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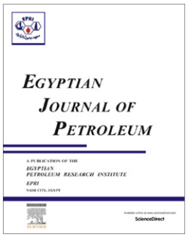

FULL LENGTH ARTICLE

Upgrading fuzzy logic by GA-PS to determine asphaltene stability in crude oil

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Abstract Precipitation and deposition of asphaltene are undesirable phenomena that arise during petroleum production which give rise to a pronounced rate of increase in operational cost and adversely affect production rates as well. Hence, it is imperative to develop a mathematical model for the assessment of asphaltene stability in crude oil. In the present study, delta *RI* which constitutes the difference between refractive index of crude oil (*RI*) and refractive index of crude oil at the onset of asphaltene precipitation (*PRI*) is employed as the principal factor for determining the asphaltene stability of the region. Fuzzy logic is a potent tool capable of extracting the underlying dependency between SARA fractions (saturate, aromatic, resin, and asphaltene) data and delta *RI* for the inexpensive and rapid diagnosis of asphaltene stability. In this study a novel strategy known as hybrid genetic algorithm-pattern search (GA-PS) is suggested for the development of an optimal fuzzy logic model as a reliable alternative for the widely-applied subtractive clustering (SC) method. While SC solely optimizes mean of input Gaussian membership functions (GMFs), GA-PS tool optimizes both mean and variance of input GMFs. Comparison between GA-PS and SC methods confirmed the capability of GA-PS for developing an optimal fuzzy logic model.

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1. Introduction

Crude oils have complex compositions. Application of individual molecular types for chemical identification of crude oil is contained by their complex composition. Hence, in lieu of individual molecular types, hydrocarbon group analysis is frequently employed for their characterization. SARA separation test is an example of such group type analysis. SARA test is a modality through which crude oil is categorized into four major chemical groups named saturate, aromatic, resin, and asphaltene. The separation is accomplished due to difference in polarity and solubility [1]. Among crude oil fractions, asphaltenes are the most important constituents owing to problems followed by their precipitation and deposition in production systems. It is proven that asphaltene is the heaviest,

