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Developing a Fuzzy Logic Model to Predict Asphaltene Precipitation during Natural Depletion based on Experimental Data

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Abstract

Although the asphaltene problems have been studied for many years, there are numerous controversial issues around the nature of asphaltene. Since asphaltene precipitation imposes significant costs on oil industry, a comprehensive research must be done to address the issues about asphaltene structures. It is extremely important to investigate the behavior of asphaltene precipitation and ways to minimize it under changeable effective thermodynamic factors such as pressure, temperature, and composition.

In this work, natural depletion tests were performed at three different temperatures of 200, 170, and 135 °F on Iranian heavy oil samples. At each step of the experiments, IP 143 standard test was used to measure the precipitated asphaltene. Then, a fuzzy logic model capable of predicting asphaltene precipitation in a range of temperatures was developed. The fuzzy logic model predicts experimental data accurately. The obtained results were finally compared with a solid model using the commercial software implementing the mentioned model, and it was concluded that there was good agreement between the fuzzy logic model and the simulation results.

Keywords: Asphaltene Precipitation, Natural Depletion, Fuzzy Logic, Solid Model

1. Introduction

Asphaltenes, often defined by their solubility characteristics, are materials insoluble in n-heptanes at a dilution ratio of 40 parts to one part crude oil and re-dissolve in toluene (Speight et al., 1985). The prediction of asphaltene precipitation during oil production is an important issue, because it may cause plugging of the formation, wellbore, and production facilities and increase the cost of oil production. There are two different models to describe the nature of asphaltenes in solution. The first approach is the solubility model, which considers asphaltenes as dissolved in a liquid state. According to this model, the asphaltenes totally dissolve in crude oil and form a uniform solution (Burke et al., 1990). The second approach is the colloidal model, which considers asphaltenes as solid colloidal particles suspended in crude oil and stabilized by large resin molecules (Leontaritis and Mansoori, 1997). Recent studies confirm that asphaltene precipitations increase when temperature decreases; this can be interpreted as a result of variation in volume fraction of the species when temperature changes (Afshari et al., 2010). Although these models predict asphaltene deposition well, they need fluid characterization and rigorous calculation of phase behavior. The aim of this work is to develop a fast, simple, and accurate fuzzy model to predict the asphaltene deposition.

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Fuzzy-set theory, which was developed by Zadeh in 1965, is a great tool for modeling the uncertainty associated with ambiguity, imprecision, and lack of information (Ross, 1995). Fuzzy logic achieves this important task through fuzzy sets. In classical bivalent sets (crisp sets), an object either belongs to a set or it does not. Unlike the crisp sets, in fuzzy sets, everything is a matter of degrees. Therefore, an object belongs to a set to a certain degree (Mohaghegh, 2000). Fuzzy logic has four foundations including fuzzy sets, membership functions (MF), fuzzy rules, and logical operations.

Fuzzy inference system (FIS) involves all of these four foundations to formulate the mapping from input to output using fuzzy logic. The determination of the exact fuzzy rules and the type and number of membership functions for a specific problem is a difficult task and requires extensive testing. Fuzzy logic has many applications in oil industry such as enhanced oil recovery (Nikravash et al., 1997), well stimulation (Zoveidavianpoor et al., 2012), and underbalanced drilling (Garrouch and Lababidi, 2001). Specifically, fuzzy logic has also been used for the prediction of asphaltene deposition (Ebadi et al., 2012); however, it is different from this work, since, in this paper, the observed data are obtained by carrying out experiments for better understanding the asphaltene behavior of the reservoir fluid when temperature and pressure change. One of the advantages of this work is the use of an experimental data set to provide a guideline of the asphaltene behavior within the fluid and to define more precise fuzzy rules. Furthermore, the fuzzy logic model is validated by comparing its results with those of a solid model.

