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Asphaltene Stability Investigation for Crude Oil Sample from The Nahr-Umr Formation / Halfaya Oil Field

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Abstract

Asphaltene precipitation and deposition have a detrimental influence on a variety of oil and gas activities, including oil recovery, oil transportation, and petroleum processing. Modeling and predicting phase behavior and asphaltene precipitation are crucial since the Halfaya oil field is still in the early stages of development. Because of the significant expense of remediating asphaltene deposition in crude oil production and processing, screening techniques for assessing the stability of asphaltenes in crude oil have been developed. In this work, the Asphaltene-Resin Ratio, the Colloidal Stability Index, and the Modified Colloidal instability Index are utilized to predict the stability of asphaltene in crude oil. These techniques, as well as the experimental data derived from them, are described in detail. The parameters that control asphaltene precipitation vary from well to well, from high-pressure, high-temperature reservoirs to surface conditions, and must be investigated on an individual basis. Using Multiflash software, this study created a thermodynamic model for bottom-hole crude oil samples from a well in the Halfaya oil field/Nahr-Umr formation. Compositional analysis, PVT data, and reservoir conditions were among the data. The Cubic-Plus Association equation of state was used to develop a thermodynamic model of asphaltene phase behavior. All results indicate the presence of asphaltene precipitation problems. The conclusions of all screening techniques indicate the presence of an asphaltene precipitation problem (asphaltene instability), which was validated by a thermodynamic fluid model.

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1. Introduction:

Asphaltenes, resins, aromatics, and light and heavy paraffins are all components of crude oil. Asphaltenes make up the largest and polarized portion of crude oil. They are polyaromatic molecules that are bound by heteroatomic chains and aliphatic (such as S, O, and N), as well as metals (such as V, Ni, and Fe) [1]. Asphaltene is one of the components of crude oil. Its definition depends on its solubility in the oil mixture rather than on its chemical basis. Asphaltene dissolves in aromatic solvents like benzene and toluene but not in light solvents like N-alkanes [2].

Precipitation is described by Zendehboudi et al [3] as the formation of the solid state from the liquid phase, whereas deposition is defined as the attachment of the solid phase to reservoirs or wellbore walls, which generally occurs after precipitation. Asphaltene can also produce flocculation, which are dense clusters of asphaltene [4, 5]. Since flocculation has a high density, it tends to deposit and fill the reservoir's pore throat [6-8]. Many parameters/variables influence asphaltene destabilization (asphaltene precipitation and deposition), including temperature, pressure, mixture properties, and precipitation amount. Solid aggregation may arise as a result of changes in thermodynamic characteristics. As compared to other thermodynamic and process factors/characteristics, it has been empirically demonstrated that pressure has the largest influence on asphaltene precipitation [9].

Because of its capacity to precipitate, deposit, and impede the continual production of oil from subsurface reserves, asphaltene is described as the cholesterol of crude oil [10]. Asphaltene precipitation and deposition may negatively affect industrial systems' efficiency (and/or profitability), both upstream and downstream. Asphaltene precipitation and deposition can have negative impacts such as pore throat blockage, altered reservoir wettability, and decreased reservoir permeability. Aside from clogging flow facilities, solids growth in storage tanks, and fouling of safety valves, asphaltene precipitation or deposition in the downstream portion also causes these issues. Additionally, asphaltene may reduce catalyst conversion and activity, which may cause coke to build up in refineries [11,24].

Numerous methods for detecting asphaltene deposition in conventional oil reservoirs have been proposed, including the colloidal stability index (CSI) [12], the asphaltene/resin (A/R) ratio method [13], the colloidal instability index (CII) [14], the modification colloidal instability index (MCII) [15], the acoustic resonance technique, the filtration method, and the light scattering technique.

The Halfaya oilfield lies in Iraq's southern Mesopotamian Basin. The basin is also known as the Mesopotamian Foredeep's Near Platform Flank. The Halfaya oilfield, like others in Iraq, has a NW-SE trending anticline roughly 30km long and 10km wide. The bulk of the petroleum system is composed of warm, shallow water carbonates from the Oligocene to the early Miocene and early to late Cretaceous, with intermittent clastic influence, mainly from the early Cretaceous and late Miocene. Throughout the tertiary and Cretaceous, 9 oil-bearing carbonate and sandstone reservoirs and 14 oil systems have been identified, with burial depths ranging from 1900m to 4400m. Halfaya oil field is separated into seven reservoirs development strata, according to the development plan.[16]

The primary goal of this study was to forecast asphaltene precipitation in the HF-oil field using crude oil composition analysis, "Screening Techniques," which rely on sample analysis and reservoir data, and validation of these techniques using Multiflash software at reservoir and surface conditions.

