GSJ: Volume 10, Issue 12, December 2022, Online: ISSN 2320-9186

www.globalscientificjournal.com

Asphaltene Precipitation in Pipeline Resulting from Water Flooding

Dooka Yirakpoa Collins [1], Dagde K.K. [2] and Nmegbu Godwin Chukwuma J.[3]

[1]Department of Petroleum Enginering, Rivers State University, Port Harcourt, Nigeria.
[2]Department of Petrochemical Engineering, Rivers State University, Port Harcourt, Nigeria.
[3]Department of Petroleum Engineering, Rivers State University, Port Harcourt, Nigeria.

ABSTRACT

Crude oil is a complex mix of hydrocarbons and other compounds with varying molecular weight, polarity and other properties. Crude oil's physical and chemical properties vary greatly from one producing region to another and even within a single region. According to viscosity, specific gravity, and API gravity, crude oil is traditionally categorized. One of the most surface-active components in crude oil is known as asphaltenes. Due to this characteristic, fluid-fluid interactions are most likely what affects how they behave during fluid flow. Water comes into touch with crude oil while it is being produced and transported through reservoirs and pipelines. This research analyse a numerical model for analyzing pipeline asphaltene precipitation issues in a field created with water injection. The modelling component includes pipeline configuration, measure for asphaltene precipitation, fluid and component transport. The PIPESIM and WINPROP softwares were utilized for this analysis. The difference between both simulators is that the PIPESIM predicts asphaltene precipitation using the thermodynamics of the system, while the WinProp software uses the mixing rule and thermodynamics of the system to predict asphaltene. From the analysis in this study it was observed that asphaltene precipitation weight percentage increases exponentially with increase in fractional water composition in the pipeline indicating that asphaltene precipitation is more severe in pipelines with high percentage of water resulting from water injection. The temperature effect analysis carried out on the sample shows that at low temperatures, asphaltene precipitation does not significantly vary with changes in temperature; however, at increasing temperature, the asphaltene precipitation increases as well. Asphaltene precipitation was observed to increases with pressure and water saturation, and for a field with significant asphaltene composition, produced with water injection, however, there is critical saturation where increase in water saturation will not cause any further precipitation of asphaltene for a particular pressure. The reduction simply implies the dissolution of precipitated asphaltene. Abundant asphaltene precipitations are noticed around bubble-point pressures which in this case is around 189 psia. The model's findings can be used to pinpoint operational circumstances that would make asphaltene precipitation less likely. This information can be used to design pipeline operating strategies during water injection. In this study we have taken a modelling approach for analysis, further studies should consider the use of experimental procedures for the purpose of adequate comparisons, justifications and improvement in findings. This study found that the effect of asphaltene precipitation in the pipeline is directly impacted by water injection. It is advised to conduct more research to find the optimal water flooding/injection approach that will lessen the difficulties in operating transportation lines, particularly with relation to the precipitation and deposition of asphaltene.

Keywords: Water flooding, Precipitation, Asphaltene, Crude oil, Winprop Software, EOS and Deposition.

1 INTRODUCTION

Crude oil is a complex mix of hydrocarbons and other compounds with varying molecular weight, polarity and other properties (Jianxin & Jill, 2003). Crude oil's physical and chemical properties vary greatly from one producing region to another and even within a single region. According to viscosity, specific gravity, and API gravity, crude oil is traditionally categorized. The four basic categories of crude oil are light, extremely light, medium, heavy, and very heavy. Low density and free flowing at room temperature, light and very light crude oil has low viscosity. They have a high API gravity (34 to 39 o API), low viscosity, and specific gravity, above 40^{O}API for very light crude)(Ghulam, et al., 2013). They generally have low wax content. Medium crude oil is used to classify any liquid petroleum with API gravity between 22 – 30^{o}API (Nwadinigwe & Alumona, 2010). Heavy crude oil does not flow effortlessly and frequently have higher density, viscosity and specific gravity than the light and medium crudes. Their API gravity are frequently less than 20^{o} and can contain a noteworthy proportion of asphalthenes and resins. Extra heavy crude oil is define with specific gravities higher than 1 and API gravity less than 10^{o}(Dusseault, 2008).

After the making of crude oil from the reservoir to the surface facilities, it can be transferred through short to long distance pipelines to a primary and secondary processing facility. A stream of crude oil can contain fractions of light and heavy components and the reaction between components as of the crude oil can lead to the selective precipitation of aromatic compounds with high molecular weights (Peng, Xiaogi, & Yongan, 2010). Asphaltences are the fractions of crude oil that precipitate in these circumstances. It is a complex mixture of many different molecular types, many of which are present in the oil as colloidal suspensions. Resin absorbed on its surface peptizes or stabilizes the mixture by adding a variety of different molecular types to it (Aquinos, Olivos, Andersen, & Liran, 2003).

The parameters of the crude oil source play a significant role in determining the quantity and composition of asphaltene that precipitates in the crude oil flow stream. This implies that apart from the compositions of the crude oil itself, the properties of other fluids present in the reservoir (whether naturally or artificially added) can affect the type, rate of formation and complexity of the asphaltene that would be precipitated(Jaghi, 2017). Heavy crude oil does not flow effortlessly and frequently have higher density, viscosity and specific gravity than the light and medium crudes. Their API gravity are frequently less than 20^o and can contain a noteworthy proportion of asphalthenes and resins. Extra heavy crude oil is define with specific gravities higher than 1 and API gravity less than 10^o . Depending on the characteristics of the making field, the kind of crude oil, and other fluids present, the amount of asphaltene in crude oil can range from 0.1 percent to more than 20 percent. They are typically described as being insoluble in paraffins like n-pentane or n-heptane and soluble in aromatic solvents like toluene or benzene (Aquinos *et al*., 2003). Owing to the alteration of ambient conditions during fluid flow through pipelines, asphaltenes are liable to be precipitated out during transportation and post-processing. Due to asphaltenes' partial pipeline clogging, these precipitates may make the process of producing oil more difficult and expensive (Festus, 2021).

Studies have shown that certain secondary/enhanced recovery procedures can add to the precipitation of asphaltenes in flow pipes (BehruzSa *et al.*, 2013). The injected water is made to help prevent the precipitation of asphaltenes during flooding since an increase in brine content reduces asphaltene precipitation (Srivastava *et al*., 1997). Nevertheless, the injected brine does not completely eliminate the formation of asphaltenes particularly when these petroleum fluids are flowing in pipelines at diverse ambient temperature compared to that in the petroleum reservoir. The Brine reduces the composition variations in the reservoir and further evades the changes in asphaltene stability, but as the crude oil is produced to the surface, the effectiveness of this function decreases and processing lines where the operating conditions results in changes in fluid properties and compositions.

