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Prediction of crude oil blends compatibility and blend optimization for increasing heavy oil processing

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A R T I C L E I N F O

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A B S T R A C T

In the present study, prediction of crude oil blends compatibility and blend optimization for increasing heavy oil processing has been attempted. The crude oil blend compatibility (K model) is determined based on the physical parameter ratios of the crude oils. The physical parameter ratios of the crude oil include at least log (Sulphur)/Carbon Residue, API/Sulphur, and Kinematic Viscosity/API. The K model is developed by coefficients obtained by regression analysis between the ratios of physical parameters of known crude oils and composite compatibility measure determined from multiple compatibility test results of the known crude oils. Nine different tests conducted to estimate crude oils blend compatibility viz. colloidal instability index (CII), colloidal stability index (CSI), Stability Index (SI), Stankiewicz plot (SP), qualitative-qualitative analysis (QQA), Stability Cross Plot (SCP), Heithaus parameter (P value), Oil compatibility model (OCM) and Spot tests. 50 different crude oils have been participated in the development and tuning of the model. The compatibility criterion is proposed as if $K \geq 0$; blend is compatible and if $K < 0$ blend is incompatible. Further, sixteen new crude oils and fourteen blends have been used for validation. Eventually, K model is able to predict composite results of all nine different laboratory based compatibility tests. Further, the predicted blend compatibility along with other blending constraints viz. viscosity, pour point, sulphur content, overall distillation yields and crude oil parcels availability have been considered for blend optimization.

There is strong relationship of K model with intensity of spot color, desalting performance and fouling behaviour which further verified through experiments. If K is positive; Spot color is darker, desalting is better and fouling is minimum. But if K is negative; there is lighter Spot color with asphaltene flocculation or precipitation, poor desalting and high fouling is observed. K model accurately predicts the blend composition to minimize operational problems while increasing heavy oil processing.

1. Introduction

Refineries typically process a blend of crude oils rather than a single crude oil to ensure that an optimum product mix can be obtained at minimum costs. To increase the margins, refineries are looking for ways to co-process heavy crude oils with light crude oils. Heavy crude oils have a high amount of paraffin or asphaltene or both as difficulty. When there is high paraffin content, it results in high viscosity and high pour point making transportation difficult. On the other hand, a high asphaltene content causes precipitation, flocculation, instability, and incompatibility related problems during processing. Therefore, increasing co-processing of heavy oil components is a real challenge.

To increase the heavy oil content in the mix of crude oils processed and also for suitable oil selection for processing, refiners encounter five common problems on day-to-day operation viz. (i) Incompatibility/Stability issues when the crude oils are blended, (ii) high viscosity of the blend, (iii) high pour point of the blend, (iv) high sulphur content in the blend, and (v) high vacuum residue yields upon processing. While selection of crude oils and blends is done, various simulations and correlations are used to ensure viscosity, pour point, distillation and residue yields, and sulphur content is appropriately managed [1–4]. However, incompatibility of crude oils and blend is still a grey area, which is currently being managed by previous operational experience and compatibility test results received from oil testing laboratories. Incompatibility is a serious problem which causes asphaltene precipitation and severely affects various equipment viz. tanks, heat exchangers, separators, columns pumps, etc., and in the absence of viable models to manage incompatibility, refining operations and costs can get severely affected [5–8].

There are various test methods reported and being practiced at

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laboratories in order to study the stability of crude oils and blends viz. colloidal instability index (CII), colloidal stability index (CSI), Stankiewicz plot (SP), qualitative-quantitative analysis (QQA), Stability Cross Plot (SCP), Heithaus parameter (or parameter P), Heptane Dilution (HD), toluene equivalence (TE), spot test and oil compatibility model (OCM) [9–13]. Some of the tests are correlation based, which requires Saturates, Aromatics, Resins and Asphaltene (SARA) analysis data to predict the stability of crude oils. OCM, TE and P parameter methods require asphaltene precipitation data when solvents like heptane or toluene are added in different ratios to estimate the stability of crude oils. Thus, these tests require samples of the crude oils and blends to be chemically tested in the laboratory before a decision can be made for purchasing and processing the crude oils.