Before starting to write the present article, the authors searched for and gathered articles dealing with Asphaltene from 2010 to 2021 that had made an apparent contribution to the solution of asphaltene problems. Figure. 1 presents the number of publications each year by searching in three well-known publishers, including Springer, Wiley, and Elsevier, with either "Asphaltene Deposition" or "Asphaltene Precipitation" keywords in the text body of the articles. The plot reveals the importance of focusing on these two problems due to their impact on production performance.

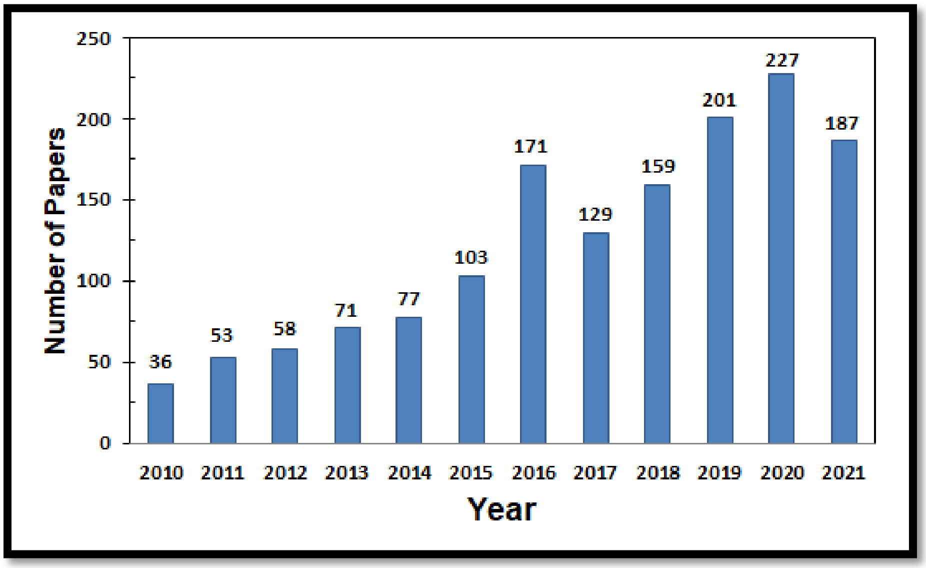

Figure 1: Number of Publications on Deposition and Precipitation of Asphaltene in The Period 2010-2021.

2. Theory & Literature Survey:

a. Colloidal Stability Index (CSI):

This measure indicates that the asphaltene component of unstable crude oils is more polar than that of stable crude oils. As demonstrated in Eq. (1), SARA fractionation and component polarity are taken into consideration.

$$CSI = \frac{\varepsilon^{Asph}\text{Asphaltene wt\%}+\varepsilon^{Sat}\text{Saturate wt\%}}{\varepsilon^{Arom}\text{Aromatic wt\%}+\varepsilon^{Res}\text{Resin wt\%}} \quad (1)$$

where dielectric constant values (ε) for SARA fractions are the following: $\varepsilon^{Asph} = 18.4$ and $\varepsilon^{Res} = 3.8$ for unstable crude oils; $\varepsilon^{Asph} = 5.5$ and $\varepsilon^{Res} = 4.7$ for stable crude oils; $\varepsilon^{Sat} = 1.921$ and $\varepsilon^{Arom} = 2.379$ for all crude oils [17,18]. If CSI > 0.95, the crude oil is unstable and asphaltenes will precipitate. If CSI < 0.95, the crude oil is stable and asphaltene precipitation is unlikely [19].

b. Asphaltene Resin (A/R) Ratio Approach:

Jamaluddin et al. **[13]** were the first to suggest the asphaltene-resin ratio technique. The model was then modified to identify two separate zones: stable and unstable, with the unstable zone being more prone to asphaltene precipitation due to the asphaltene to resin weight ratio [20].

c. Colloidal Instability Index (CII):