In this work, a fuzzy logic model was developed to predict asphaltene precipitation behavior during natural depletion based on experimental data. Then, the fuzzy logic model was utilized for predicting asphaltene precipitation at various temperatures, including 130 and 180 °F. Finally, the obtained results were compared with a solid model using commercial software (CMG, WinProp module). The precipitation of asphaltene phases in WinProp is modeled using a multiphase flash calculation in which the fluid phases are described with an equation of state, and the fugacities of components in the solid phase are predicted using the solid model**.** The solid phase may consist of one or more components**.** The approach for modeling asphaltene precipitation is described in detail elsewhere (Nghiem et al., 1993; Nghiem et al., 1996). In the solid model tried by Gupta (1986) and Thomas et al. (1992), the precipitated asphaltene is represented as a pure solid, while the oil and gas phases are modeled with a cubic equation of state (EOS).

2. Experimental setup and procedure

2.1. Setup

A schematic of the experimental setup is shown in Figure 1. It consists of a hydraulic pump, a heating system, a high pressure 0.5 µm metal filter, a PVT cell, a transfer vessel, a pressure transducer, a sampler, lines, and several pressure gauges. The tests were started at reservoir pressure and temperature of 4470 psia and 200 °F respectively. Table 1 shows the reservoir fluid composition and Table 2 summarizes the properties of the reservoir fluid.

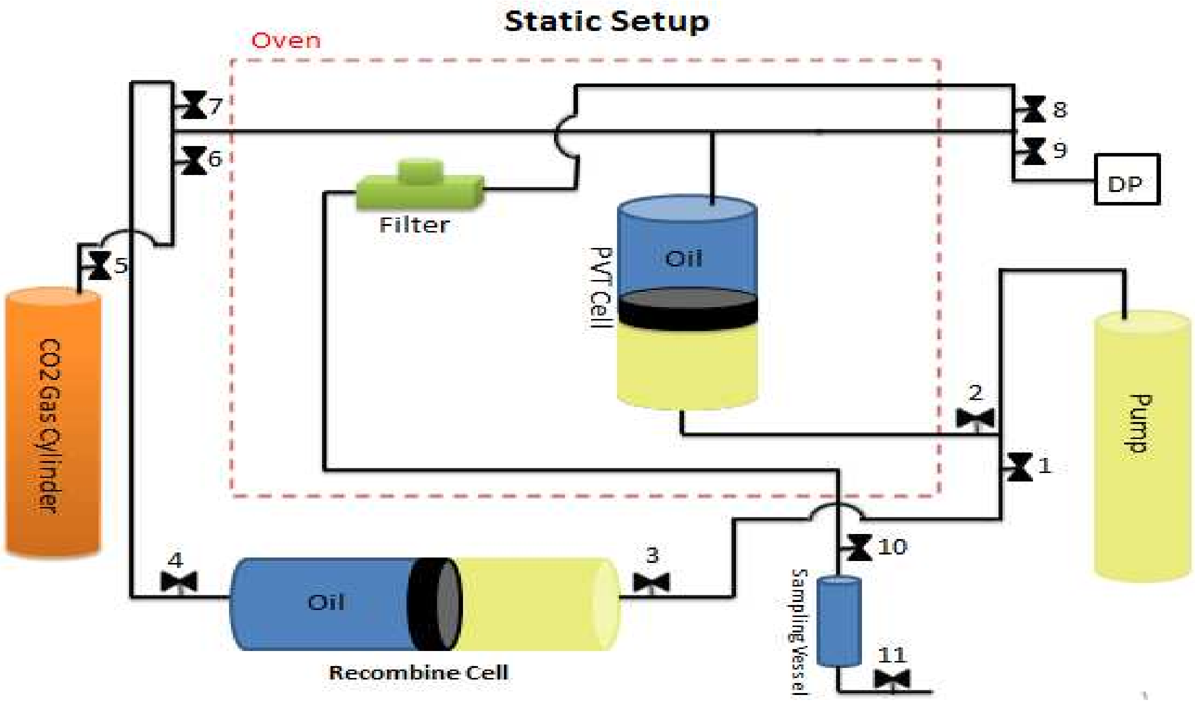

Figure 1
High pressure-high temperature apparatus.