1.2 Statement of the Problem

Anywhere along the production line, the precipitation of asphaltenes can result in serious issues with oil production, processing, and distribution. In their study, de Boer *et al.* (1995), shown that even a tiny amount of asphaltene in light oils can cause issues during production, and that heavy oils with a significant asphaltene component can lead to more serious and complex issues. Asphaltene precipitation and deposition can happen at any point along the production chain, including during the production of reservoir fluid, transportation through pipelines of produced fluid, and processing the fluid in downstream processes. Asphaltenes can precipitate under traditional crude oil production settings like normal pressure depletion or under improved oil recovery conditions like acid stimulation, water flooding, gas-lift operations, and miscible flooding. Asphaltene precipitation can be caused in pipelines, tubulars, and surface facilities when heavy oil is recovered by water flooding operations and diluted with paraffinic solvent or lighter oils to lessen its viscosity (Asok, 2012).

Asphaltene precipitation and deposition in wells, pumps, flowlines, transportation pipes, and other making facilities can harm pumps, impair or obstruct flowlines and pipelines, and clog or restrict the operation of foul making handling systems (Saniere *et al.*, 2004). An imperative aspect of asphaltene precipitation is its upshot on the flow assurance of the system. The term "flow assurance" is frequently used to refer to a number of fluid flow-related issues that affect the flow of water, gas, and oil via production and transportation systems like pipelines. The flow assurance engineer's main objective is to ensure that the process and transportation systems operate as intended, and the precipitation of asphaltene can pose a very serious threat to the system's reliability.

Numerous factors have been identified to lessen the operational of these remedial methodologies. In a study by Hassen (2004) the impact of injected water on asphaltene precipitation was found to be poorly known. Study two diverse reservoirs with diverse recovery mechanisms, although injected brine has the ability to stop the precipitation and deposition of asphaltenes, he found that it does not, nevertheless, in flow pipes and conditions, the upshot of injected water on asphaltene deposition prevention might be counter intuitive. So it's essential to comprehend how asphaltene precipitates and deposits in transportation lines in order to apply remedial mitigation techniques that consistently produce favorable outcomes (Gonzalez & Vargas, 2005). The compatibility of asphaltenes with other crude ingredients is just as important as the quantity of precipitated asphaltenes (such as water) that affects rheological properties of crude oils (Bearsley *et al.*, 2004)

When modeling the behavior of the asphaltene phase, it is necessary to take into account the presence of emulsified water in crude oils. Frequently, reservoir fluid samples with little to no water are used to predict the behavior of asphaltene phases or to determine the likelihood of precipitation in a laboratory setting (Boek *et. al*., 2008). However, during secondary or enhanced oil recovery procedures, reservoir fluids are frequently co-produced with formation water and/or injected water. Water-in-oil emulsion development is inevitable in bitumen extraction operations since froth treatment requires a significant amount of water. In terms of the measured onset and yield of precipitated asphaltenes, the impact of the presence of water on asphaltene precipitation is not fully known. As a result, it's important to examine how emulsified water affects the precipitation of asphaltenes from crude oils. The phase behavior modeling for asphaltenes precipitation must be adjusted if there is an outcome.

1.3 Aim of the Study

The aim of this study is to determine how water flooding recovery mechanisms affect precipitation and asphaltene deposition along pipelines used to carry crude oil in the Niger Delta.

1.4 Objectives of the Study

The objectives of this study are as follows:

i. To evaluate and test a characterization methodology that can be used to characterize asphaltene precipitation in transportation pipelines that is caused by pressure as well as solvents.
ii. To examine the effects of pipeline operating parameters on the interactions between water and asphaltene in the crude oil flowing through the transportation pipeline (such as temperature and pressure).
iii. To evaluate the effects of rain from crude oil flowing through pipes on asphaltenes.
iv. To simulate optimal water into oil ratio for safe transportation of crude oil in pipeline.

1.5 Scope of the Study

A substantial number of research has gone into analysing the upshot of asphaltene deposition in reservoir systems and how this affects overall accepted. In this study, the major focus is on asphaltene precipitation in transportation pipelines. The literature has utilized a variety of modeling strategies to simulate asphaltene precipitation from crude oils in reservoir systems. The colloidal and thermodynamic model types are the two main categories. The most popular type of model is thermodynamics. Regular solution theory, cubic equations of state, and association equations of state are a few thermodynamic models that have been used to predict the precipitation of asphaltene.

Equations of state (EOS) based models are typically employed for oils at high pressure and temperature, with solution or injected gas, and are ideally suited for vapour-liquid equilibrium computations. They have not yet been effective when used to treat pipeline asphaltene precipitation (Eskin *et al.*, 2011). The simplest approach is to use a normal solution, which can be easily modified to simulate precipitate caused by dilution with incompatible solvents. The regular solution approach is used in this thesis to represent the precipitation of asphaltene from crude oil mixtures passing via a pipeline.

This analysis of asphaltene precipitation caused by water is presented. This analytical strategy will involve the creation of an analytical model to forecast asphaltene precipitation in the pipeline using the composition of the flowing fluid and operational parameters (temperature, pressure and relative humidity).

2 Materials and Methods

2.1 Materials

The software programs WINPROP and PIPESIM were the respective study materials.

2.1.1 Method of Analysis

In this work, we developed a tactic to appraise the upshot of water on asphaltene precipitation in pipelines and to forecast the onset and the number of asphaltene precipitation for any given condition of pressure, temperature and composition. PIPESIM software is used for the scrutiny of water composition on the precipitation of asphaltene in a pipeline. WinProp software is used for the asphaltene predictive modelling to appraise the likelihood of asphaltene precipitation at numerous composition, pressures and temperatures. WinProp is used in this case because of its robustness in the forecast of interaction factors for the sample components. While PIPESIM predicts asphaltene precipitation using thermodynamics and kinetics calculations, the WinProp software does this using both the component mixing rule and thermodynamics making it more precise for predictive purposes (Abdolvahab & Rastgoo, 2017).

The difference between both simulators is that the PIPESIM predicts asphaltene precipitation using the thermodynamics of the system, while the WinProp software uses the mixing rule and thermodynamics of the system to predict asphaltene. In both simulators, the Peng-Robinson EOS were be used for thermodynamic calculations.

Making logging tests yielded the pressure and temperature needed for the study, which were then paired with asphaltene precipitation curves produced by the thermodynamic model utilizing the fluid data. The pressure transient along the pipeline was used as the determining factor for predicting the fluid gradient which is vital for the estimation of the precipitation condition and point. PIPESIM in this study was used specifically for the validation of the designated simulation models used in WINPROP.

2.2 Field Data

Numerous models and equations required for the evaluation of the upshot of water injection on asphaltene precipitation in transportation pipelines were analysed. For this analysis, the data used were gotten from three diverse oil samples from the Niger Delta (Port Harcourt) Crudes. The properties and components of the fluid samples are listed in the tables 2.1 & 2.3 respectively.

