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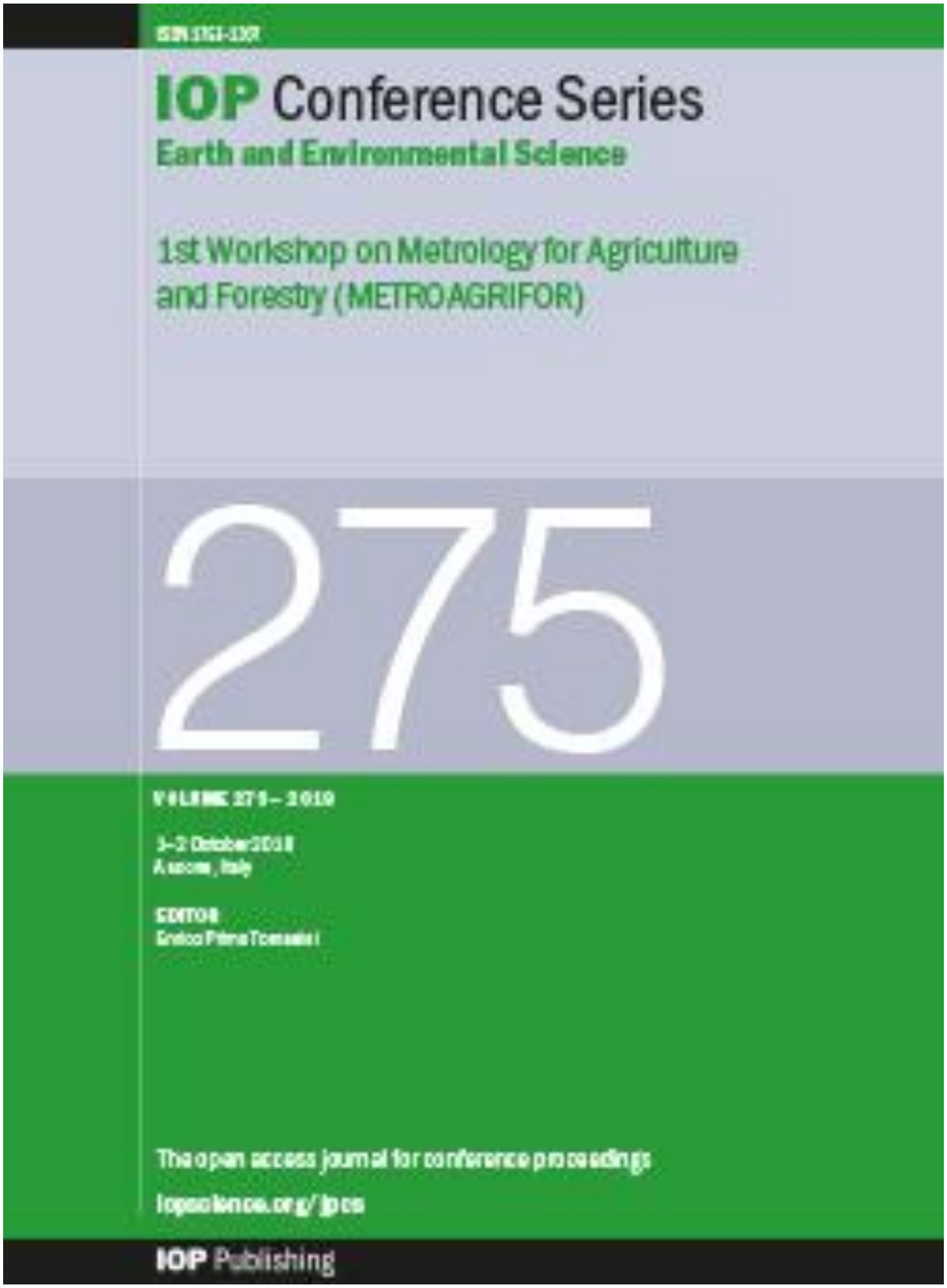

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Preface

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6TH International Conference of Earth Science, Mineral and Energy
ICEMINE
"Accelerating the Advancements in Lower Carbon Energy for A Sustainable Environment"
2023

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Preface

Greetings and a warm welcome to the expansive compilation of research and scholarly contributions presented in the Proceedings of the ICEMINE 2023. In the spirit of intellectual exploration and collaboration, this voluminous collection encapsulates the diverse and profound discussions that unfolded during the conference. As we delve into the following pages, readers will encounter a comprehensive exploration of knowledge, innovation, and interdisciplinary collaboration within the overarching theme of ICEMINE 2023.