Table 1
Reservoir oil composition.

Components	Reservoir Oil Composition (Mole %)
H_2S	0.00
N_2	0.39
CO_2	1.74
C_1	20.55
C_2	7.31
C_3	5.34
iC_4	1.00
nC_4	3.65
iC_5	3.10
nC_5	4.75
C_6	5.48
C_7	3.23
C_8	1.32
C_9	2.27
C_{10}	2.19
C_{11}	1.81
C_{12+}	35.87

Table 2
Reservoir oil properties.

Property	Value
API	20.32
Total AS content (wt. %)	12.80
GOR (SCF/STB)	319.04
Reservoir pressure (psia)	4470.00
Saturation pressure (psia)	1433.70
Reservoir temperature (°F)	200.00
Molecular weight of residual Oil	269.00
Molecular weight of C_{12+} fraction	370.00
Molecular weight of reservoir oil	169.00
Specific gravity of C_{12+} fraction @ 60/60 °F	0.98

2.2. Procedure

The experiments were conducted by transferring the heavy oil into the PVT cell. Pressure depletion tests, including four or five pressure steps, started at reservoir pressure. Three different temperatures were selected to investigate the effect of temperature on asphaltene precipitation. After reaching equilibrium conditions at a specific pressure and temperature, the soluble part of asphaltene was transferred to the sampler by filter. The asphaltene precipitation in PVT cell was obtained by subtracting flashed oil asphaltene precipitation from initial asphaltene content. Standard IP 143 test was used to measure asphaltene content at each pressure step.

3. Result and discussion

3.1. Natural depletion

The results of natural depletion test for three temperatures are shown in Figure 2. As it can be seen in the figure, above the bubble point pressure, as the pressure decreases, the asphaltene precipitation increases; this is because of the dominancy of the solubility model. However, because the colloidal model is dominant below the bubble pressure, asphaltene precipitation decreases as the pressure declines.

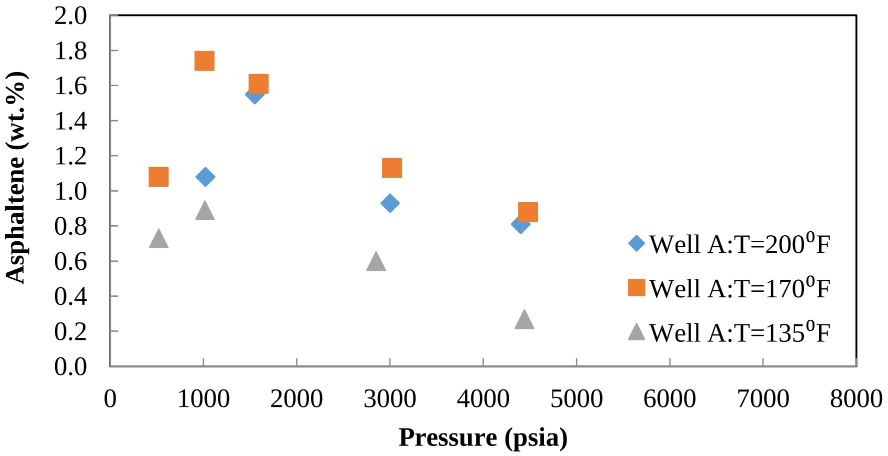

Figure 2
Results of natural depletion test at different temperatures.

3.2. Fuzzy logic model

The experimental results of natural depletion were used to develop fuzzy rules and the fuzzy logic model. In this model, there are two input parameters, namely pressure and temperature, and one output, i.e. asphaltene precipitation in the PVT cell. Membership function (MF) is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership between 0 and 1). The Gaussian membership function, because of its highly accurate prediction, has been selected in this work. There are three membership functions for temperature input, including low, moderate, and high (Figure 3). Six membership functions were defined for pressure input, including very low, low, moderate, high, very high, and extremely high (Figure 4). Further six membership functions including null, low, moderate, high, sever, and extremely severe were selected for the output (Figure 5).