Table 2.1: Properties of Crude Oil Samples used for the analysis

Properties	**A**	**B**	**C**
Density of Crude (lb/gal)	6.51	7.01	6.92
API Gravity (^{o}API)	49.91	36.95	38.80
BSW	0.6	0.72	0.7
Average Water Content (% by volume)	0.2	0.23	0.18
Viscosity(**cp**)	0.33	0.42	0.38

Table 2.2: Flow Conditions

Properties and Values		
Pressure	30- 350	Psia

GSJ: Volume 10, Issue 12, December 2022
ISSN 2320-9186

Temperature	60 - 150	^oF

Table 2.3: Crude Oil Sample Compositions

Component	Mol % Field A	Field B	Field C
N_2	0.86	0.75	0.94
CO_2	0.10	0.12	0.16
Sulphur	0.16	0.22	0.19
C_1	24.05	34.05	28.65
C_2	1.2	0.77	1.01
C_3	3.560	2.450	3.89
i-C_4	1.300	0.98	0.87
N-C_4	5.702	3.60	4.56
I-C_5	1.2	0.9	01.3
N-C_5	2.33	3.5	2.96
C_6	1.34	2.9	1.70
C_7	1.3	1.9	2.1
C_8	2.34	3.4	2.80
C_9	3.42	2.98	3.24
C_{10}	0.6	1.1	1.23
C_{11+}	48.33	35.90	40.80
Resin	1.1	1.9	2.30
Asphaltenes	1.108	2.58	0.40
Total	100	100	100

2.3 Solution Techniques

The IMPES (implicit pressure, explicit saturation) method is used to solve compositional problems of this type, where pressure is treated implicitly and component masses/moles are treated explicitly to account for saturation variations. This method were implemented using the principle similar to the type employed in the PIPESIM software.

2.3.1 Equation of State (EOS)

These equations were derived from the theoretical framework of van der Waals (1873), who took into account the attraction and repulsion forces between molecules as well as non-zero molecular volume under infinite pressure (b) (a). More recent adjustments led to the more widely used are Soave-Redlich-Kwong and Peng-Robinson EOS equations, which provide more trustworthy quantitative predictions. These equations, which are stated in literature were utilized in compositional reservoir analysis to determine fluid characteristics and predict phase behaviour. They are as follows:

i. Soave-Redlich-Kwong equation(SRK)

ii. Peng-Robinson equation(PR)

Figures 2.1 and 2.2, which are provided below, demonstrated the simulation flow charts.

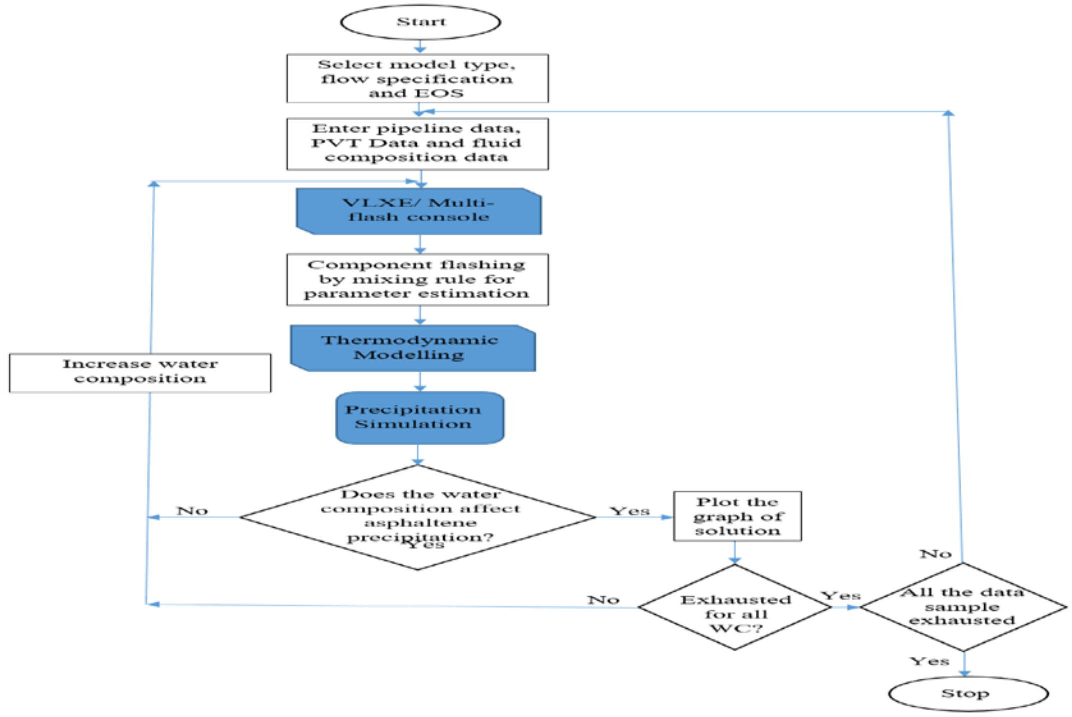
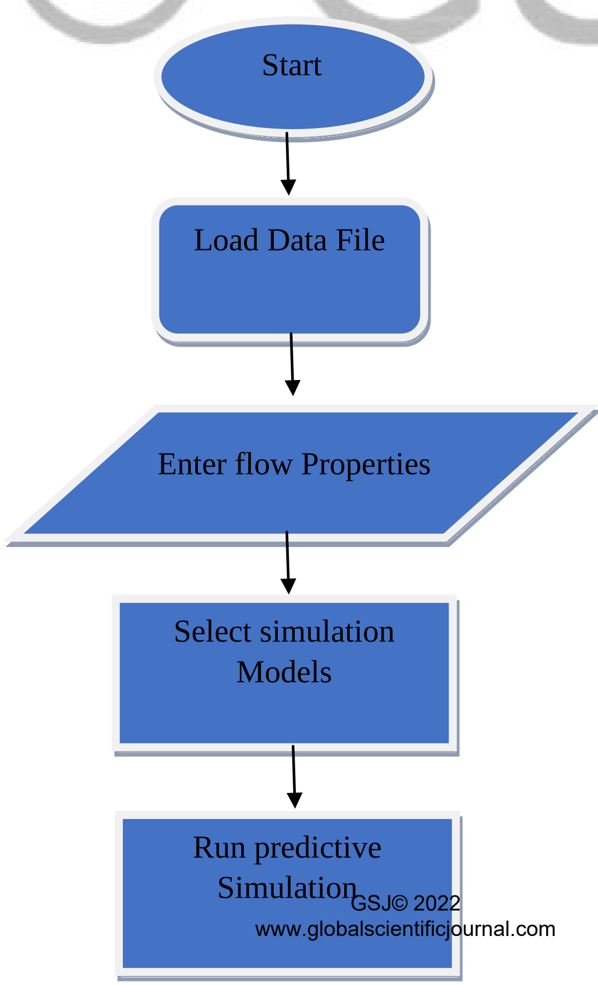


Figure 2.1: An analysis flow chart illustrating the method used in this work to evaluate the impact of water injection on asphaltene precipitation in WINPROP.



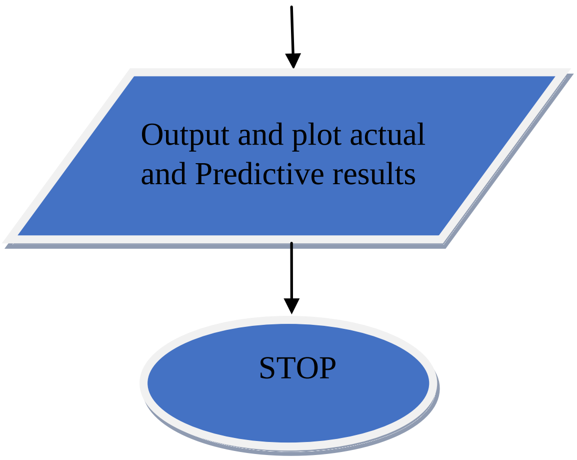


Figure 2.2: A flow chart showing the process of for model validation using PIPESIM

3 Results and Discussion

Asphaltene precipitation profile data for the sample A, was plotted against the simulated precipitation using PIPESIM models. The result is shown in Figure 3.1. The simulated precipitation results closely matched the reported deposition profile which gives us confidence in the model for this analysis. One quick point of reference shows the graphical relationship of precipitation of asphaltenes with respect to pressure as parabolic in nature.