ICEMINE 2023 is the 6th International Conference hosted by the Faculty of Mineral Technology, Universitas Pembangunan Nasional "Veteran" Yogyakarta, Indonesia. The conference was held at Grand Keisha Hotel, Yogyakarta, Indonesia, on the 9th of November 2023. The theme of this year's program is *"Accelerating the advancements in lower carbon energy for a sustainable environment"*.

We extend our appreciation to our esteemed partner university, whose unwavering dedication and scholarly contributions have significantly enriched the contents of this conference proceedings. In collaboration with our partner universities, Trisakti University and PEM Akamigas, UPN Veteran Yogyakarta creates an academic platform that fosters diverse perspectives, innovative ideas, and interdisciplinary exchange. Their insightful research and collaborative spirit have undeniably elevated the quality of discourse within our academic community, fostering an environment conducive to intellectual growth and innovation.

Furthermore, we would like to express our profound gratitude to our sponsors, whose generous support has been pivotal in bringing this event to success. Their unwavering commitment to advancing research and cultivating intellectual exchange underscores the importance of their role in shaping the trajectory of our academic disciplines.

Reflecting on Sustainability in Indonesia

In recent years, the imperative to decrease carbon emissions and shift towards energy sources with lower carbon footprints has become exceptionally crucial. Emphasizing the importance of transitioning to cleaner energy sources is paramount for preserving our environment and addressing climate change. The significance of advancing lower carbon energy technologies cannot be overstated, as they play a vital role in mitigating the adverse impacts of climate change and ensuring a sustainable environment for future generations. As scholars and researchers, we carry a distinct responsibility to accelerate the development of these technologies, driving innovation, encouraging critical thinking, and offering the expertise and solutions needed to forge a more sustainable future.

The chosen theme for ICEMINE 2023, *Accelerating the advancements in lower carbon energy for a sustainable environment,* resonates with the evolving landscape of academic inquiry and technological advancement. This theme has served as a catalyst for researchers to delve into various aspects, spanning the theoretical frameworks to practical applications. The rich tapestry of this proceedings volume mirrors the comprehensive exploration undertaken by the conference participants, representing a mosaic of perspectives that collectively contribute to the ongoing narrative of Sustainability.

Within this volume lies a plethora of research, articles, case studies, and theoretical explorations carefully curated from the vast pool of submissions and presentations at the conference. These contributions, emanating from a global community of earth science scholars, reflect the breadth and depth of insights shared during ICEMINE 2023. The contributions cover a wide spectrum of earth sciences, which are:

1. Geological Science and Engineering
2. Geophysics, Geomatics and Geochemistry
3. Earth Resources Project Evaluation and Valuation
4. Petroleum and Geothermal Engineering
5. Mining and Metallurgical Engineering
6. Taxation and Policy
7. Conservation, Geoheritage and Geopark
8. Disaster Management
9. Reclamation and Environmental Issues

Navigating the future: a vision for what lies ahead

As we engage with the contents of this proceedings volume, let us not only celebrate the documented achievements but also contemplate the trajectory of our respective fields. The ideas presented here have the potential to seed new research directions, innovative solutions, and transformative advancements. Readers are encouraged to interact critically with the content, fostering discussions and collaborations that transcend traditional academic silos. The interdisciplinary nature of the contributions invites us to explore the intersections of knowledge, where groundbreaking ideas often emerge from the convergence of diverse perspectives. May the knowledge shared within this volume inspire future generations, spark new avenues of inquiry, and contribute to the advancement of our collective understanding.