Fourteen fuzzy rules and Mamdani fuzzy interference system (FIS) were utilized to develop the model. Figure 6 shows a three dimension diagram of pressure-temperature-asphaltene response of the model.

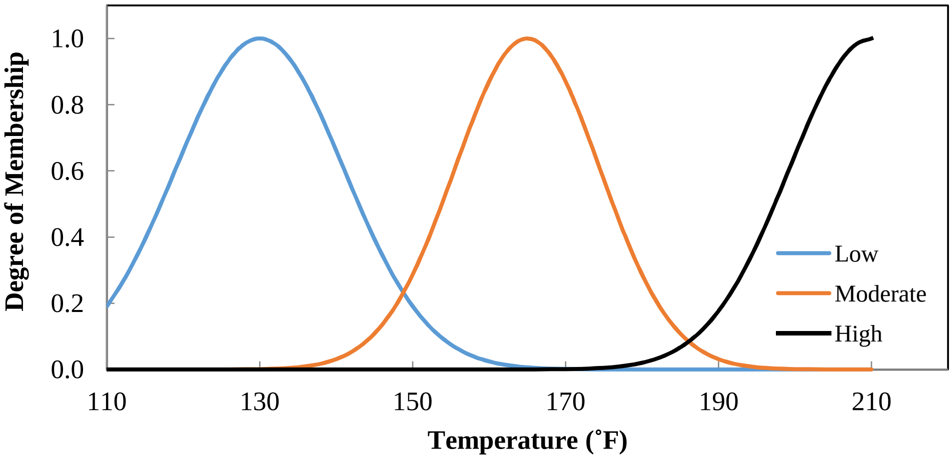

Figure 3
Membership function of temperature.

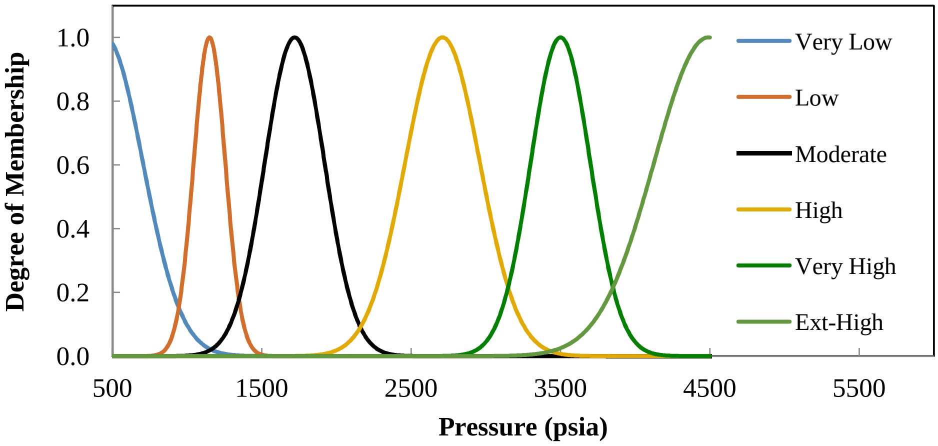

Figure 4
Membership function of pressure.