3.1 Model Validation

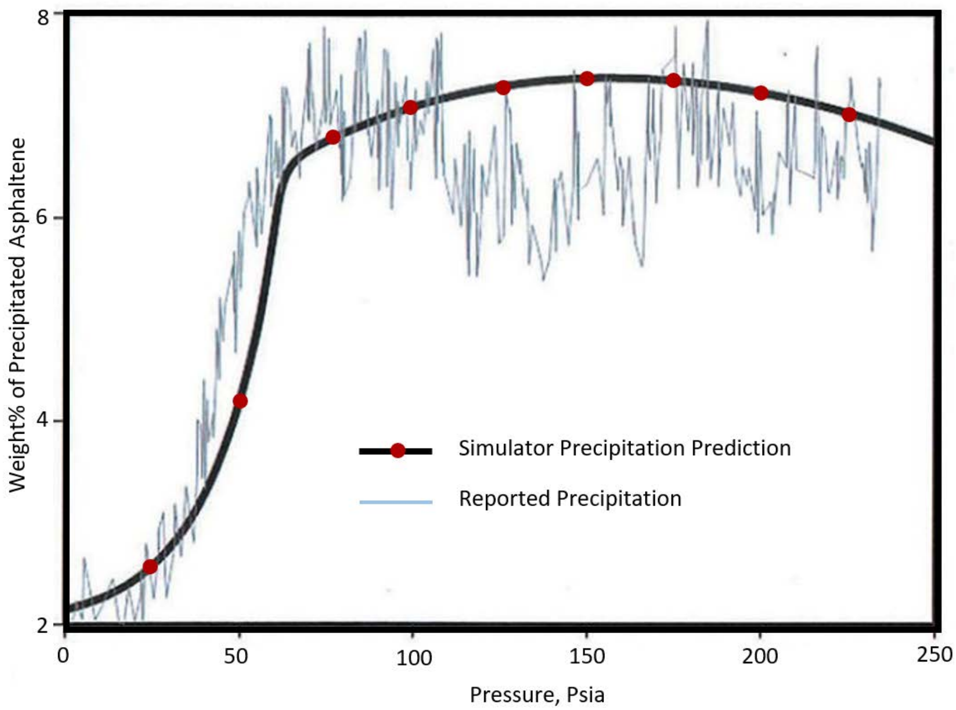


Figure 3.1: A comparison between simulated asphaltene precipitation prediction and reported data for asphaltene precipitation weight (Sample A using PIPESIM)

3.2 The Asphaltene Precipitation Predictive Model

Figure 3.2 shows a plot of pipeline pressure on asphaltene precipitation for diverse water saturation. The water composition was used to account for the upshot of water injection.

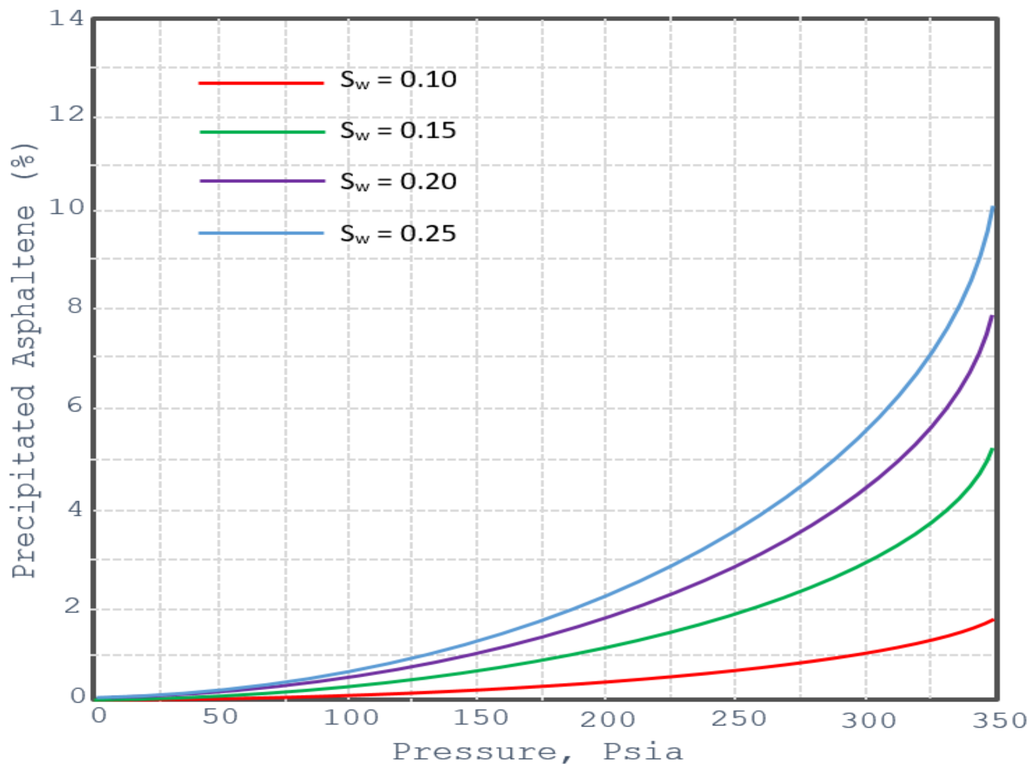


Figure 3.2: Plotting the percentage of asphaltene precipitation against pipeline pressure at various water saturation levels

It can be noticed that asphaltene precipitation upsurges with pressure and water saturation. This implies that for a field produced with water injection, if the produced fluid has high asphaltene composition, precipitation of asphaltene would be inevitable due to the high water saturation in the fluid sample resulting water injection. From the result, it can be noticed that the percentage precipitation difference lessens with upsurge in water saturation. Figure 3.3 indicates a comparable outcome for the relationship between pipeline size and asphaltene precipitation. Pressure and tubing size increases are correlated with increases in asphaltene precipitation. The upshot of pipeline size can be attributed to the fact that upsurge in pipe diameter lessens the level of intermolecular and wall collisions which lessens particular energy and favouring flocculation.

