

Comparative Study of Characterization Schemes for Asphaltene Precipitation Modelling

Priyanka Singh¹

¹Student, Dept. of Petroleum Engineering, Presidency University Bangalore, Karnataka-560064

Abstract - When asphaltene precipitates its particles are aggregated and a new solid phase is generated which can remain as a suspended solid in the oil flow and it will continue to flow until the solid particles (precipitates) settle down which leads to asphaltene deposition. Asphaltene deposition is a common problem in the upstream oil industry and has damaging effects on a variety of production processes in oilfields. Due to this, the cost associated with remediation increases along with production loss. Thus, it is very advantageous for oil companies to forecast the precipitation behavior of asphaltene in the reservoir before it transpires. Complex compositional reservoir fluid phase behavior was studied and employed which can simulate/predict the dynamic features of asphaltene precipitation. In this paper Whitson characterization, which utilizes the Gamma probability distribution function, and Chi-Square characterization, which utilizes the Chi-Square probability distribution function have been used to characterize heptane-plus components. The molar weight distribution is used either in the form of a Single Carbon Number (SCN), which divides the C7+ fraction into respective components like C7, C8, C9, etc. and/or pseudo-components by combining multiple carbon numbers fractions. These methods are used to enhance the Equation Of State (EoS) predictions for asphaltene precipitation. To confirm the fit of the data to the models, different characterization parameters, like molar mass, specific gravity of C7+, etc. are used to regress the parameters. After characterization, correlations are used to find the mole fraction of the precipitated asphaltene using the PC-SAFT EoS.

Key Words: Asphaltene, Precipitation, Whitson Characterization, Chi-Square Characterization, PC-SAFT, Equation of State.

1. INTRODUCTION

Asphaltenes reflect the heaviest and the most polar components in crude oil^[1] which include many different hydrocarbon molecules. Asphaltenes are insoluble compounds in aliphatic hydrocarbons namely n-Pentane and n-Heptane and soluble in aromatics like benzene and toluene^[2]. Asphaltene precipitate if solid-phase starts to form from the liquid phase and asphaltene deposit when solid-phase adsorbs on the reservoir rock surface. Precipitation of asphaltenes is caused by many reasons,

including alteration in the chemical composition of crude oil, temperature, pressure, mixing of oil with diluents, and other oil and gas components like CO₂ during stimulation^[3]. Asphaltene precipitation and deposition can modify the reservoir rock wettability^[4], can lead to severe formation damage^[5], and can clog wells^[6], flowlines, and surface facilities^[7], so, it can cause potential flow assurance issues. Flow assurance issues increase the need for controlling measures so we can reduce or eliminate the amount of risk. Thus, it's vital to precisely model asphaltene phase behavior at a broad range of temperature and pressure^[8]. We must characterize the oil accurately to predict the phase behavior of the heavy oil system. Heavy oils comprise thousands of components, and thus, the hydrocarbons are generally lumped into pseudo-components in order to model the behavior of heavy oil systems^[9].

Prediction and modeling of asphaltene precipitation, for the most part, is done employing either solubility theory or colloidal theory. The solubility theory presumes that the asphaltenes are dissolved in crude oil in the beginning, and precipitation can only transpire if the solubility limit becomes less than a particular threshold level^[10]. The colloidal theory presumes that the asphaltenes exist as colloidal particles which are stabilized by resins adsorbed onto their surfaces^[11], and, if an adequate amount of resins desorb, then asphaltenes will destabilize and precipitate^[12]. Two main solubility theory approaches are regular solution theory and Equation of State (EoS). Ting^[13] and Gonzalez^[14] developed a saturates-aromatics-resins-asphaltenes (SARA) characterization for the Perturbed-Chain Statistical Associating Fluid Theory (PC-SAFT) EoS^[15] to model the phase behavior of asphaltenic crude oil efficiently. In 1978, the earliest scheme of reservoir fluid characterization was introduced according to which we split the crude into different single carbon number (SCN) sets based on their boiling point^[16]. After that, Whitson^[17] altered that method based on the average boiling point of each SCN cut using Riazi and Daubert correlations^[18].

