model can be a more accurate method than scaling equations to predict the asphaltene precipitation.

1. Introduction

Crude oils have complex composition; hence characterization by the individual molecular types is not possible. Instead, hydrocarbon group type analysis is commonly employed (Jewell et al., 1972; Leontaritis, 1997). The SARA separation is an example of such group type analysis, separating the crude oils in four main classes based on differences in solubility and polarity. Instead of molecules or atoms, certain structures are here considered as the components of the crude oil. The four SARA fractions are saturates, aromatics, resins and asphaltenes. Asphaltenes are high-molecular weight solids which are soluble in aromatic solvents such as benzene and toluene and insoluble in paraffinic solvents (Ali and Al-Ghannam, 1981; Speight et al., 1984). Asphaltene precipitation is one of the most common problems in both oil recovery and refinery processes. In oil recovery, especially in gas injection, formation of asphaltene aggregation, following their deposition causes blocking in the reservoir. This makes the remedial process costly and sometimes uneconomical. Unfortunately, there is no predictive model for asphaltene problem treatment. Hence it is necessary to predict the amount of asphaltene precipitation, as a pre-emptive measure. The major questions in facing such problems are "How" and "How much" heavy organic compounds will precipitate in operational condition. Over the years, many researchers have tried to find the answer. They introduced experimental procedures or even analytical models, but a fully satisfactory interpretation is still lacking. The problem is very difficult mainly because of the fuzzy nature of asphaltene and the large number of parameters affecting precipitation. However the existing models fall into three categories: (I) Molecular thermodynamic models in which asphaltenes are dissolved in crude oil and crude oil forms a real solution (Hirschberg et al., 1988; Kawanaka et al., 1991; Nghiem et al., 1998). The validity of such models depends on the reversibility of asphaltene precipitation. Reversibility experiments strongly support this type of models (Kawanaka et al., 1991; Ramos et al., 1997; Hammami, 1999; Peramanu et al., 2001). (II) Colloidal models in which, asphaltene is suspended in crude oil and peptized by resins. The asphaltene precipitation is irreversible in such models (Pfeiffer and Saal, 1940; Leontaritis and Mansoori, 1987; Mansoori, 1997). Reversibility experiments are strongly against this type of models. (III) Models based on scaling equation, in which the properties of complex asphaltenes are not involved (Rassamdana et al., 1996; Rassamdana and Sahimi, 1996; Hu et al., 2000; Hu and Guo, 2001). Analytically, an EOS used for calculating thermodynamic parameters assuming asphaltene precipitation is completely reversible. The calculation process is often found to be a difficult task because of the complexity of asphaltene. Nevertheless,

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Table 1
SARA analysis of the oil under study.

Fractions	Saturates	Aromatics	Resins	Asphaltenes (n-C_7)
Wt.%	29.3	35.2	27.2	8.3

neither using EOS nor assuming asphaltene reversibility brings enough accuracy and trustable results.

2. Scaling equation

Rassamdana et al. (1996) gathered extensive experimental data for the amount of precipitated asphaltene formed with crude oil and various solvents. All experiments were performed at atmospheric pressure and room temperature. They employed a thermodynamic model that uses Flory–Huggins theory of polymer solutions and an equation of state was also used for predicting the experimental data, and its predictions were found in disagreement with the data. As an alternative, they proposed a simple scaling equation that appears to be capable of providing accurate prediction for the data. They assumed that formation of asphaltene structure is to some extent similar to aggregation and gelation phenomena (Park and Mansoori, 1988). These phenomena are associated with universal properties independent of many microscopic properties of their structure.

To develop such scaling equation, they manipulated three main variables:

W_t Amount of asphaltene precipitated (wt.%),
R_v Solvent to oil dilution ratio (mL/g),
M_w Molecular weight of solvent,

and combined them into two new variable X and Y in which:

$$X = R_v / M_w^{\,Z} \tag{1}$$

$$Y = W_t / R_v^{\,Z'} \tag{2}$$

Z and Z' are two adjustable parameters and must be carefully tuned to obtain the best scaling fit of the experimental data. They suggested that Z' is a universal constant of −2 and $Z = 0.25$ regardless of oil and precipitant used. The proposed scaling equation is expressed in terms of X and Y through a third-order polynomial function

$$Y = A_1 + A_2X + A_3X^2 + A_4X^3 \quad (X > X_c) \tag{3}$$

where X_c is the value of X at the onset of asphaltene precipitation.