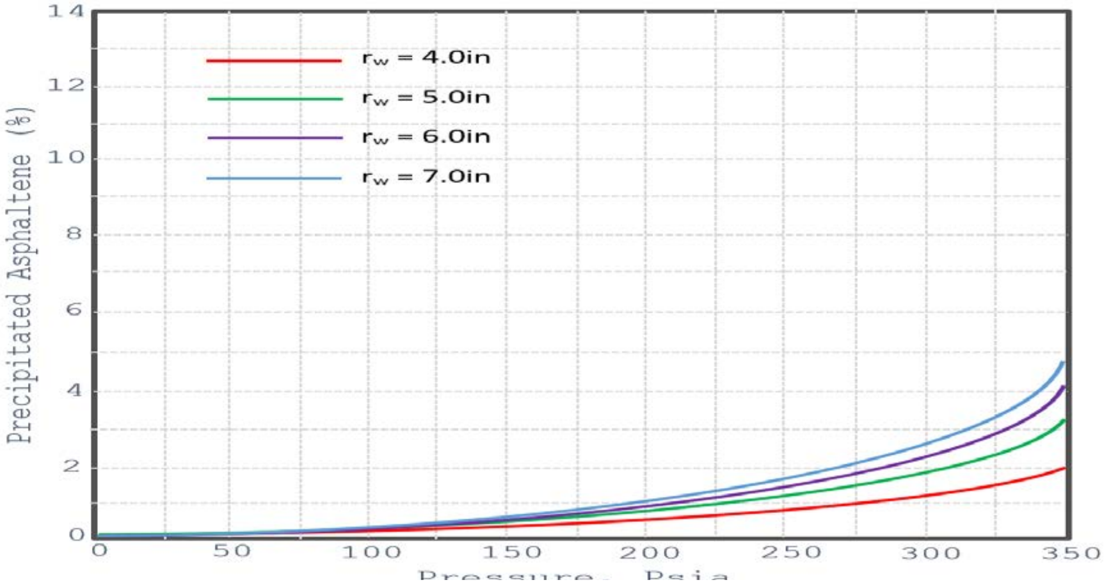


Figure 3.3: Plotting the percentage of asphaltene precipitation vs pipeline pressure for various water pipeline composition values

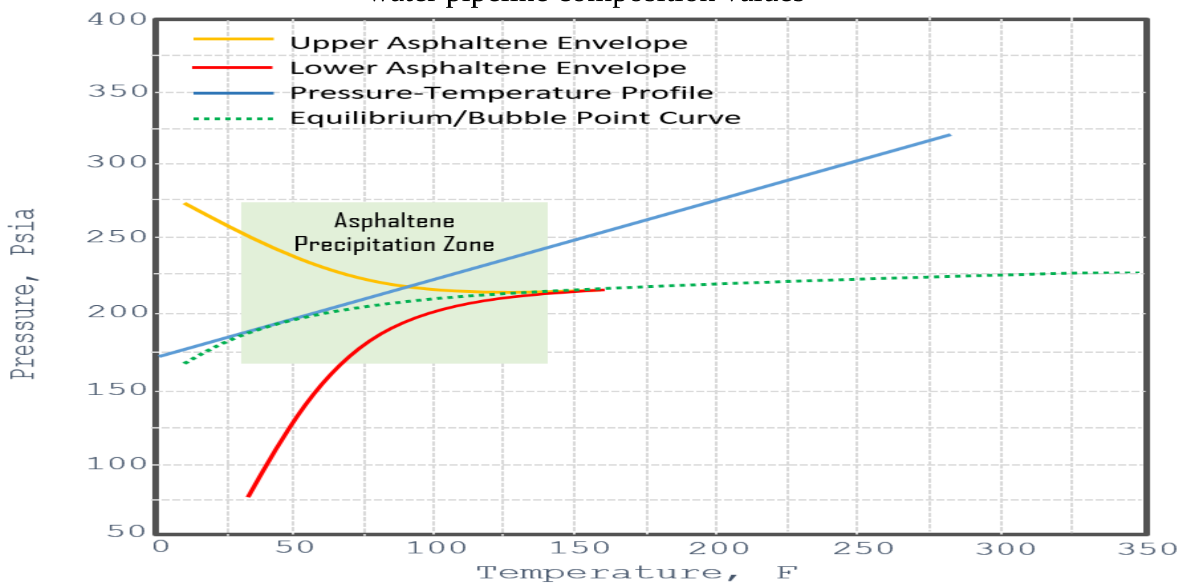


Figure 3.4: Asphaltene precipitation phase envelope for the identification of precipitation zones for a particular flow stream composition (WC = 0.2).

This result also implies that there is a saturation referred to as a critical saturation where upsurge in water saturation will not cause any further precipitation of asphaltene for a particular pressure.

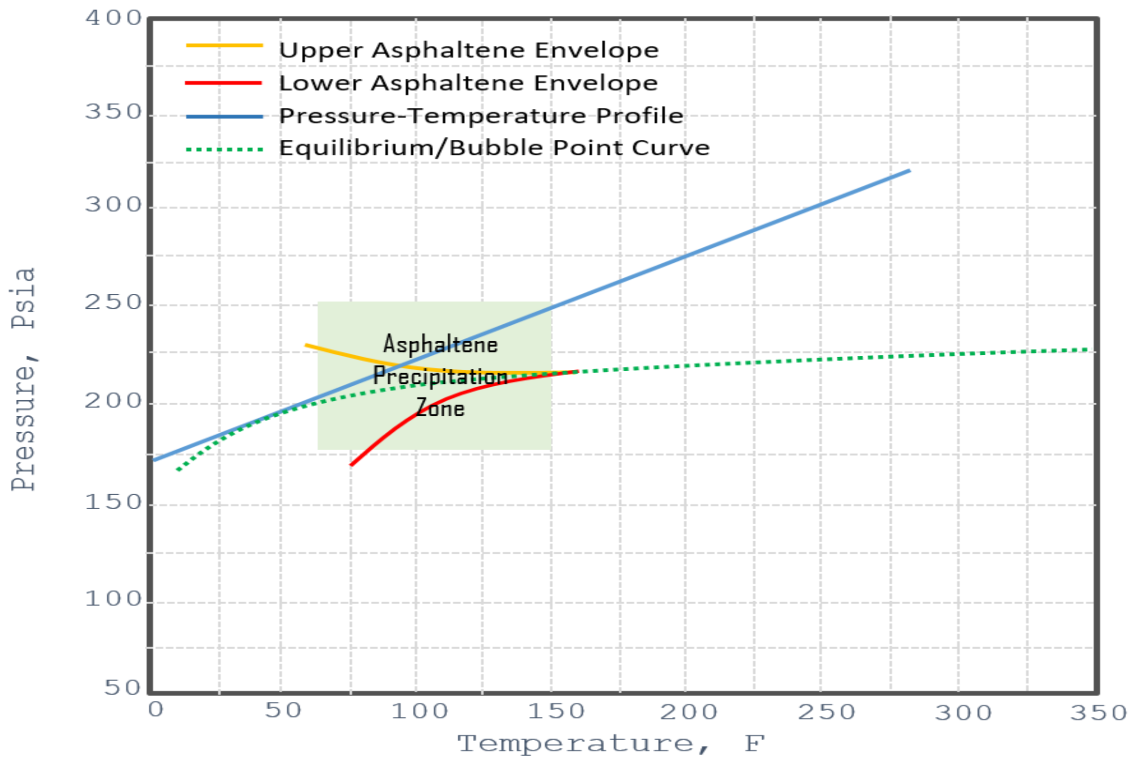


Figure 3.5: Asphaltene precipitation phase envelope for the identification of precipitation zones for a particular flow stream composition (WC=0.1)

Further analysis to comprehend the upshot of water composition on the precipitation zone was carried out. It was noticed that with upsurge in water composition in the pipeline widens the asphaltene precipitation zone thereby increasing the chances for asphaltene formation for small changes in the flow.