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most polar and, most complicated portion of a petroleum fluid [2]. Asphaltenes are conventionally defined as colloid-like heavy fractions of crude oils that are completely miscible with aromatic hydrocarbons like benzene and toluene but precipitate when excess of low-molecular weight normal alkanes like *n*-pentane and *n*-heptane are added [3]. At initial reservoir condition, asphaltene is stable in crude oil by virtue of peptizing by resin [4]. Owing to the sensitivity of phase stability of asphaltene to change in thermodynamic conditions such as variation in pressure, temperature, and crude oil composition, delicate balance between asphaltene and other components in crude oil might be disturbed and asphaltene commence to phase-separate from crude oil and deposit in solid form in the production system [5]. The precipitation and deposition of asphaltene impinge both upstream and downstream of petroleum industry. Upstream, deposition of asphaltene has detrimental effects on reservoir rock properties owing to mechanisms of wettability alteration and pore throat blockage [6]. Downstream, precipitation and deposition of asphaltene arise in topside production facilities and transportation pipeline which induce a considerable increase in production operational costs as well as an adverse effect on production rates [7]. Marked increase in operation cost fostered by asphaltene precipitation created a need to develop a simple and effective model with the view to grasping the underpinning fundamentals of the phase behavior of asphaltene precipitation. Extensive studies have been undertaken to clarify the phase behavior of asphaltene, but efforts for achieving a precise model for prediction of the threshold point at which asphaltene separate from petroleum fluids and its amount is hindered mainly as a consequence of its fuzzy nature and myriad of parameters affecting its precipitations [8]. Each of the three main classes of models takes various approaches to describe the precipitation conditions and they are as follows: (I) Molecular thermodynamic models [9], (II) colloidal approach [10], and (III) Models which are based on scaling approach [11]. The stability of asphaltene in crude oil is one of the major challenging issues in oil industry and has been the subject of extensive studies. Many researchers introduced different criteria for monitoring asphaltene stability in crude oil [12–14]. Leontaritis and Mansoori, [12] posited that stabilizing the asphaltene in crude oil would be achieved by means of peptizing by resin; therefore, they introduced asphaltene and resin contents as the pre-eminent factors that affect asphaltene stability in crude oil. They introduced the resin to asphaltene ratio as the indicator for diagnosis of asphaltene stability. Yen et al. [13] claimed that portions of each of the SARA fractions play a significant role in stabilizing asphaltene in crude oil. As a result, a new screening criterion professed as colloidal instability index was introduced in order to identify the potentiality of asphaltene deposition in crude oil systems. Their index is defined as the ratio of sum of asphaltene and aromatic to the sum of resin and aromatic. Recently, Fan et al. [14] proposed a new criterion to quantitatively investigate asphaltene stability. They used two distinct factors, refractive index of crude oil (RI) and refractive index of crude oil at the onset of asphaltene precipitation (PRI), for the diagnosis of asphaltene stability in crude oil. They employed the difference between RI and PRI as a decisive factor for assessment of asphaltene stability in crude oil. They pointed out that delta RI ($\Delta RI = RI - PRI$) greater than 0.06 corresponds to crude oil with stable asphaltene while delta RI ($\Delta RI = RI - PRI$) less than 0.045 is indicative of crude oil which is more likely to have asphaltene deposition problems. Crude oil with delta RI ($\Delta RI = RI - PRI$) in the range of 0.045 and 0.06 is considered in the border region. Ideally, RI is computed by using a Refractometer. Calculating RI from experimental technique is costly, time consuming, and limited to light crude oils. Limitations associated with the experimental method have created the need to develop an accurate mathematical model for relating the RI to the SARA experimental data. Available mathematical models for assessment of asphaltene stability in crude oil through the use of refractive index fall into two major categories. In the first class, empirical correlations are used for the diagnosis of asphaltene stability in crude oil through relating the SARA fractions data to RI [14–15]. In the second class, Least-Square Support Vector Machine is employed as an intelligence model for construction of a model between SARA fractions data and RI [16]. Aforementioned mathematical approaches predict RI by the use of SARA fractions data and consider the constant value of 1.44 for PRI. Subsequently, determination of the asphaltene stability region was achieved by virtue of computing the difference between RI and PRI. Although application of empirical correlations and intelligence model for the diagnosis of asphaltene stability in crude oil is useful, they possess some drawbacks as they do not have enough accuracy and they also consider the constant value for PRI without considering the variation of PRI by crude oil composition. Pertaining to the above explanation, it seemed crucial to propose a satisfactory mathematical model as an alternative for direct prediction of delta RI by the use of SARA fractions experimental data and for assessing the asphaltene stability in crude oil. In the light of the above, a novel methodology was offered to construct a fuzzy model for connecting the SARA fraction data to delta RI. The widely-held approach for developing fuzzy clusters and fuzzy rules between input/output data is subtractive clustering. However, the mentioned procedure is established upon the basis of producing Gaussian membership functions (clusters) with constant spread. To be more descriptive, spread of Gaussian membership functions will not be optimized. To overcome this problem, a hybrid genetic algorithm-pattern search technique was suggested for extracting the optimal values of parameters involved in fuzzy clusters. This strategy has dramatically widened in function for it optimizes traditional subtractive based fuzzy model and enhances the accuracy of the final prediction.

2. Optimizing fuzzy logic by genetic algorithm-pattern search

Fuzzy logic is an extension of Boolean logic that views problems as a degree of truth or 'fuzzy sets of true or false' [17]. The process of mapping a set of input data into an output using the fuzzy logic is called fuzzy inference system. This procedure is illustrated through the following equations from a mathematical perspective. Suppose that input membership functions for the fuzzy inference system are designated to estimate delta RI from SARA fraction data and are as follows:

$$\mu_i(S) = \exp(-(S - m_{Si})^2 / 2\sigma_{Si}^2) \tag{1}$$

$$\mu_i(A) = \exp(-(A - m_{Ai})^2 / 2\sigma_{Ai}^2) \tag{2}$$

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