The crude oil is treated as a colloidal solution, including the pseudo-components saturates, aromatics, resins, and asphaltenes, according to the Colloidal Instability Index. The CII (Eq.2) is defined as the mass ratio of asphaltenes and their flocculants (saturates) to them peptizes (resins and aromatics) in crude oil, and it indicates the stability of asphaltenes in terms of these pseudo-components [21]:

$$CII = \frac{\text{Asphaltene wt\%+Saturate wt\%}}{\text{Aromatic wt\%+Resin wt\%}} \quad (2)$$

The weight percentages derived from SARA analysis are used in the colloidal instability index just as they are in the asphaltene–resin ratio. The CII has been used to evaluate the stability of asphaltenes in crude oil-solvent mixtures. It has been demonstrated that indices related to the CII, such as the Saturates-Peptizes ratio (Saturates/Aromatics Resins), or the Asphaltene-Peptizers ratio (Asphaltenes/Aromatics Resins), may be used to correlate the stability of asphaltenes in crude oils and their mixture. Based on the vast database of crude oils, empirical evidence shows that values of 0.9 and higher suggest an oil with unstable asphaltenes, while values below 0.7 indicate an oil with stable asphaltenes; values between 0.7 and 0.9 indicate an oil with questionable asphaltene stability [21].

d. Modified Colloidal Instability Index (MCII):

In order to reduce the cost of conducting SARA analysis on the one hand and rely on data with reservoir conditions on the other, Akram Hamoudi et al. [22] modified the CII equation by using PVT data (compositional analysis by chromatography) instead of SARA analysis. The new equation is named as the modified CII (MCII) as shown in Eq. (3). They employed three wells from Iraq's Kurdistan region in their research. After comparing the results to the original CII equation and using the de Boer plot, they decided that this modification was acceptable.

$$MCII = \frac{Lc+Mc}{Hc+Nc} \quad \text{(3)}$$

Mc is a Mole % of medium hydrocarbons
Lc is a Mole % of light hydrocarbons
Nc is a Mole % of Non-hydrocarbons
Hc is a Mole % of heavy hydrocarbons

- If MCII < 0.7, no Asphaltene problem.
- If MCII > 0.9, there is an asphaltene problem.
- If 0.7 < MCII< 0.9, may be a problem with Asphaltene.

The reservoir fluid components identified by PVT analysis can replace SARA fractions. Since the components are expressed as mole percentages and add up to 100, the inputs to the equation agree with the original one, but we still need to assign each component to one of the SARA elements. The equivalent SARA percentages for each component are shown in Table. 1. The definition of each constituent in the SARA analysis served as the basis for the classification, which is based on molecular weight. For instance, aromatics have the lowest molecular weight, but asphaltenes have the highest. The phrase "non-hydrocarbons" has been used to make up for the lost resin weight % because there are no resins. This equation may be changed to produce outcomes that are similar to the test data since the sum of the experimental data and the sum of the CII inputs both equal 100 [22].

Table 1: SARA Fractions Related to Hydrocarbon Components

The Name	Component Group	SARA Corresponding
Light component	C_1-C_5	Aromatics
Medium component	C_6-C_8	Saturates
Heavy component	C_9^+	Asphaltene
Non-hydrocarbon	CO_2, H_2, N_2, H_2S	Resins

3. Methodology

Asphaltene Phase Envelope (APE) Determination:

A software called *Multiflash* was used to forecast the asphaltene phase envelope for the Nahr-Umr crude oil samples. The precipitation of asphaltene during the depletion of a reservoir uses a phase behavior that integrates an advanced solid thermodynamic model. This program enables modeling of up to three fluid phases that are in equilibrium with the solid. *Multiflash* employs the cubic-plus association CPA-EOS, which is the most widely used method for predicting oil and gas phase states [23]. EOS is widely used by Multiflash to determine the phase behavior of reservoir fluids. It also calculates and predicts the interaction coefficients that are used to account for interactions between molecules that are not related. Figure. 2 depicts the basic processes involved in modeling an asphaltene precipitation model with Multiflash.