In figure 3.6, it can be noticed that during depressurization the number of precipitated asphaltene upsurges until a particular pressure, known as the saturation pressure is reached, where asphaltene precipitation is maximum, and then continues to reduce with further depressurization. The reduction simply implies the dissolution of precipitated asphaltene as discussed in many literatures (Mei, 2000). Abundant asphaltene precipitations are noticed around bubble-point pressures which in this case is around 189 psia. It can also be noticed that precipitation percentage weight upsurges with upsurge in water composition in the pipeline. Nevertheless, the difference in percentage precipitation with upsurges water composition lessens for higher water composition. This result implies that there is a critical water saturation where increasing water saturation may not lead to further upsurge in asphaltene precipitation; a result similar to that highlighted in the study of Nghiem, *et. al.*, (2000).

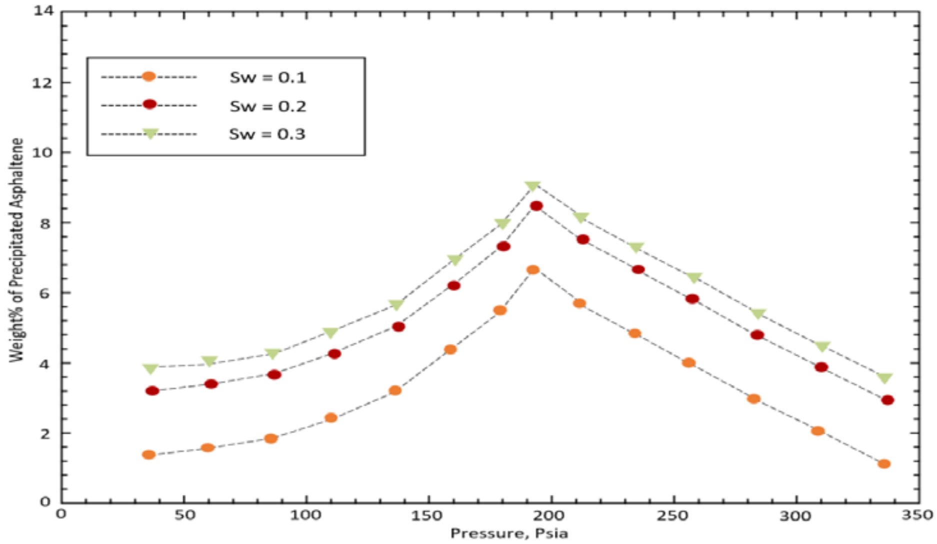


Figure 3.6: Asphaltene Precipitation by weight plotted as a function of pressure for diverse values of Water Saturation (Generated in WINPROP).

4 Conclusion and Recommendations

4.1 Conclusion

The set objectives of this study have been attained and the upshot of water injection on asphaltene precipitation have been analysed extensively. The following are the key findings of this study on the impact of water injection on asphaltene precipitation:

i. The precipitation weight percentage upsurges exponentially with upsurge in fractional water saturation in the pipeline.

ii. At low temperatures, asphaltene precipitation does not noteworthyly vary with changes in temperature which is consistent with the original assumption for the progress of the analytical model; nevertheless, at increasing temperature, the asphaltene precipitation upsurges as well, indicating a disparity in model assumptions at higher temperatures.

iii. Asphaltene precipitation upsurges with pressure and water saturation, and for a field with noteworthy asphaltene composition, produced with water injection, precipitation of asphaltene would be inevitable due to the high water saturation in the fluid sample resulting water injection Abundant asphaltene precipitations are noticed around bubble-point pressures which in this case is around 189 psi

iv. This information can be used to design pipeline operating strategies during water injection.

v. The proportion of asphaltene present in the crude oil decides how much upshot water composition from water injection can affect asphaltene precipitation.

vi. With upsurge in water composition in the pipeline widens the asphaltene precipitation zone thereby increasing the chances for asphaltene formation for small changes in the flow.

4. 2 Recommendations

i. This work is the first of its kind as there is no literature that clearly considers the analysis of asphaltene precipitation in pipelines due to water flooding, therefore there is need to delve deeper into this concept by carrying out further research. Although, noteworthy study has gone into analysing the upshot of water flooding on asphaltene precipitation in petroleum reservoirs, little or no study has been able to extend to pipelines.

ii. Additionally, in this study we have taken a modelling tactic for analysis, further studies should consider the use of experimental procedures for the purpose of adequate comparisons, justifications and improvement in findings.

iii. This study has discovered that water injection has unswerving impact on the upshot of asphaltene precipitation in pipeline. It is advised that more research be done to determine the optimal water flooding/injection approach that can lessen the difficulties connected with operating transportation lines, in relation to the precipitation and deposition of asphaltene.

iv. By taking into account the results, the evaluation of the impact of asphaltene precipitation due to water injection can be expanded and the role interfacial tensions plays on the precipitation of asphaltenes since intermolecular attraction plays a major role in fluid induced asphaltene precipitation.

4.3 Contributions to Knowledge

i. The results of this study have improved knowledge of how water and asphaltenes interact in crude oil systems, which will eventually result in the creation of cost-operational solutions to this flow assurance problem.

ii. This study was able to create and test a characterization methodology that can be used to characterize asphaltene precipitation in transportation pipelines that is caused by pressure as well as solvents.

iii. The impact of pipeline operating variables (such as temperature and pressure) on the interactions between water and asphaltene in the crude oil flowing through the transportation pipeline was also examined

iv. This study has showed the changes in crude oil composition when exposed to injected water and the role this plays in the precipitation of asphaltenes in pipelines.

REFERENCES

Abdolvahab-Rastgoo, R. K. (2017). *Investigation of Asphaltene Deposition and Precipitation in Production Tubing.* Petroleum University of Technology, Petroleum Engineering. Ahwaz, Iran: International Journal of Clean Coal and Energy.

Aboozar, S., Mohammad, Y., Shahin, K., & Omid, M. (2018). A review on methods of determining onset of asphaltene precipitation. *Journal of Petroleum Exploration and Production Technology*, 1375 - 1396.

Abouie, A., Darabi, H., & Sepehrnoori, K. (2016). Data-Driven Comparison between Solid Model and PC-SAFT for Modeling Asphaltene Precipitation. *Offshore Technology Conference* (pp. 359 - 364). Houston: Journal of Petroleum Technology.

Alkafeef, S. F., Al-Medhadi, F., & Al-Shammari, A. D. (2005, May). A simplified method to predict and prevent asphaltene deposition in oilwell tubings. *SPE Journal of Production & Facilities*, 126 - 132.

Alkafeef, S. F., Al-Medhadi, F., & Al-Shammari, A. D. (2005, May). A simplified method to predict and prevent asphaltene deposition in oilwell tubings: Field Case. *SPE Journal of Production and Facilities, 24*(5), 126 - 197.