Cordially yours,

Dr. Widyawanto Prastistho

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KEYNOTE SPEAKERS

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BEST PRESENTERS

Naufal Setiawan	The Prospect of Typhoon Landfall Observation Utilizing L-band InSAR	Geomatics Engineering UPNVY
Andra Y Ginting	The Effectiveness of Soil Washing as a Remediation Method on Oil Spill Contaminated Soil (Case Study: Wonocolo Traditional Oil Mine)	Environmental Engineering UPNVY
Muhammad Irvingia Al Farizzi	Telomoyo Volcano Complex Geotourism: An In-Depth Analysis and Future Development	Geological Engineering UPNVY
David Michael	Optimizing the Impact of Rheological Properties on Bentonite Prehydrated- Based Drilling Mud Through the Utilization of Prehydration	Trisakti University
Muhammad Naufal Hisya Himendra	Comparative Analysis of The Use Emulsion and Watergel Explosive on Fragmentation at PT Dahana Site Kaltim Jaya Bara, East Kalimantan	Mining Engineering, Trisakti University
Nungky N. Wijayanti	Determination of Perforation to Obtain the Optimum Rate in "NKY" Well Of "MWA" Field	Petroleum Engineering, UPNVY
Kyeong Park	Geoparks and Sustainability - Korean Case	Sungshin Women's University, South Korea

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"The 6th International Conference on Earth Science, Mineral, and Energy."

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Preface

Geological Science and Engineering

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The characteristics of produced oils in the miscible CO_2 displacement process

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The characteristics of produced oils in the miscible CO_2 displacement process

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Abstract. CO_2 flooding is an effective technique for enhancing oil recovery by changing the hydrocarbon fluid's characteristics. One of the fundamental mechanisms of the interaction between CO_2 and hydrocarbon fluid by miscible CO_2 injection is the extraction phenomenon of the hydrocarbon components by CO_2. It results in altered produced and residual oil characteristics. This study aims to examine the characterizations of produced oil during the process of CO_2 displacement. It is critical to anticipate any issues that can arise from miscible CO_2 flooding, such as asphaltene deposition. A light-dead oil sample from an Indonesian oil field was used in this investigation. The miscible CO_2 displacement process was conducted by a slim tube experiment at operating temperature of 90ºC and 70ºC, which represents the reservoir and surface temperature, respectively. The properties of produced oil were further characterized by analyzing the composition based on its polarity, including saturate, aromatic, resin, and asphaltene. The results show that increasing injection pressures decrease resin and asphaltene fractions in produced oil. Furthermore, the proportions of asphaltene and resin fractions in the crude sample exhibit a significant decrease when conducted at a lower temperature in comparison to when carried out at a higher temperature. This study helps to explain how the displacement process by CO_2 affects the properties of the produced oil.

1. Introduction

CO_2 flooding is an effective technique for enhancing oil recovery by changing the characteristics of the hydrocarbon fluid [1]–[3]. The extraction phenomenon of light to intermediate hydrocarbon due to CO_2 injection is a crucial process in the interaction between CO_2 and hydrocarbon fluid by miscible CO_2 injection [4]–[5]. Injecting CO_2 into the fluid reservoir alters the phase behavior of the reservoir fluid. It changes the properties of produced and residual oils [7]. Therefore, it has the potential for instability of crude oil that leads to asphaltene precipitation and deposition. Ashoori et al. (2017) examined the correlation between the instability of crude oil and its compositions using SARA fractions as a basis.

However, they did not consider how CO_2 flooding affected the properties of produced and residual oils [8]. Alimohammadi et al. (2019) reported that the introduction of CO_2 flooding can lead to the occurrence of issues [9]. The production system performance is negatively impacted by the problems with asphaltene deposition, which also lowers the efficiency of the recovery process both upstream and downstream. The adverse impacts of asphaltene precipitation and deposition include, for example, clogging of pore throats, and reduction of reservoir permeability. Moreover, the downstream portion's asphaltene precipitation or deposition causes flow facility obstruction, solids accumulation in storage containers, and safety valve fouling [11], [12]. Therefore, this study aims to investigate the characterizations of produced oil during the CO_2 displacement process. Understanding the characterizations of produced oil during the CO_2 displacement process is important to forecast and predict any possible problems due to miscible CO_2 flooding, such as asphaltene deposition and CO_2 flooding implementation. In order to achieve this objective, the CO_2 displacement process was conducted using a slim tube experiment at miscible conditions and operating temperatures representing reservoir temperature. The compositions of produced oils were then examined by their saturate, aromatic, resin, and asphaltene (SARA) fractions.