In this paper, I do a comparative study on Whitson and Chi-Square characterization schemes for asphaltene precipitation using the PC-SAFT EoS, then the prediction of

asphaltene precipitation is done. First, we characterize the fluid, The characterization procedure uses the SCN type approach by combining multiple carbon numbers fractions. For this we split the components using Whitson and Chi-Square distribution then we lump the components into 3-5 groups. In our paper, we compare the Whitson and Chi-Square characterization schemes to check which of these gives us a more accurate result. It was observed that Whitson's characterization scheme gave better results than the Chi-Square characterization scheme.

2. THEORY

2.1. Whitson Characterization Scheme

Whitson (1983) proposed that the molar distribution of C7+ fraction can be described using the gamma probability function consisting of three variables. The gamma function has the flexibility of outlining a broad set of distributions by regulating its variance, which is an adjustable parameter^[19].

According to Whitson, The gamma probability density function can be written as:

$$p(M) = \frac{(M - \eta)^{\alpha-1} \exp\left\{-\left[\frac{M - \eta}{\beta}\right]\right\}}{\beta^\alpha \Gamma(\alpha)} \quad (1)$$

Here, α defines the shape of the distribution whose value normally ranges from 0.5 to 2.5.

The gamma function is denoted by Γ , and,

$$\beta = \frac{M_{C_{7+}} - \eta}{\alpha} \quad (2)$$

Here η stands for the lower limit of the molecular weight observed in the C₇₊ fraction.

2.2. Chi-Square Characterization Scheme

The Chi-square distribution is a subset of the gamma distribution and it's considered as one of the most broadly used probability distributions in inferential statistics^[10].

We distribute the C₇₊ mass fraction according to the CS(p) function that best represents the mass distribution of the fluid to characterize the oil fraction with high molecular weight^[10]. The common form of the CS(p) distribution function can be written mathematically as:

$$f_{dis} = \frac{2^{-p/2}}{\Gamma(p/2)} e^{-s/2} s^{(p/2)-1} \quad (3)$$

Here s varies from zero to infinity and is considered as a mass distribution variable. The mass fraction of the light component which corresponds to the integral from zero to an initial s_0 value is excluded. Thus,

$$M_6 = \int_0^{s_0} f_{dis} ds = \frac{1}{MW_T} \left[\sum_i x_i MW_i \right] \quad (4)$$

here M_6 accounts for the combined light mass fraction till C₆ fraction, the value of s that satisfies the above equation is represented as s_0 . All the light compounds in a given oil sample till hexanes are covered by the summation over i , and the total molar mass of the fluid is termed as MW_T .

The C₇₊ fraction is characterized as m number of heavy fractions F_i of mass fraction $f m_i$ according to the equation:

$$f m_i = \int_{s_{i-1}}^{s_i} f_{dis} ds \quad (5)$$

The molar mass MW_i of the fraction F_i is given by:

$$MW_i = \overline{MW} \hat{s}_i \quad (6)$$

Here \hat{s}_i denotes the center of mass for the F_i fraction, and can be written as:

$$\hat{s}_i = \frac{1}{f m_i} \int_{s_{i-1}}^{s_i} s f_{dis} ds \quad (7)$$

also, \overline{MW} can be expressed as:

$$\overline{MW} = \frac{MW^+}{(1 - M_6)} \sum_{i=1}^m \frac{f m_i}{\hat{s}_i} \quad (8)$$

Here MW^+ stands for molar mass of the C₇₊ fraction.

This approach is first used to find the optimal CS(p) function in fluid characterization procedures. It is sufficient to only take into consideration the CS(p) functions with a value of p between 2 to 10 at intervals of 0.01. Then, the entire C₇₊ fraction is characterized in a reasonable number of heavy fractions employing the optimal CS(p) probability distribution function^[20].

2.3. PC-SAFT EoS

An EoS model was developed based on the Statistical Associating Fluid Theory (SAFT), for predicting the phase equilibria^[21]. This EoS can be expressed based on the

residual Helmholtz energy which is written as a^{res} , this is an aggregate of three different terms which consists of contributions from different intermolecular forces.

The overall expression for the Helmholtz energy is:

$$a^{res} = a^{seg} + a^{chain} + a^{assoc} \quad (9)$$

Here, a^{seg} constitutes segment-segment interactions, for instance, Lennard-Jones interactions. The term a^{chain} is because of the existence of covalent chain-forming bonds between the segments, for example, the Lennard-Jones segments. The term a^{assoc} is considered for the increase of a^{res} because of the existence of site-site particular interactions between the segments, such as hydrogen bonding interactions.