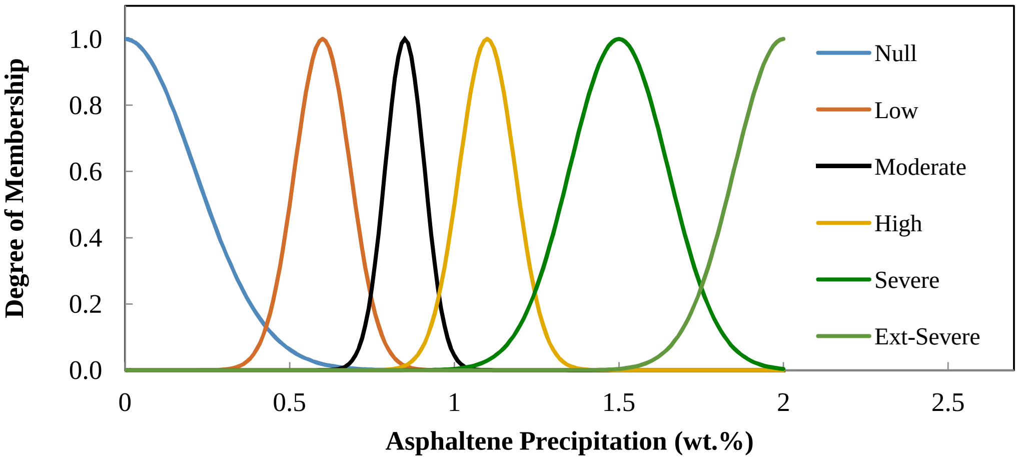

Figure 5
Membership function of asphaltene precipitation.

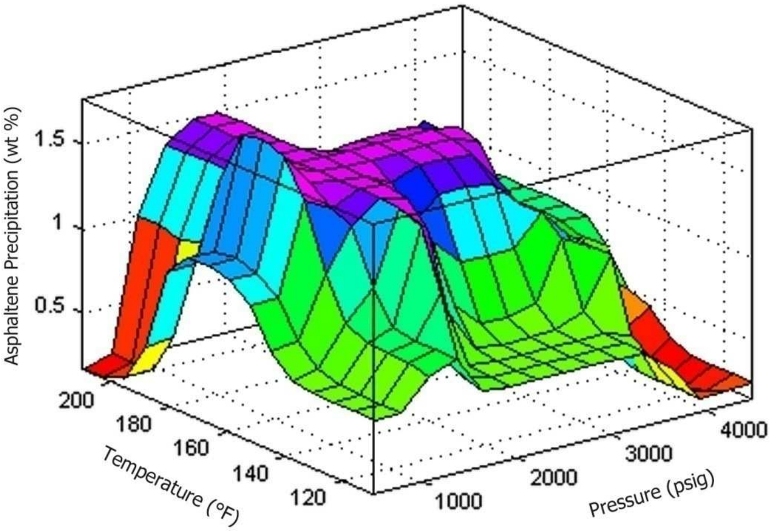

Figure 6
Three dimensional plot of pressure-temperature-asphaltene using the fuzzy logic model.

3.3. Comparison of the experimental and fuzzy model results

The fuzzy model properly predicts experimental data and the coefficient of determination is equal to 0.94625. Figure 7 shows the cross-plot of the fuzzy model predictions and experimental data. According to this figure, the fuzzy model is ready to predict asphaltene precipitation at other pressures and temperatures. The comparison of the experimental data and the fuzzy logic prediction was performed at three different temperatures including 200, 170, and 135 °F (Figures 8.a-8.c). Good agreement between the experimental data and the fuzzy model predictions is observed.

To test the generality of the developed model, the fuzzy logic model was used to predict the asphaltene weight percent versus pressure at other temperatures such as 130 and 180 °F. At these temperatures, the fuzzy logic results were compared with a rigorous solid model using commercial software and it was concluded that there were acceptable differences between the results of the fuzzy logic models and those of the simulation (Figure 9).