2. Materials and Methods

2.1 Materials

The light dead crude oil sample used in this study was taken from an Indonesian oilfield. Its density is 810.26 kg/m^3, and its specific gravity is 36.4°API, all of which were determined at standard temperature of 15.5°C (60°F) under ambient circumstances. The field's reservoir has an average temperature of 90°C, whereas the surface and reservoir have an average temperature of 70°C**.** The crude sample's composition, as presented in Table 1, was measured using Gas Chromatography. The IP-143 method was utilized to analyze the polarity of the crude sample, specifically to determine the proportions of saturate, aromatic, resin, and asphaltene (SARA). The fractions of saturate, aromatic, resin, and asphaltene in crude sample, are presented in Table 2.

Table 1. Compositional crude sample.

Carbon Number	mole (%)	Carbon Number	mole (%)
nC_6	0.00	nC_{24}	3.42
nC_7	2.26	nC_{25}	3.24
nC_8	3.85	nC_{26}	2.77
nC_9	7.28	nC_{27}	2.63
nC_{10}	9.13	nC_{28}	1.87
nC_{11}	6.58	nC_{29}	1.69
nC_{12}	5.30	nC_{30}	1.02
nC_{13}	4.75	nC_{31}	0.90
nC_{14}	4.62	nC_{32}	0.50
nC_{15}	4.57	nC_{33}	0.42
nC_{16}	4.10	nC_{34}	0.16
nC_{17}	3.97	nC_{35}	0.11
nC_{18}	3.95	nC_{36}	0.00
nC_{19}	4.23	nC_{37}	0.00
nC_{20}	4.04	nC_{38}	0.00
nC_{21}	4.25	nC_{39}	0.00
nC_{22}	4.31	nC_{40}	0.00
nC_{23}	4.10	Total Mole	100.00
MW (gram/mole)			187.7

Table 2. SARA Fractions of Crude Sample .

SARA Component (wt.%)	JTB
Saturate	61.6
Aromatic	26.4
Resin	6.9
Asphaltene	5.1
Total fractions	100.00

2.2 Experimental Apparatus

A slim tube apparatus with a silica sand pack calibrated to 230–310 µm silica and a maximum pore volume of 120 cc was utilized in the CO_2 displacement process experiment. The slim tube system used in this study can test the dynamic displacement process at reservoir conditions with a maximum temperature is 150ºC. The average porosity of sand pack is 0.35. The length and extrenal diameter of tube is 24 m and ¼ inch, respectively. Figure 1 shows the simplified of the slim tube apparatus diagram.

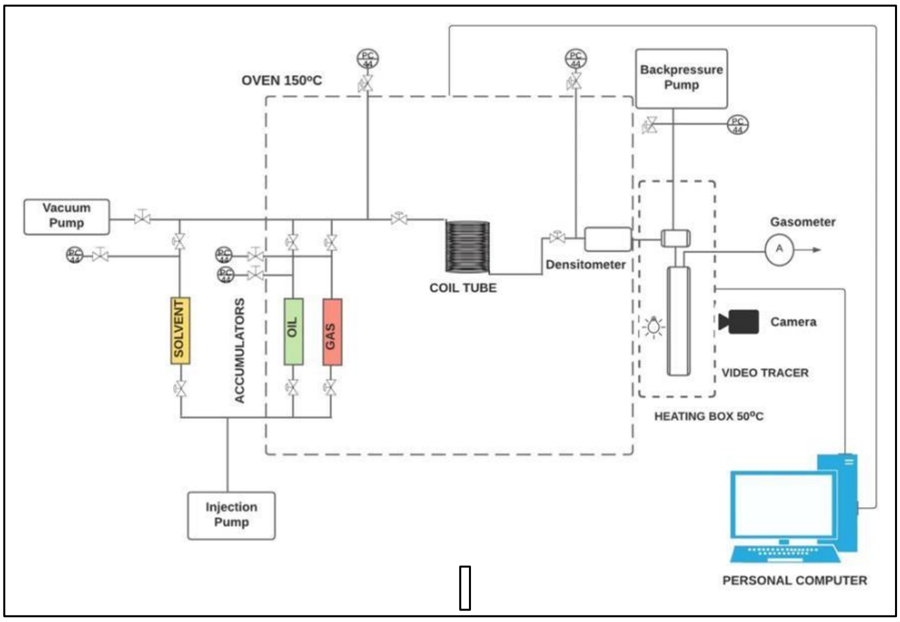

Figure 1. Simplified slim tube apparatus diagram.