They also determined the critical dilution ratio R_c, at which onset of asphaltene precipitation takes place as a function of molecular weight of the solvent with setting $Y = 0$. The result was $R_c = 0.275M_w^{1/4}$ which shows that at onset, R_c only depends on solvent molecular weight. A general form of above equation is $R_c = CM_w^{1/4}$ in which C is a temperature dependent constant.

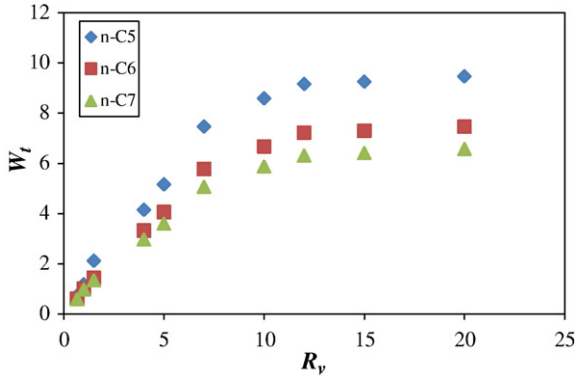

Fig. 2. Variation of asphaltene precipitation with dilution ratio at $T = 50$ °C.

Despite the simplicity and accuracy of the scaling equation mentioned above, it is restricted to use at a constant temperature and since temperature is not involved in the scaling equation as a variable, it is not adequate for correlating and predicting the asphaltene precipitation data measured at different temperatures. Due to this issue, Rassamdana and Sahimi (1996) modified their scaling equation by implanting temperature parameter in the scaling equation. Based on the previous equation, they defined two new variables x and y:

$$x = X / T^{\,C1} \tag{4}$$

$$y = Y / T^{C2} \tag{5}$$

in which X and Y are variables defined as in Eqs. (1) and (2) and constant C_1 and C_2 are adjustable parameters. They reported that the good fit of their experimental data can be achieved by setting $C_1 = 0.25$ and $C_2 = 1.6$.

Again the new scaling equation is a 3rd order polynomial in general form of:

$$y = b_1 + b_2x + b_3x^2 + b_4x^2 (x > x_c) \tag{6}$$

Hu et al. (2000) performed a detailed study on the application of scaling equation proposed by Rassamdana et al. (1996) for asphaltene precipitation. They checked the predictive capability of the scaling equation in comparison with literature precipitation data and reported that the scaling equation is an attractive tool for modeling asphaltene precipitation. They examined the universality of

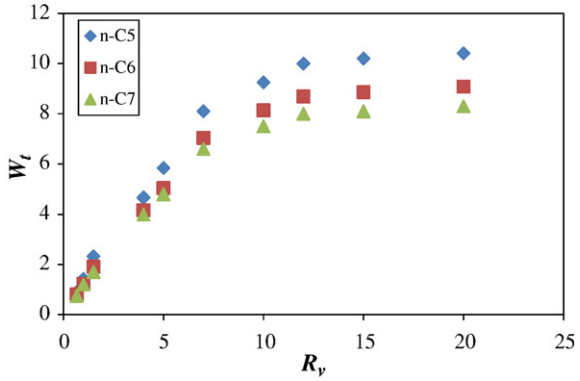

Fig. 1. Variation of asphaltene precipitation with dilution ratio at $T = 30$ °C.

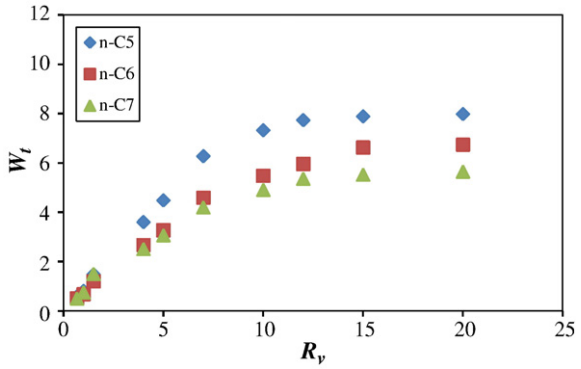

Fig. 3. Variation of asphaltene precipitation with dilution ratio at $T = 70$ °C.