Subsequently, in 2001, applying a perturbation theory for chain molecules and changing the suitable model constants to the pure-component properties of n-alkanes a dispersion expression was found for chain molecules^[15]. This newly obtained EoS utilized the existing chain term and association term as the prior SAFT equations. This recently developed model was termed perturbed-chain SAFT (PC-SAFT) since a hard-chain fluid is used as a reference for the perturbation theory, instead of spherical molecules as in the former SAFT equations.

After defining the reference chain fluid, we can use the perturbation theory of Barker and Henderson^[22] to figure out the attractive part of the chain interactions. Here, the Helmholtz free energy is expressed as a sum of first and second-order contributions based on the following equation:

$$\frac{A^{disp}}{KTN} = \frac{A_1}{KTN} + \frac{A_2}{KTN} \quad (10)$$

Then, the reduced Helmholtz free energy can be written as:

$$\hat{a}^{res} = \frac{A^{res}}{NkT} \quad (11)$$

In terms of the molar quantity, it can be represented as:

$$\hat{a}^{res} = \frac{\hat{a}^{res}}{RT} \quad (12)$$

The residual Helmholtz free energy comprises the hard-chain reference contribution and the dispersion contribution.

$$\hat{a}^{res} = \hat{a}^{hc} + \hat{a}^{disp} \quad (13)$$

Here, the Hard-Chain Reference Contribution is:

$$\hat{a}^{hc} = \bar{m}\hat{a}^{hs} - \sum_i x_i(m_i - 1) \ln g_{ii}^{hs}(\sigma_{ii}) \quad (14)$$

where m_i is the mean segment number in the mixture.

$$\bar{m} = \sum_i x_i m_i \quad (15)$$

For the hard-sphere fluid, Helmholtz free energy is given on a per-segment basis as:

$$\hat{a}^{hs} = \frac{1}{\zeta_0} \left[\frac{3\zeta_1\zeta_2}{(1-\zeta_2)} + \frac{\zeta_2^3}{\zeta_3(1-\zeta_2)^2} + \left(\frac{\zeta_2^3}{\zeta_3} - \zeta_0 \right) \ln(1-\zeta_2) \right] \quad (16)$$

Here,

$$\zeta_n = \frac{\pi}{6} \rho \sum_i x_i m_i d_i^n \quad n \in \{0, 1, 2, 3\} \quad (17)$$

Also, the temperature-dependent segment diameter d_i of component i can be written as:

$$d_i = \sigma_i \left[1 - 0.12 \exp\left(-3 \frac{\epsilon_i}{kT}\right) \right] \quad (18)$$

The dispersion contribution to the Helmholtz free energy is expressed as:

$$\hat{a}^{disp} = -2\pi\rho I_1(\eta, \bar{m}) \overline{m^2 \epsilon \sigma^3} - \pi\rho \bar{m} C_1 I_2(\eta, \bar{m}) \overline{m^2 \epsilon^2 \sigma^3} \quad (19)$$

here, C_1 is the compressibility expression.

$$C_1 = \left(\frac{1 + \bar{m} \frac{8\eta - 2\eta^2}{(1-\eta)^4} + (1-\bar{m}) \frac{20\eta - 27\eta^2 + 12\eta^3 - 2\eta^4}{[(1-\eta)(2-\eta)]^2}} \right)^{-1} \quad (20)$$

And,

$$\overline{m^2 \epsilon \sigma^3} = \sum_i \sum_j x_i x_j m_i m_j \left(\frac{\epsilon_{ij}}{kT} \right) \sigma_{ij}^3 \quad (21)$$

$$\overline{m^2 \epsilon^2 \sigma^3} = \sum_i \sum_j x_i x_j m_i m_j \left(\frac{\epsilon_{ij}}{kT} \right)^2 \sigma_{ij}^3 \quad (22)$$

Now, we substitute the integrals of the perturbation theory with simple power series in density.