2.3 Experimental Procedures

The general procedures and steps of the experiments are shown in Figure 2. Compositional analyses in this study were conducted to perceive the extraction phenomena of the light hydrocarbon component and the composition based on SARA fractions. The process of the CO_2 displacement was conducted using a slim tube test. The output of the slim tube experiment was recovery performance at each injection pressure. The produced oil from the slim tube test was then analyzed its compositions by gas chromatograph and its SARA fractions.

The dynamic CO_2 displacement process was conducted using a slim tube test at operating temperature of 90ºC, representing reservoir temperature and under the miscible condition. The operating pressures used in the displacement process are 1000 psi, 2000 Psi, 3000 psi, 4000 psi, and 5000 psi. The detail experimental procedures of the dynamic slim test refer to the author previous work [2]. The polarity components of the oil produced by CO_2 displacement, which include saturate, aromatic, resin, and asphaltene fractions (SARA), were further analyzed to examine the impact of dense CO_2's extraction of the hydrocarbon components. The ASTM D6560, referred to as IP-143, was used to measure the asphaltene fraction of the produced oil [13], [14]. In addition, the Minimum Miscibility Pressure (MMP) was determined by identifying the point of highest curve at a recovery factor of 1.2 Pore Volume (PV) gas injection and plotting it against pressure [15], [16]. A second attempt at the CO_2 displacement experiment was carried out at 70°C.

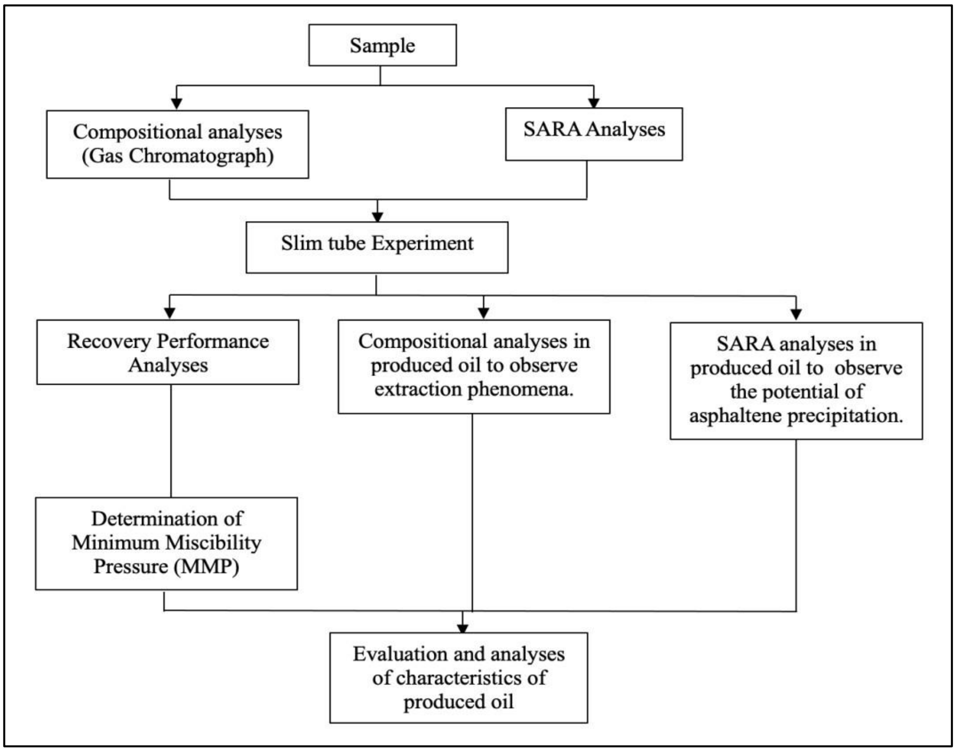

Figure 2. The steps of the experiments.