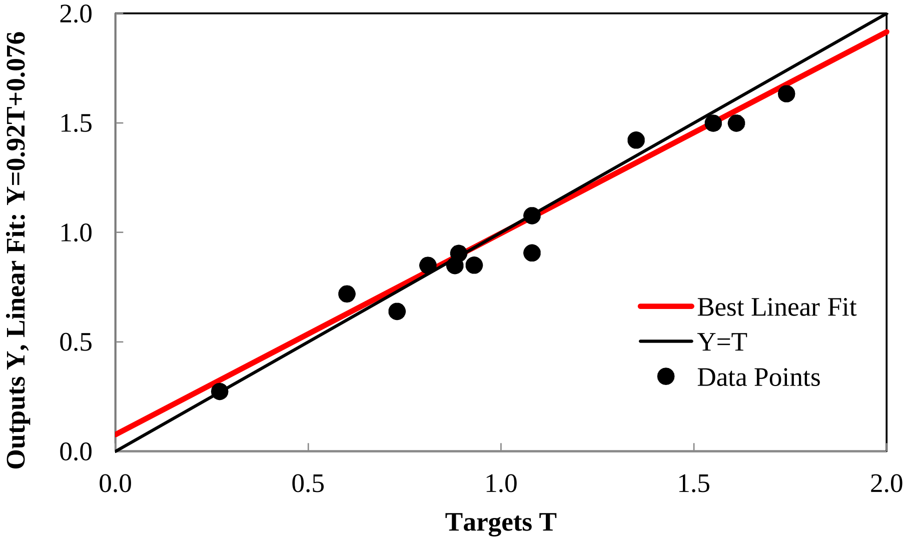

Figure 7
Fuzzy prediction data versus experimental data.

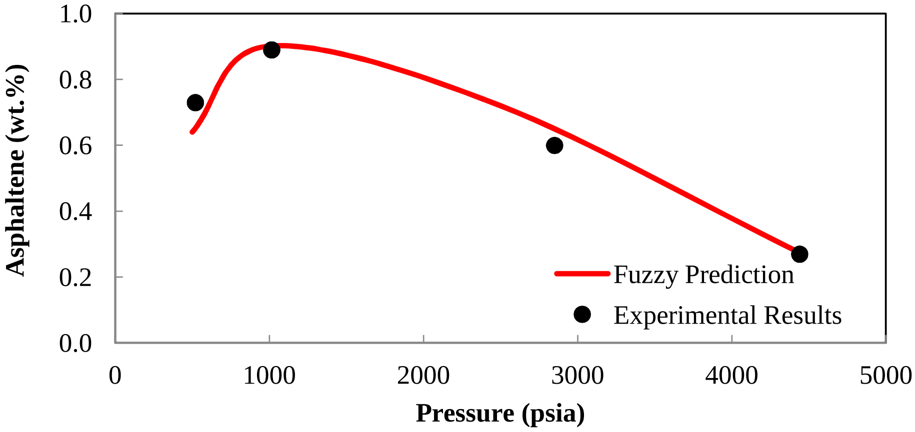

Figure 8.a
Comparison of experimental data and fuzzy prediction at T= 135 °F.

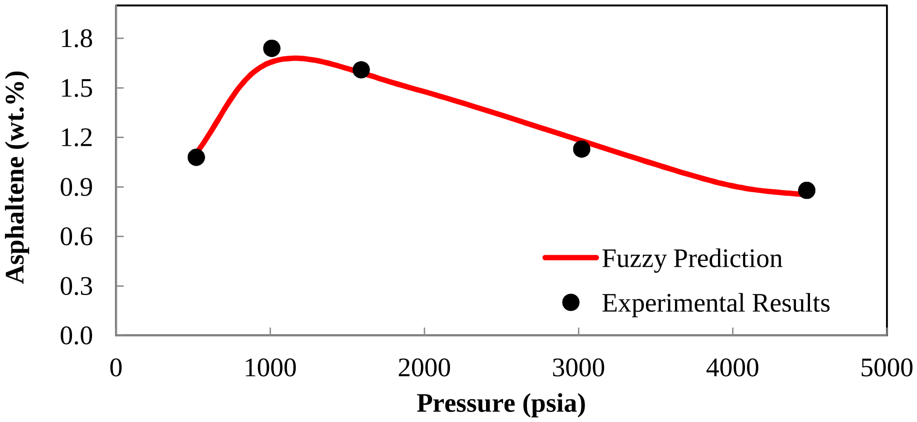

Figure 8.b
Comparison of experimental data and fuzzy prediction at T= 170 °F.