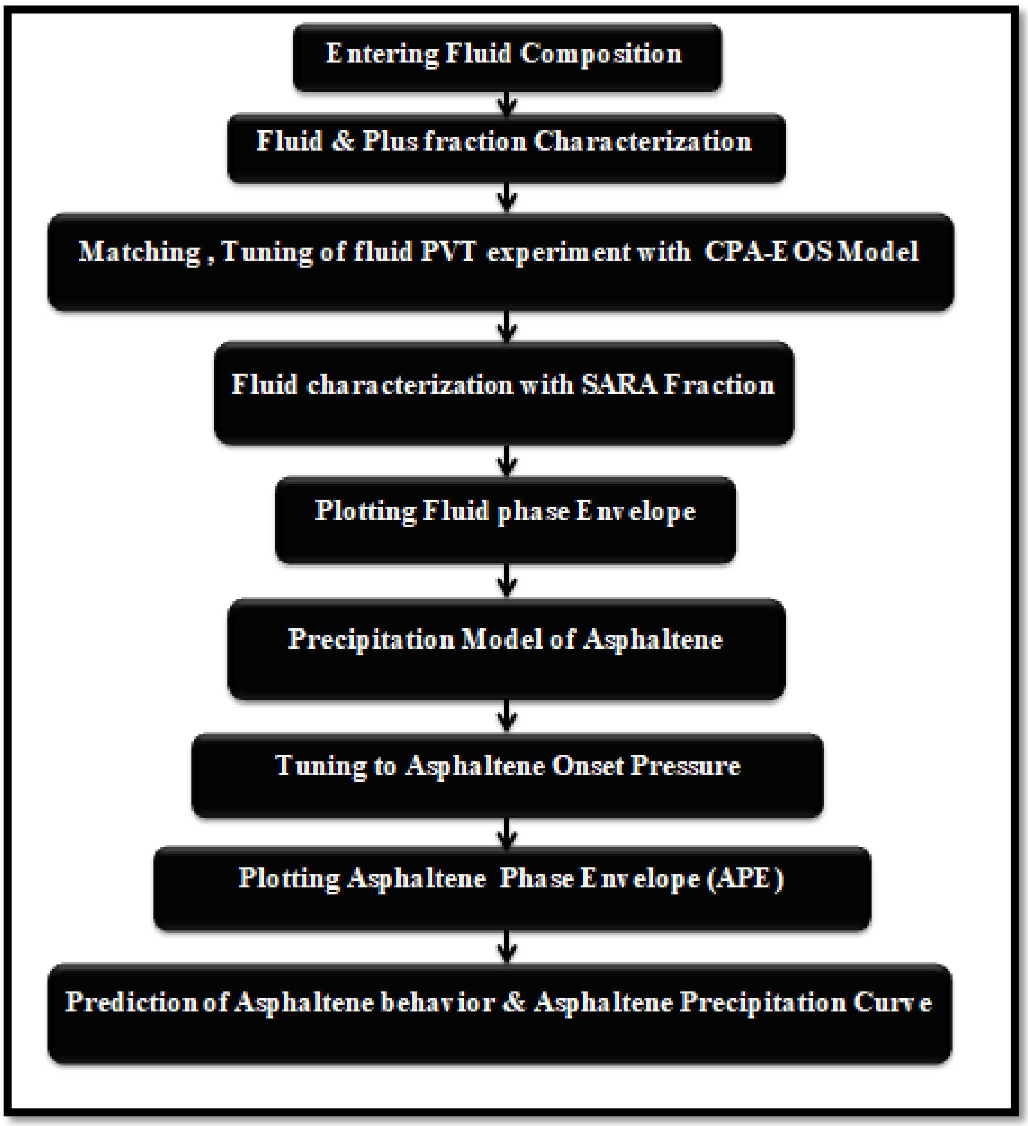

Figure 2: The Flow Chart of Asphaltene Precipitation Modeling.

4. Results & Discussion

A. Colloidal Stability Index (CSI):

This approach uses Eq. (1) with a saturated weight percent of 63.23 wt %, an aromatic weight percent of 24.36 wt %, a resin weight percent of 5.11 wt %, and an asphaltene weight percent of 7.3 wt %. also uses $\varepsilon^{Asph} = 18.4$, $\varepsilon^{Res} = 3.8$, $\varepsilon^{Sat} = 1.921$, and $\varepsilon^{Arom} = 2.379$ for unstable crude oils. Because the value of CSI is 3.3 and it is greater than 0.9, the findings indicate that there is a possibility of asphaltene precipitation (unstable asphaltene).

$$\mathrm{CSI} = \frac{\varepsilon^{Asph}\text{Asphaltene wt\%} + \varepsilon^{Sat}\text{Saturate wt\%}}{\varepsilon^{Arom}\text{Aromatic wt\%} + \varepsilon^{Res}\text{Resin wt\%}} = \frac{(18.4) * (7.3) + (1.921) * (63.23)}{(2.379) * (24.36) + (3.8) * (5.11)} = 3.3$$