Al-Sahhaf, T. A., Fahim, M. A., & Elkilani, A. S. (2002). Retardation of asphaltene precipitation by addition of toluene, resins, deasphalted oil and surfactants. *Journal of Fluid Phase Equilibria*, 1047 - 1057.

Al-Sahhaf, T. A., Fahim, M. A., & Elkilani, A. S. (2002). Retardation of asphaltene precipitation by addition of toluene, resins, deasphalted oil and surfactants. *Journal of Fluid Phase Equilibria*, 1047 - 1057.

Aquinos, T., Olivos, M. A., Andersen, S. I., & Liran, G. C. (2003). Comparisons between asphaltenes from the dead and live oil samples of the same crude oils. *Journal of Petroleum Science and Technology*, 1017 - 1041.

Asok, K. T. (2012). *Asphaltene Precipitation from Crude Oil Blends, Conventional Oils, and Oils with Emulsified Water*. University Of Calgary, Department of Chemical and Petroleum Engineering. Calgary, Alberta: University Engieering Journal.

Bearsley, S., Forbes, A., & Haverkamp, R. G. (2004). Direct observation of the as-phaltene structure in paving-grade bitumen using confocal laser-scanning microscopy. *Journal of microscopy*, 149–155.

Boer, R., & Leerlooyer, K. (1992). Screening of Crude Oils for Asphalt Precipitation. *SPE European Petroleum Conference* (pp. 23 - 37). Cannes, France: SPE Journal.

Carniani, C., & Correra, S. (2005). Predicting Asphaltene Deposition Problems: The De Boer Plot Revisited. *The Offshore Mediterranean Conference and Exhibition* (pp. 28 - 36). Ravenna, Italy: OnePetro.

Christine, M. S. (2016). *Asphaltene Precipitation and Depositionfrom Crude Oil with CO_2 and Hydrocarbons: Experimental Investigationand Numerical Simulation.* London: Imperial College LondonDepartment of Chemical Engineering.

Chu, Y. P., Hu, Y. F., & Ming, Y. .. (2003). Experiment on precipitation amount and mechanism of asphaltene in high-pressure gas injection process. *Journal of China University of Petroleum (Edition of Nature Science),* 74-77.

Chukwudeme, E. A., & Hamouda, A. A. (2009). *Enhanced Oil Recovery (EOR) by Miscible CO2 and Water Flooding of Asphaltenic and Non-Asphaltenic Oils.* Norway: Department of Petroleum Engineering, University of Stavanger.

Correra, S., & Merino-Garcia, D. (2007). Simplifying the Thermodynamic Modeling of Asphaltenes in Upstream Operations. *Journal of Energy Fuels, 21*(3), 1243 - 1247.

Creek, J. L., Wang, J., & Buckley, J. S. (2003). Verification of Asphaltene-Instability-Trend (ASIST) Predicitions for Low-M0lecular-Weight Alkanes. *Society of Petrleum Engineering*, 23 -34.

Dehan, H. K. (2007). Modelling of Asphaltene Precipitation in Oil Reservoirs: Applicability of Peng-Robinson Equation of State. *Journal of Petroleum Technology*, 23 - 34.

Dimitrios, A. A. (1992). *Thermodynamics of Gas Hydrate Eqilibrum.* Heriot-Watt University, Department of Petroleum Engineering, Edinburgh.

Dusseault, M. B. (2008). “Comparing Venezuelan and Canadian Heavy oil and Tar Sands. *Comparing Venezuelan and Canadian Heavy oil and Tar Sands* (pp. 234 - 238). Calgary, Canada: Journal of Petroleum Energy.

Eskin, D., Ratulowski, J., Akbarzadeh, K., & Pan, S. (2011). “Modelling asphaltene deposition in turbulent pipeline flows. *Canadian Journal Chemical Engineering*, 421- 441.

Eskin, D., Ratulowski, J., Akbarzadeh, K., & Pan, S. (2011). Modelling asphaltene deposition in turbulent pipeline flows. *Canadian Journal of Chemical Engineering, 89*(3), 421 - 441.

Ghedan, S. (2009). Global Laboratory Experience of CO2-EOR Flooding. *2009 SPE/EAGE Reservoir Characterization and Simulation Conference* (pp. 12 - 17). Abu Dhabi: SPE/EAGE.

Gonzalez, D. L., & Vargas, F. M. (2005). Modeling Studyof CO2-Induced Asphaltene Precipitation. *Journal of Oil & Gas Science and Technology*, 537–546.

Haley, J., & Portak, H. K. (2018). Precipitation of Asphaltene: Causes and Effect. *Journal of Petroleum Technology*, 23 - 34.

Halleigh, G. (2009). *Molecular Structure of Asphaltenes: Understanding the Bonding Characteristics of Asphaltene Particles.* Texas, USA: Elsevier.

Hammami, A., & Ratulowski, J. (2007). *Precipitation and Deposition of Asphaltenes in Production Systems: A Flow Assurance Overview*. New York: Springer Science.

Hassel, J. (2007). Precipiation of Aspahtenes in Production and Transportation Networks: Causes, Problems and Remedy. *Journal of Petroleum Technology*, 6 -11.

Hassen, J. K. (2007). Characteristics of Asphaltenes and Resins: Enemies or Friends. *Journal of Applied and Industrial Chemistry*, 345 - 353.

Holland, G. (2009). Asphaltene Depositon In Production Facilities: A review for Fields in the North Sea. *SPE Journal of Production Engineering*, 34-37.

Jamaluddin, A. (2002). Laboratory Techniques to Measure Thermodynamic Asphaltene Instability. *Journal of Petroleum Engineering*, *41*(7), 43 - 59.

Jianxin, W., & Jill, B. S. (2003). Asphaltene stability in crude oil and aromatic Solvents: The Influence of Oil Composition. *New Mexico. Energy and fuels, 17*, 1445 - 1446.

Johan, T. K. (2008). Aspahltene Precipitation Modelling: A Colloidal Model Approach. *Journal of Petroleum Technology*, 2354 - 2366.

Jones, K. L. (2013). Ananlysis of Asphaltene Precipitation in Petroleum Systems. *Journal of Petroleum Technology*, 34 - 39.

Jones, M. T., & Aglingh, T. Y. (2008). Effect of Water Flooding on Pipeline Transportation Performance. *Journal of Petroleum Engineering*, 34 - 45.

Karuka, Y. J., & Wang, J. X. (2018). Flow Assurance and Subsea Productivity: Closing the Loop with Connectivity and Measurements. *SPE Annual Technical Conference and Exhibition* (pp. 34 - 45). Houston, Texas: Society of Petroleum Engineers.

Khanifar, A., Alian, S. S., Demiral, B., & Darman, N. (2011). Study of Asphaltene Precipitation and Deposition Phenomenon during WAG Application. *SPE Enhanced Oil Recovery Conference* (pp. 43 - 48). Kuala Lumpur, Malaysia: Society of Petroleum Engineers.

Leontaritis, K. J. (1997). Simplified Analytical Model for Asphaltene Induced Formation Damage. *SPE Journal of Production Engineering*, 277 - 288.