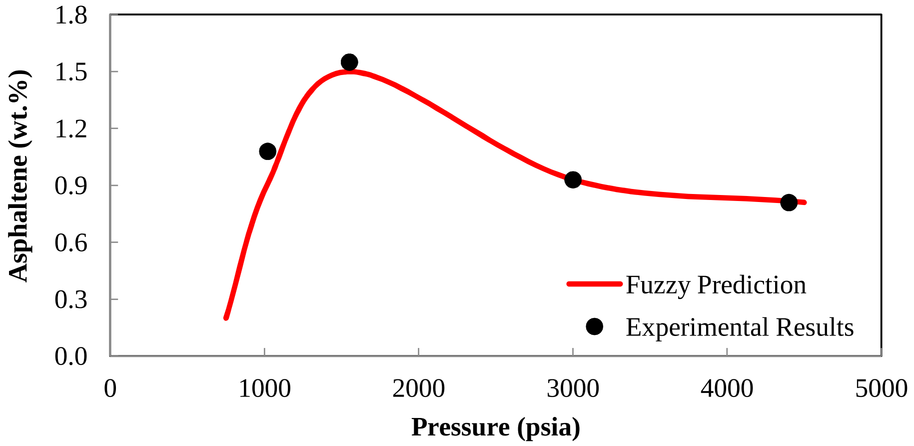

Figure 8.c
Comparison of experimental data and fuzzy prediction at T= 200 °F.

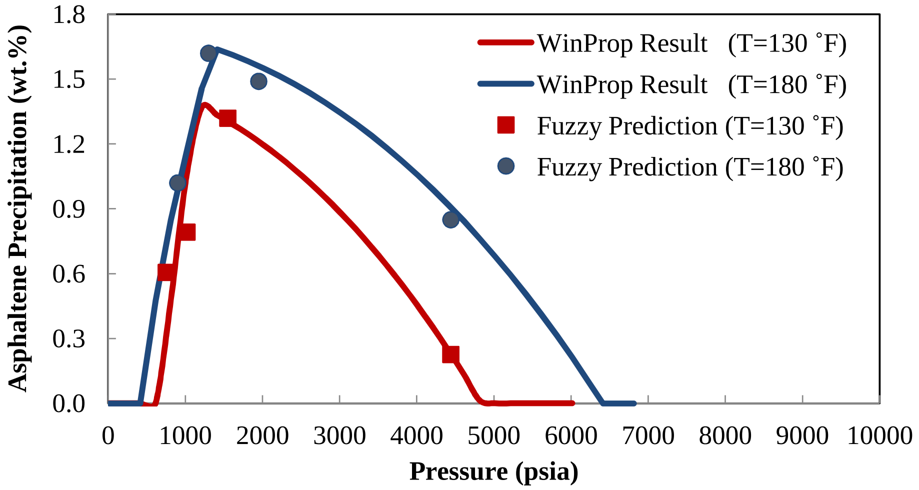

Figure 9
Asphaltene weight percent versus pressure graph using commercial software and fuzzy logic prediction data at constant temperatures.

4. Conclusions

Natural depletion tests were carried out at three different temperatures, i.e. 200, 170, and 135 °F. It was observed that as the reservoir pressure decreases to the bubble point pressure, asphaltene precipitation increases. Furthermore, as the pressure falls below the bubble point pressure, asphaltene precipitation decreases. Moreover, it is concluded that the solubility model is dominant above the bubble point pressure, and that the colloidal model is dominant below the bubble point pressure. In a further step, a fuzzy logic model was developed to predict asphaltene precipitation during natural depletion at other temperatures. It was shown that there is good agreement between the experimental data and the fuzzy logic model. The coefficient of determination between the fuzzy model prediction and the experimental data is close to unity (0.94625) confirming good accuracy in the predictions. Finally, the fuzzy logic results were compared with those of the solid model run using a commercial software package ending up in acceptable agreement.

Although fuzzy logic is a powerful tool for these kinds of vague systems, there is no capability of learning and pattern recognition in the fuzzy system. To overcome this shortcoming, neurofuzzy systems, which refer to the combinations of artificial neural networks and fuzzy logic, could be considered as very useful alternatives in the petroleum industry.

Nomenclature

MF	: Membership function
FIS	: Fuzzy inference system
EOS	: Equation of state
P	: Pressure
T	: Temperature
API	: American Petroleum Institute
GOR	:Gas oil ratio

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