B. Investigation of Asphaltene Stability Using Asphaltene -Resin (A/R) Ratio:

SARA fractionation, which is an analytical technique of dividing oil into four parts according to their polarity: saturates, aromatics, resins, and asphaltenes [25]. It is one of the finest ways to describe an oil mixture. The SARA fraction values from an oil sample recovered from Well HF-X. The weight percentage of asphaltene is 7.3 wt%, whereas the weight percentage of resin is 5.11 wt%. The results indicate that the Asphaltene is unstable as well as the possibility of asphaltene precipitation, as shown in Figure. 3.

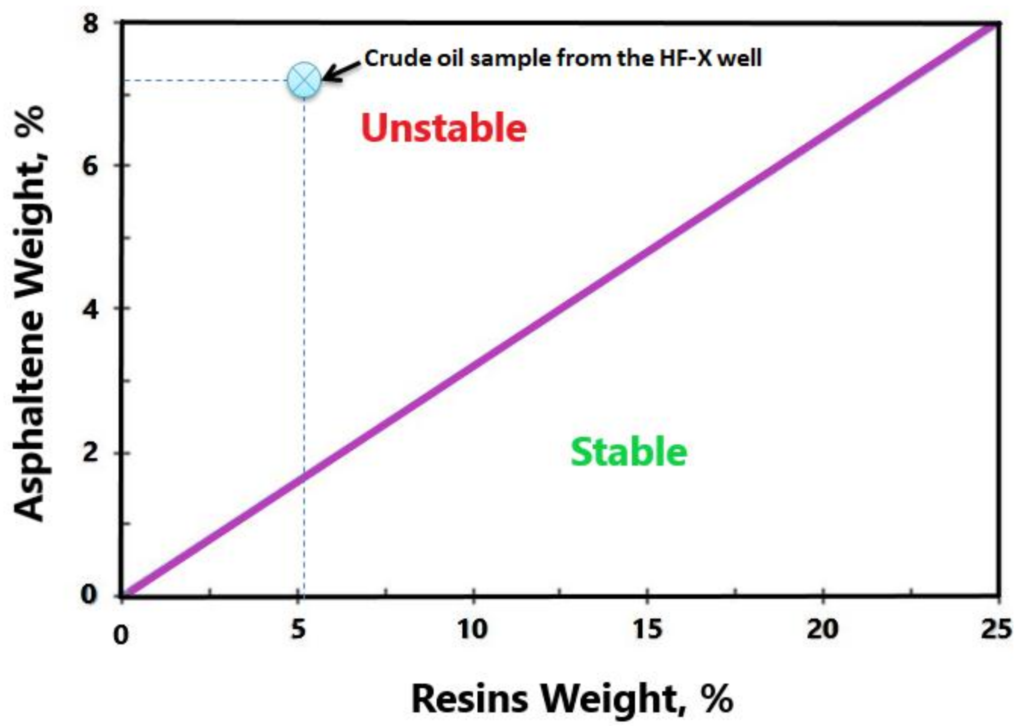

Figure 3: HF-X Well Examination by Asphaltene/resin Relationship for Predicting Asphaltene Precipitation, A/R Plot From[20].

C. Investigation of Asphaltene Stability Using Modified Colloidal Instability Index (MCII):

To use Eq. (3), first calculate the mole percentage of each group (Lc, Mc, Nc, and Hc) for well HF-X, as shown in Tables 1. The reservoir fluid's composition was separated into four categories, as shown in Table. 2 below:

Table 2: Classification of Components Corresponding to SARA Analysis

Component	Recombined Fluid Mole %	The Group	mole% summation for each group
H2	0	Nc (non-hydrocarbons)	Nc = 1.24
H2S	0		
CO2	1.01		
N2	0.23		
C_1	26.84	Lc (light hydrocarbons)	Lc = 49.25
C_2	7.24		
C_3	6.01		
i-C_4	1.25		
n-C_4	3.6		
C_5(Neo-Pentane)	0.01		
i- C_5	1.82		
n- C_5	2.48		
C_6	3.81	Mc (medium hydrocarbons)	Mc = 11.93
C_7 (M-C-Pentane)	0.55		
C_7 (Benzene)	0.1		
C_7 (Cyclohexane)	0.31		
C_7 (Heptanes)	3.08		
C_8 (M-C-Hexane)	0.53		
C_8 (Touene)	0.33		
C_8 (Octanes)	3.22		
C_9 (E-Benzene)	0.23	Hc (heavy hydrocarbons)	**Hc = 37.58**
C_9 (M/P-Xylene)	0.51		
C_9 (O-Xylene)	0.2		
C_9 (Nonanes)	2.7		
C_{10} (1,2,4-TMB)	0.24		
C_{10} (Decanes)	2.95		
C_{11}	2.82		
C_{12}	2.41		
C_{13}	2.22		
C_{14}	1.85		
C_{15}	1.77		
C_{16}	1.56		
C_{17}	1.32		
C_{18}	1.24		
C_{19}	1.2		
C_{20}	1.04		
C_{21}	0.92		
C_{22}	0.83		
C_{23}	0.75		
C_{24}	0.68		
C_{25}	0.61		
C_{26}	0.56		
C_{27}	0.51		
C_{28}	0.49		
C_{29}	0.46		
C_{30}	0.44		
C_{31}	0.43		
C_{32}	0.38		
C_{33}	0.35		
C_{34}	0.35		
C_{35}	0.29		
C_{36}^{+}	5.27		
	100%		**100%**

$$\text{MCII} = \frac{Lc+Mc}{Hc+Nc} = \frac{49.25+11.93}{37.58+1.24} = 1.576$$

Since MCII = 1.576 (i.e. > 0.9), then the Asphaltene is unstable (Asphaltene problem)

D. Investigation of Asphaltene Stability Using Colloidal Instability Index (CII):

This approach uses equation (2) with a saturated weight percent of 63.23 wt percent, an aromatic weight percent of 24.36 wt percent, a resin weight percent of 5.11 wt percent, and an asphaltene weight percent of 7.3. Because the value of CII is 2.39, and it is greater than 0.9, the findings indicate that there is a possibility of asphaltene precipitation (unstable asphaltene).

$$\text{CII} = \frac{\text{Asphaltene wt\%}+\text{Saturate wt\%}}{\text{Aromatic wt\%}+\text{Resin wt\%}} = \frac{7.3+63.23}{24.36+5.11} = 2.39$$

Because CII= 2.93 (i.e. > 0.9) again there is an Asphaltene problem.

E. Validation of Screening Techniques with a Thermodynamic Model:

After completing the stages shown in Figure. 2, we plot the asphaltene phase envelope (APE) and reflect the reservoir and wellhead conditions onto it. Next, we build a line from the point of reservoir conditions to the point of wellhead conditions. We can observe that the line crosses through the three-phase area (APE), indicating that once the pressure drops below the AOP threshold, asphaltene precipitation is possible. (See Figure. 4)