Liao, Z., Zhao, J., Creux, P., & Yang, C. (2009). Discussion on the Structural Features of Asphaltene Molecules. *Journal of Energy Fuels*, *23*(12), 6272 - 6274.

Maghani, H. (2007). The Prediction of Asphaltene Precipitation in Flow lines. *Journal of Petroleum Techonology, 23*(12), 45 - 57.

Maqbool, T., Srikiratiwong, P., & Fogler, H. S. (2011). Effect of temperature on theprecipitation kinetics of asphaltenes. *Energy & Fuels*, 694–700.

Mark, H., Jonas, K., & Ryan, J. (2008). A systematic approach for the prevention of formation damage caused by asphaltene precipitation. *SPE Journal of Production & Facilities*, 150 - 163.

Mei, H. (2000). *The Precipitation Mechanism and Thermodynamic Model Research of Organic Solid.* Hefei, Anhui: University of Science and Technology of China.

Miftachul, C. (2010). *Study of CO2 Effect on Asphaltene Precipitation and Compositional Simulation of Asphaltenic Oil Reservoir.* Stavanger: University of Stavanger.

Mullins, O. C. (2010). The modified Yen model. *Journal of Energy Fuels, 24*(4), 2179 - 2207.

Mullins, O., Sheu, E., Hammami, A., & Marshall, A. (2007). *Asphaltenes, Heavy Oils, and Petroleomics.* New York: Springer.

Nasoa, D., Vafaie, S., & Fasih, M. (2020). Experimental Investigation on Asphaltene Depositon in Porous Media During Miscible Gas Injection. *Iranian Journal of Chemical Engineering, 26*(4), 24 - 32.

Nghiem, L. X., Kohse, B. F., Ali, S. M., & Doan, Q. (2000). Asphaltene Precipitation: Phase Behaviour Modelling and Compositional Simulation. *SPE Asia Pacific Conference on Integrated Modelling for Asset Management* (pp. 285 - 302). Yokohama: SPE Journal.

Nwadinigwe, C. A., & Alumona, T. N. (2010). *Quantitative assessment of n-Alkanes asphaltenes and resins in different crudes.* Nsukka: . Department of Pure and Industrial Chemistry, University of Nigeria,.

Okwen, R. (2006). Formation Damage by CO2-Induced Asphaltene Precipitation. *SPE International Symposium and Exhibition on Formation Damage Control* (pp. 236 - 247). Lafayette, LA: Journal of SPE.

Oskui, G. P., & Abuhaimed, W. A. (2009). Laboratory Investigation of Asphaltene Precipitation Problems During CO2/Hydraocarbon Injection Project for EOR Application in Kuwait Reservoirs. *Kuwait International Petroleum Conference and Exhibition* (pp. 24 - 32). Kuwait City, Kuwait: SPE Journal.

Parra-Ramirez, M., Peterson, B., & Deo, M. (2001). Comparison of First and Multiple Contact Carbon Dioxide Induced Asphaltene Precipitation. *SPE International Symposium on Oilfield Chemistry* (pp. 456 - 477). Houston, Texas: Society of Petroleum Inc.

Peng, l., Xiaogi, W., & Yongan, G. (2010). "Characterisation of asphaltenes precipitate with three light alkanes under different experimental conditions: fluid phase equilibria,. *Journal of Petroleum Technology*, 103 - 110.

Ramirez-Jaramillo, E., Lira-Galeana, C., & Manero, O. (2006). Modeling Asphaltene Deposition in Production Pipelines. *Energy & Fuels, 20*(7), 1184-1196.

Regan, H. K. (2012). Asphaltene Precipitation in Reservoirs: Causes, Effect and Remedy. *Journal of Petroleum Technology*, 43 - 54.

Rodgers, R. P., Hendrickson, C. L., Blakney, G. T., Savory, J. T., Kaiser, N. T., Mapolelo, M. M., McKenna, A. M. (2010). The compositional continuum of petroleum: detailed molecular characterization of heavy crude oils and asphaltenes by ultrahigh resolution FT-ICR mass spectrometry,. *AIChE Annual Meeting* (pp. 605 - 616). Salt Lake City, UT: AIChE: Journal.

Rogel, E., & Carbognani, L. (2003). Density Estimation of Asphaltenes Using Molecular Dynamic Simulations. *Journal of Energy Fuels, 17*(2), 378 - 386.

Ruiz-Morales, Y., & Mullins, O. (2015). Coarse-grained molecular simulations to investigate asphaltenes at the oil-water interface. *Journal of Energy and Fuels*, 1597 - 1609.

Ruthammer, G., Potsch, K., & Thou, S. (2010). Dectection of Asphaltene Flocculation Onset in a Gas Condensate System. *SPE paper 59092 presented at SPE Production Operations Symposium* (pp. 34-39). Oklama City, Oklahoma: SPE Journal - SPE paper 59092.

Saaid, I., Masoudi, R., & Alta'ee, A. F. (2019). Carbon Dioxide Injection and Asphalten Precipitation in Light Oil Reservoirs. *Eleventh Mediterranean Petroleum Conference and Exhibition* (pp. 23 - 25). Tripoli – Libya: MPCE Report.

Sam, T. H., & White, H. K. (2003). Asphaltene Deposition In Processing and Transportation Lines: A case of Study of the Hassi Messaoud field. *Journal of Petroleum Technology*, 6 - 12.

Saniere, A., Hénaut, I., & Argiller, J. F. (2004). "Pipeline transportation of heavy oils, a strategic, economic and technological challenge. *Journ. Oil & Gas Sci. Technol (REV IFP), 5*(59), 455 - 466.

Sima, S., & Omar, A. (2011). "Study of Asphaltene Precipitation Induced Formation Damage During CO2 injection for a Malaysian light oil. *World Academy of Science, Engineering and Technology* (pp. 78 -84). Kuala Lumpur, Malaysia: SPE Journal.

Soulgani, B., Tohidi, B., Rashtchian, D., & Jamialahmadi, M. (2008). Modelling of Asphaltene Precipitation in Well Column of Iranian Crudes: Kuapl Case Study. *Canadian International Petroleum Conference*, (pp. 234 - 247). Calgary: Canadian Journal of Engineering.

Srivastava, R., Huang, S., & Dong, M. (1997). Asphaltne Deposition During CO2 Flooding. *SPE paper 59092 presented at SPE Production Operations Symposium* (pp. 6 - 9). Oklama City, Oklahoma: Society of Petroleum Engineers.

Wang, S., & Civan, F. (2005). Preventing Asphaltene Deposition in oil Reservoir by Early Water Injection. *SPE Production and Operation Symposium* (pp. 344 - 351). Oklahoma City, U.S: SPE Journal.

Yen, A., Yin, Y., & Asomaning, S. (2001). Evaluating Asphaltene Inhibitors: LaboratoryTests and Field Studies. *SPE International Symposium on Oilfield Chemistry* (pp. 1364 - 1377). Houston, Texas: Society of Petroleum Engineers Inc.

Zuo, J. Y., Mullins, O. C., Freed, D., & Zhang, D. (2010). A simple relation between solubility parameters and densities for live reservoir luids. *Journal of Chemical Engineering*, 2964 - 2969.