$$I_1(\eta, \bar{m}) = \sum_{i=0}^6 a_i(\bar{m}) \eta^i \quad (23)$$

$$I_2(\eta, \bar{m}) = \sum_{i=0}^6 b_i(\bar{m}) \eta^i \quad (24)$$

The coefficients a_i and b_i depend on the chain length and are given as:

$$a_i(\bar{m}) = a_{oi} + \frac{\bar{m} - 1}{\bar{m}} a_{1i} + \frac{\bar{m} - 1}{\bar{m}} \frac{\bar{m} - 2}{\bar{m}} a_{2i} \quad (25)$$

$$b_i(\bar{m}) = b_{oi} + \frac{\bar{m} - 1}{\bar{m}} b_{1i} + \frac{\bar{m} - 1}{\bar{m}} \frac{\bar{m} - 2}{\bar{m}} b_{2i} \quad (26)$$

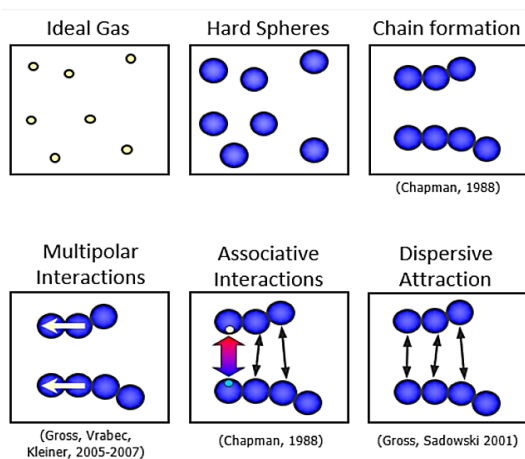


Fig -1: Development of the PC-SAFT Equation of State^[23].

The PC-SAFT EoS can be applied in a compositional reservoir simulator to model asphaltene precipitation. Good results have been obtained with PC-SAFT after simulating asphaltene onset points and modeling the effect of gas injection on the precipitation of asphaltenes^[24].

Table -1: PC-SAFT Correlation^[14].

Sl. No.	Parameter	Function
1	m	$(0.0257 * MW) + 0.8444$
2	$\sigma(A)$	$4.047 \frac{4.8013 * \ln(MW)}{MW}$
3	$\epsilon(K)$	$exp\left(5.5769 - \frac{9.523}{MW}\right)$

According to Stavrou^[25], most variants of the SAFT-type EoS use the Lorenz-Berthelot combining rules.

$$\sigma_{ij} = \frac{1}{2} (\sigma_i + \sigma_j) \quad (27)$$

As a modification of the Lorenz-Berthelot combining rules, the binary interaction parameter the term k_{ij} is used as a

correction to the dispersive energy parameter for the binary pair:

$$\epsilon_{ij} = (1 - k_{ij})\sqrt{\epsilon_i \epsilon_j} \quad (28)$$

Binary interaction parameters are very often adjusted to experimental phase equilibrium data of the binary mixtures. If the focus is on the qualitative trends/behaviors, we set all the binary interaction parameters between all the pseudo-components to zero^[13].

3. METHODOLOGY

A data set (Table 2) was used to characterize the fluid by defining the compositions of components up to C6 and pseudo-components describing the C7+ fraction. The composition data up to C6 has been used, and the C7+ fraction has been characterized using Whitson and Chi-Square schemes.

Using the PC SAFT EoS we find different parameters (m, $\sigma(A)$ and, $\epsilon(K)$). We have kept the binary interaction parameter as 0 for our pseudo-components. The asphaltene component is specified by splitting the heaviest component of the oil into precipitating and non-precipitating components.

Table -2: Mol% of components in oil^[26].

Sl. No.	Components	Mol%
1	Carbon dioxide	2.46
2	Nitrogen	0.57
3	Methane	36.37
4	Ethane	3.47
5	Propane	4.05
6	i-C4	0.59
7	n-C4	1.34
8	i-C5	0.74
9	n-C5	0.83
10	C6	1.62
11	C7+	47.96

Table -3: Properties of oil^[26].

Sl. No.	Property	Value
1	MW (C7+) (g/mol)	329
2	Live Oil MW (g/mol)	171.4
3	API (degree)	19
4	Asp. Content (wt.%)	16.8
5	Res. Temp. (F)	212
6	Sat. Pressure (psi)	2950
7	SG (C7+)	0.9594

The complete EoS can be expressed as a hard-chain contribution (hc), an ideal gas contribution (id), and a perturbation contribution, which stands for the attractive interactions (disp).

$$Z = Z^{hc} + Z^{id} + Z^{dis} \quad (29)$$

here Z represents the compressibility factor, with $Z = (Pv)/(RT)$ and $Z^{id} = 1$.

$$Z = 1 + \eta \left(\frac{\partial \bar{a}^{res}}{\partial \eta} \right)_{T, x_i} \quad (30)$$

We must determine the density at a given system pressure P^{sys} iteratively until we obtain $P^{calc} = P^{sys}$ by adjusting the reduced density η .