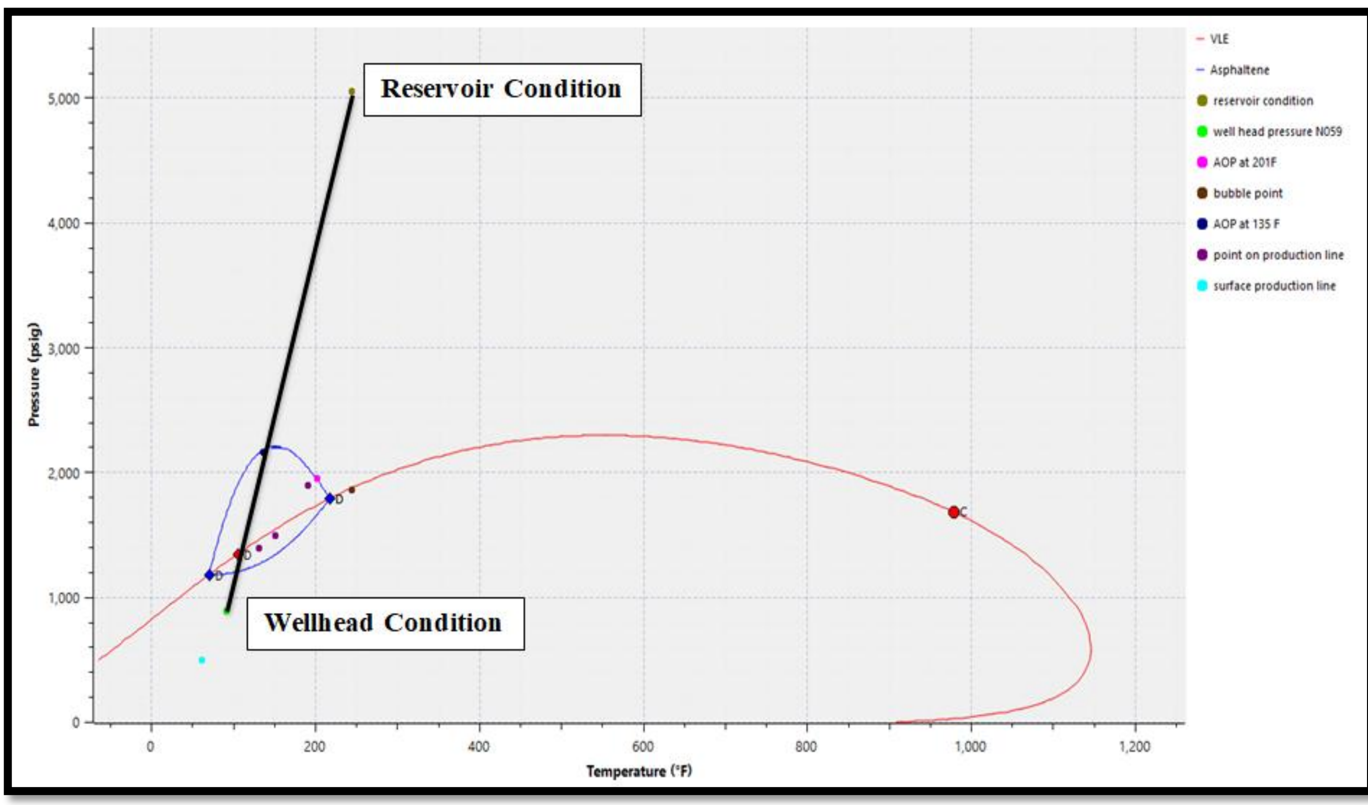

Figure 4: Phase Diagram of Fluid (Red Curve) & Asphaltene Phase Envelope (Blue Curve).

The results of the four screening techniques may now be compared to the thermodynamic fluid model, as shown in Table. 3. Because these techniques imply that asphaltene is unstable, the problem of asphaltene precipitation is quite likely to arise when production time and pressure decrease. As a result, steps to mitigate the dangers posed by asphaltene deposition are required, whether in the reservoir or in the wellbore.

Table 3: Summary of Results

The Method	The Result
Colloidal stability index (CSI)	Unstable asphaltene (Asphaltene problem)
Asphaltene -Resin (A/R) Ratio	Unstable asphaltene (Asphaltene problem)
Colloidal instability index (CII)	Unstable asphaltene (Asphaltene problem)
Modified colloidal instability index (MCII)	Unstable asphaltene (Asphaltene problem)
Thermodynamic model using CPA-EOS by Multiflash	High probability of Asphaltene precipitation

5. Conclusions

This research led to the following conclusions:

- The stability of asphaltene in dead and living oil was predicted utilizing investigation approaches. The effectiveness of the indicators is supported by data from real-world production systems and simulations of thermodynamic fluid models. The need for reliable SARA data was underlined since it enables more precise calculations of asphaltene stability.
- The study highlighted crucial steps and procedures required to create a phase behavior model for asphaltene in wells in the Maysan Governorate using Multiflash software, which utilizes EOS. The model used chromatograph and PVT analysis data to model asphaltene.
- After using the multiflash program to match the results of screening, it was found that the CPA-EOS model predicts that, based on the best matching of the data, precipitation of the asphaltene will occur in the future due to the pressure drop, and the precipitation will develop either through the porous medium or the pipelines.

Nomenclature

HF = Halfaya oil field
A/R = Asphaltene/Resin ratio
AOP = Asphaltene onset pressure
APE = Asphaltene phase envelope
CII = Colloidal instability index
CSI = Colloidal stability index
CPA = Cubic-plus Association
EOS= Equation of state
Hc = Mole % of heavy hydrocarbons
Lc = Mole % of light hydrocarbons
Mc = Mole % of medium hydrocarbons
Nc = Mole % of non-hydrocarbons
MCII = modified colloidal instability index
SARA= Saturates Aromatic Resin Asphaltene

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