In the past, various research groups have attempted to develop methods and correlation models to predict asphaltene precipitation and crude oil stability and compatibility. Insolubility number (I_N) and solubility blending number (S_{BN}) have been recognized as important parameters to predict asphaltene precipitation [11]. Higher the S_{BN} number, there is less possibility for incompatibility. Sollaimany and Bayandori [15] studied the asphaltene deposition behaviour. According to their results, CSI such as the (Aromatics + Resin)/(Asphaltene + Saturates) ratio and (Aromatics + Resin)/Asphaltene ratio are less significant for asphaltene stability rather structural parameters of asphaltenes and resins are important. Asomaning [16] conducted various tests such as spot test, CII, Asphaltene/Resin ratio, and solvent method with near-infrared spectroscopy to predict the asphaltene stability in crude oils. CII and solvent titration method prediction results found closer to the field deposition results. However, some of the papers concluded that CII is not an appropriate method for prediction of asphaltene precipitation when asphaltene content is low and saturate content is high. Guzman et al. [14] have extensively reviewed different methods and concluded that CII and SP methods were predicts unsatisfactory results, on the other hand, QQA and SCP predicts better for asphaltene stability in crude oils. Stratiev et al. [17] have correlated asphaltene solubility with the asphaltene hydrogen content and the oil solubility power correlated well with the oil saturate content. Higher asphaltene aromaticity help in solubilizing asphaltene compounds. They also found that some of the physical parameters such as specific gravity, Conradson carbon, and viscosity are able to predict the hydrogen, saturates, and asphaltenes content of vacuum residual oils [18]. Similarly, there are few tests reported to predict asphaltene precipitation based on experimental physical properties data. Mendoza et al., predicted incompatibility of blends of crude oils with liquid hydrocarbon from dynamic viscosity and density. They observed that increase in viscosity and density of the crude oil blends mixed with liquid hydrocarbon increases tendency of asphaltene aggregation. Incompatible region determined by viscosity data is more superior to density data [17–19]. Moreover, as the test results may vary depending on the test method used, methods based on one or two tests are incapable of accurately predicting compatibility. In addition to this, models reported in the literature are not applicable to all ranges of properties, for example when crude oils which have a low amount of asphaltene (≤ 0.5 wt%) and high amount of saturates. ASTM D 7112 [20] test method covers an automated procedure involving titration and optical detection of precipitated asphaltenes for determining the stability and compatibility of heavy oils more accurately, but this test method is not relevant to oils that contain $< 0.05\%$ asphaltenes. As a result, more than three to four tests are needed to confirm the compatibility of crude oils and blends [14]. Most of the compatibility test methods are based on combination of characterization and correlation based for prediction of asphaltene precipitation or deposition. Rodriguez et al. [6] studied various experimental set up for studying the compatibility of crude oil blends under dynamic conditions viz. temperature, pressure, solvent type, and flow and generated data. Although experimental set up based method generates data irrespective of prior information about asphaltene content of the samples, but these methods are time consuming in case of testing multiple blends. Refinery processes mix of various crude oils and requires regular monitoring, controlling and optimization of blends meeting processing parameter constraints and product demand. While these methods are comprehensive either standard compatibility tests method or under dynamic conditions, they are experiment based, and one crude oil blend sample can be tested at a time. By the time results come, suboptimal crude oil blends are processed or asphaltene precipitation problems are created in the refineries, which requires substantial efforts and price to resolve. Thus, while there are multiple different approaches studied for determining compatibility of crude oils in blends, the compatibility test methods are usually time consuming because final blend compatibility decision is not fully reliable based on one standard test [9–21].

The objective of the present work is (1) To provide for quick and effective method for prediction of crude oil blend compatibility and blend optimization for increasing heavy oil processing using a 'prediction model tool'. The prediction model is based on the measurement of a few bulk physical parameters ratio, which are conventionally and regularly analyzed at quality control laboratory of refineries. These analyses typically take less than an hour and therefore the present method is rapid for predicting crude oil blend compatibility. No additional tests are required and the blending decisions can be made quickly. In contrast to conventional methods, the present subject matter does not require comprehensive laboratory testing for compatibility checking and blending, which otherwise normally takes about two weeks' time. Using this as tool, increasing heavy oil processing and help to substantially eliminate operational problems (asphaltene precipitation) caused due to crude oil blend incompatibility in refineries.

Furthermore, using existing laboratory test methods, blends of only two crude oils can be optimized at a time. To optimize a blend of three crude oils, first a compatible blend of two crude oils has to be obtained and then a mix of the two crude oils with the third has to be optimized. If additional crude oils are to be blended, the compatibility checking and blend optimization become even more complicated.

(2) Hence, another objective of the present work is to devise a methodology for compatibility prediction and optimization of blends having n-crude oils based on the physical parameter ratios of each of the n-crude oils. Thus, the present subject matter can be used for increasing heavy oil processing and helps to substantially eliminate operational problems caused due to crude oil blend incompatibility in refineries.

2. Experiments and compatibility tests

2.1. Crude oil characterizations

Crude oil samples were sourced internationally from various part of the world and these samples were received directly from crude oil suppliers/traders and in-house refinery samples. Crude oils and blends were characterized for API gravity (ASTM D4052), Sulphur (ASTM D2622, D4294, D5453), Kinematic Viscosity (ASTM D445), Micro Carbon Residue (ASTM D4530), Conradson Carbon Residue Carbon Residue (ASTM D189), Ramsbottom Carbon Residue (ASTM D524), Pour Point (ASTM D97, D5853, D5950), Saturate content, Aromatic content, Resin content and Asphaltene content (IP143) and True Boiling Point (TBP) and PotStill distillation (ASTM D2892 and D5236). Fifty crude oils were characterized and considered for model development. Some of the properties are reported in Table 1 below.

2.2. Compatibility tests

Different tests such as colloidal instability index (CII), colloidal stability index (CSI), Stability index (SI), Stankiewicz plot (SP), qualitative-quantitative analysis (QQA), Stability Cross Plot (SCP), spot test, Heithaus parameter, and oil compatibility model (OCM) were carried out for the fifty different crude oils samples. A composite result from

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