The density of molecules (ρ) is calculated using η :

$$\rho = \frac{6}{\pi} \eta \left(\sum_i x_i m_i d_i^3 \right)^{-1} \quad (31)$$

We calculate the residual chemical potential fugacity coefficient $\varphi_k(T, P)$ according to:

$$\ln \varphi_k = \frac{\mu_k^{res}(T, v)}{kT} - \ln Z \quad (32)$$

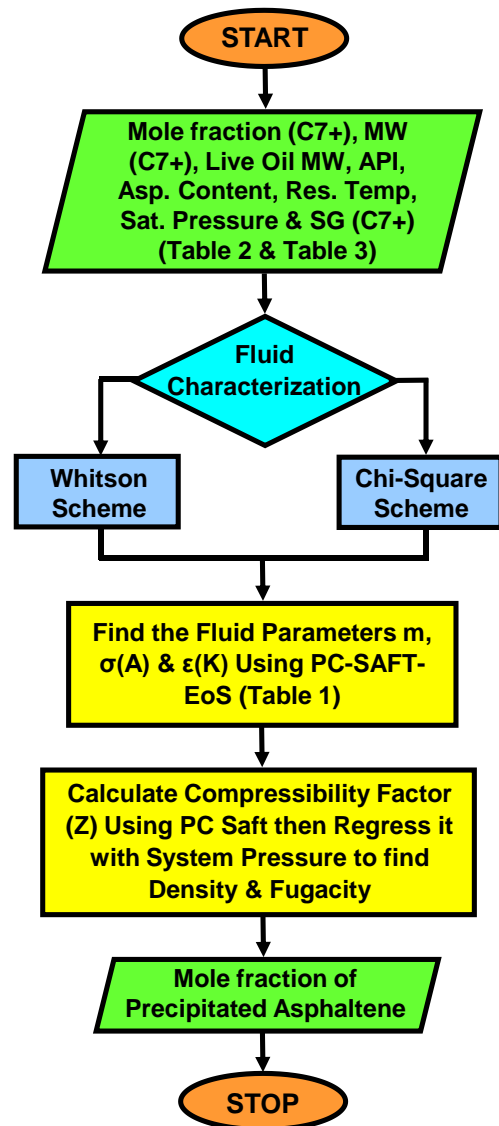


Fig -2: Process of Crude Oil Characterization for Modeling Asphaltenic Crude Phase Behavior Using PC-SAFT.

Here, the chemical potential can be obtained using

$$\frac{\mu_k^{res}(T, v)}{kT} = \bar{a}^{res} + (Z - 1) + \left(\frac{\partial \bar{a}^{res}}{\partial x_k} \right)_{T, v, x_{i \neq k}} \quad (33)$$

$$- \sum_{j=1}^N \left[x_j \left(\frac{\partial \bar{a}^{res}}{\partial x_j} \right)_{T, v, x_{i \neq j}} \right]$$

We determine the mole fraction of the asphaltene component using the relation:

$$x_{Asph} * MW_{Asph} = w_{Asph} * MW_{Oil} \quad (34)$$

Then, parameters generated after regression are used to predict the precipitation behavior.

4. RESULT

Table -4: Whitson Characterization Result.

Sl. No.	Component	Mol %	Molar Mass (g/mol)
1	CO2	2.46	44.010
2	N2	0.57	28.013
3	C1	36.37	16.043
4	C2	3.47	30.070
5	C3	4.05	44.097
6	IC4	0.59	58.124
7	NC4	1.34	58.124
8	IC5	0.74	72.151
9	NC5	0.83	72.151
10	FC6	1.62	86.000
11	HYP1	20.83	138.119
12	HYP2	20.23	356.977
13	HYP3	6.90	822.500

Table -5: Chi-Square Characterization Result.

Sl. No.	Component	Mol %	Molar Mass (g/mol)
1	CO2	2.46	44.010
2	N2	0.57	28.013
3	C1	36.36	16.043
4	C2	3.47	30.070
5	C3	4.05	44.097
6	IC4	0.59	58.124

7	NC4	1.34	58.124
8	IC5	0.74	72.151
9	NC5	0.83	72.151
10	FC6	1.62	86.000
11	PC1	22.64	232.421
12	PC2	15.12	347.787
13	PC3	10.21	515.119

Table -6: Static Precipitation Test Results from live oil.

Sl. No.	Test Pressure (psia)	Experimental (wt%)	Whitson (wt%)	Chi-Square (wt%)
1	1014.7	0.403	0.362	0.351
2	2014.7	1.037	0.784	0.734
3	3014.7	0.742	0.807	0.883
4	4014.7	0.402	0.383	0.380

Table -7: Comparison of Error.

Sl. No.	Test Pressure (psia)	Whitson Error (%)	Chi-Square Error (%)
1	1014.7	0.1017	0.1290
2	2014.7	0.2440	0.2919
3	3014.7	0.0876	0.1903
4	4014.7	0.04726	0.0547
Sum =		0.1201	0.1665

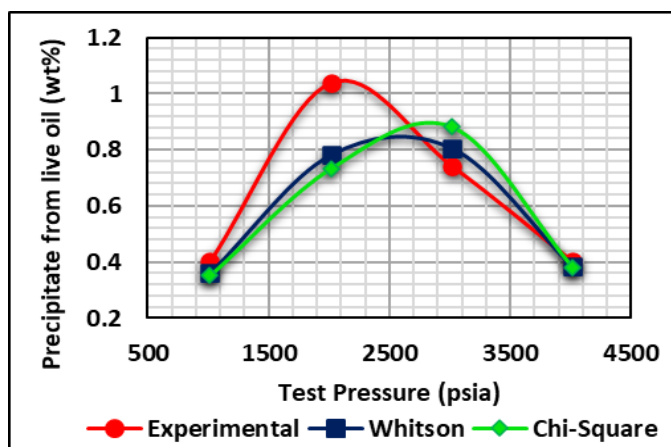


Fig -3: Static Precipitation Test Results.

5. CONCLUSIONS

From the results, we can deduct that the Whitson Characterization gives us an error of 12.01%, whereas, the Chi-Square Characterization gives us an error of 16.65%. Thus, it can be concluded that the Whitson Characterization scheme is better than the Chi-Square Characterization scheme. We can improve the analysis further by comparing SARA characterization and aromaticity. Also, different types of oil samples should be studied to determine the effect of various characterization schemes.

ACKNOWLEDGEMENT

I would like to express my deep and profound gratitude to Mr. Sugat Srivastava, Assistant Professor, Department of Petroleum Engineering, for his continuous support, timely encouragement, and excellent guidance. I sincerely appreciate his supervision and assistance in various aspects of the work. I am also grateful to all the faculty and staff of the Petroleum Engineering Department, Presidency University Bangalore.

REFERENCES

- [1] Mullins, O.C., 2011. The Asphaltenes. *Annual Review of Analytical Chemistry*, 4, 393-418.
- [2] Speight, J.G., 2004. Petroleum Asphaltenes—Part 1: Asphaltenes, Resins and the Structure of Petroleum. *Oil Gas Sci. Technol.*, 59, 467-477.
- [3] Kokal, S.L., Sayegh, S.G., 1995. Asphaltenes: The Cholesterol Of Petroleum. In *SPE Middle East Oil Show*; Society of Petroleum Engineers: Bahrain.
- [4] R.S.H., Al-Maamari, J.S., Buckley, 2003. Asphaltene precipitation and alteration of wetting: the potential for

wettability changes during oil production, *SPE Reservoir Eval. Eng.* 6, 210e214.

- [5] A., Memon, C., Borman, O., Mohammadzadeh, M., Garcia, D.J.R., Tristancho, J., Ratulowski, 2017. Systematic evaluation of asphaltene formation damage of black oil reservoir fluid from Lake Maracaibo, Venezuela, *Fuel* 206, 258e275.
- [6] C.E., Haskett, M., Tartera, 1965. A practical solution to the problem of asphaltene deposits-Hassi Messaoud Field, Algeria, *J. Petrol. Technol.* 17, 387e391.
- [7] C.A., Torres, F., Treint, C.I., Alonso, A., Milne, A., Lecomte, 2005. Asphaltenes pipeline cleanout: a horizontal challenge for coiled tubing, in *SPE/ICoTA Coiled Tubing Conf. Exhib.*, Society of Petroleum Engineers.
- [8] Zhang, Xiaohong, Pedrosa, N., Moorwood, T., 2012. Modeling Asphaltene Phase Behavior: Comparison of Methods for Flow Assurance Studies. *Energy & Fuels*. 26. 2611-2620. 10.1021/ef201383r.
- [9] Leontaritis, Kosta, 1997. PARA-Based (Paraffin-Aromatic-Resin-Asphaltene) Reservoir Oil Characterizations. 10.2118/37252-MS.
- [10] David, Ting, P., Hirasaki, G.J., Chapman, W.G., 2003. Modeling of Asphaltene Phase Behavior with the SAFT Equation of State. *Petroleum Science and Technology*, 21 (3-4), 647-661.
- [11] Leontaritis, K J., Mansoori, G.A., 1987. Asphaltene Flocculation During Oil Production and Processing: A Thermodynamic Colloidal Model. In *SPE International Symposium on Oilfield Chemistry*, 4-6 February; Society of Petroleum Engineers: San Antonio, Texas.
- [12] Agrawala, M., Yarranton, H.W., 2001. An Asphaltene Association Model Analogous to Linear Polymerization. *Industrial & Engineering Chemistry Research*, 40 (21), 4664-4672.
- [13] Ting, P.D., 2003. Thermodynamic stability and phase behavior of asphaltenes in oil and of other highly asymmetric mixtures. Ph.D. Thesis. United States, Texas: Rice University.
- [14] Gonzalez, D.L., Hirasaki G.J., Creek, J., Chapman, W.G., 2007. Modeling of asphaltene precipitation due to changes in composition using the perturbed chain statistical associating fluid theory equation of state. *Energy Fuels*; 21:1231-42.
- [15] Gross, J., G., Sadowski, (2001). Perturbed-chain SAFT: An equation of state based on a perturbation theory for chain molecules. *Ind. Eng. Chem. Res.* 40, 1244-1260.
- [16] D.L., Katz, A., Firoozabadi, 1978. Predicting phase behavior of condensate/crude-oil systems using methane interaction coefficients, *J. Petrol. Technol.* 30,

- 1e649. methane interaction coefficients, J. Petrol. Technol. 30, 1e649.
- [17] C.H., Whitson, 1983. Characterizing hydrocarbon plus fractions, Soc. Petrol. Eng. J. 23, 683e694.
- [18] Riazi, M.R., Daubert, T.E., 1980. "Simplify Property Predictions," Hydrocarbon Processing, Gulf Publishing, U.S.A., Vol.59, No.3, p.115-116, & p.107-112.
- [19] Ahmed, T., 2016. Equations of State and PVT Analysis: Applications for Improved Reservoir Modeling: Second Edition.
- [20] Quiñones Cisneros, Sergio, Zéberg-Mikkelsen, C., Baylaucq, Antoine, B., Christian, (2004). Viscosity Modeling and Prediction of Reservoir Fluids: From Natural Gas to Heavy Oils. International Journal of Thermophysics. 25. 1353-1366. 10.1007/s10765-004-5743-z.
- [21] J.A., Barker, D., Henderson, J., 1967, Perturbation Theory and Equation of State for Fluids: The Square-Well Potential Chem. Phys. 47, 2856.
- [22] Roth, Patrick, 2009, Models for thermostats and chemical reactors: modeling and creating a user interface, VDM Verlag Dr. Müller, 9783639123265.
- [23] Seitmaganbetov, Nurzhan, Rezaei, Nima, Shafiei, A., (2021). Characterization of crude oils and asphaltenes using the PC-SAFT EoS: A systematic review. Fuel. 291. 120180. 10.1016/j.fuel.2021.120180.
- [24] Stavrou, Marina, Bardow, André, Gross, J., (2015). Estimation of the Binary Interaction Parameter k_{ij} of the PC-SAFT Equation of State Based on Pure Component Parameters Using a QSPR Method. Fluid Phase Equilibria. 416. 10.1016.
- [25] Burke, Nancy, E., Hobbs, Ronald E., and Samir F, Kashou, 1990. Measurement and Modeling of Asphaltene Precipitation, J Pet Technol 42 (1990): 1440–1446.

BIOGRAPHY



Priyanka Singh is currently a final year student pursuing B.Tech in Petroleum Engineering from Presidency University Bangalore.