3. Results and Discussions

3.1 The Extraction of Light to Intermediate Hydrocarbon Component

The CO_2 displacement process leads to the extraction phenomenon of some component hydrocarbon, exceptionally light to intermediate components of hydrocarbon [4], [18]. The extraction phenomena of the intermediate component hydrocarbon by dense CO_2 can be seen from the compositional analysis of the original crude sample with various CO_2 displacement pressures at a temperature of 90°C, as shown in Figure 3. Figure 3 clearly shows that the mole percentage of intermediate components (C_6-C_9) reduces with increasing CO_2 displacement pressures. However, the component of C_{24}-C_{30} showed slightly higher with increasing CO_2 injection pressures than the original crude sample. The reduction of lighter hydrocarbon components from the crude causes an increase in the density of the fluids. It is possible for more asphaltene can enter the solution when the crude oil loses its light hydrocarbon components [11], [19]. Therefore, it requires further analysis of the produced oil's composition based on its SARA fractions. The discussion about compositions of produced oil based on its polarity will be discussed in the following chapter.

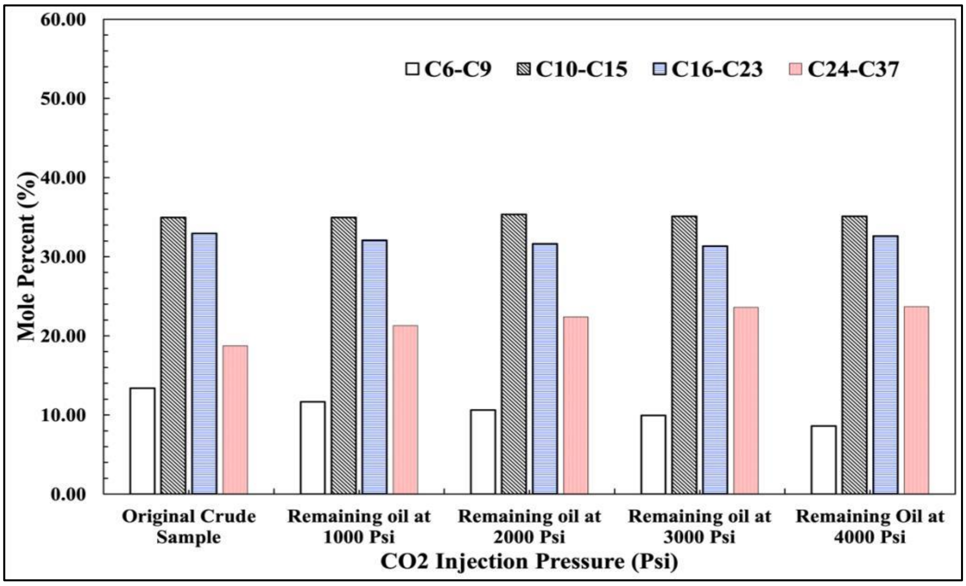

Figure 3. The extraction of hydrocarbon component by dense CO_2.

3.2 The Properties of Produced Oil

Figure 3 shows that during the CO_2 displacement process, CO_2 can precipitate asphaltenes in addition to extracting some component of the hydrocarbons. Hence, the properties and characteristics of the produced and residual oil may vary. The measured SARA fractions of the produced oil are shown in Figures 4 and 5, which were obtained from the slim tube's outlet following CO_2 breakthrough at various miscible injection pressures and temperatures. The SARA fractions of the residue oil are also compared to those of the original crude sample. It can be seen in Figure 4 that the wt.% of resins and asphaltene in the produced oil decreased with the increasing displacement pressures. Because more asphaltene precipitation occurs at a miscible CO_2 displacement pressure, the amount of asphaltene fractions in produced oil has decreased. These findings are consistent with the findings of Wang et al. (2015) [7]. In such cases, resins are a peptizing agent [9], [20]. The addition of CO_2 to the reservoir fluid alters its phase behavior [7], [21]. As a result, the quantity of asphaltene that forms solid deposits in porous materials rises in proportion to the injection pressure.

Figure 5 shows the same trend as Figure 4, that resins and asphaltenes fractions decrease with the increasing CO_2 injection pressures. Figure 5 demonstrates that the asphaltene fraction in the produced oil is lower at a temperature of 70°C compared to the wt.% of asphaltene fractions in the produced oil at a temperature of 90°C. It indicates that asphaltenes tend to precipitate at lower operating temperatures. It is possible because of the relationship between viscosity and temperature. The effective diffusivity of the particles increases with temperature as the mixture's viscosity lowers [22]. Consequently, the reduced viscosity at higher temperatures makes asphaltene in crude oil more stable.

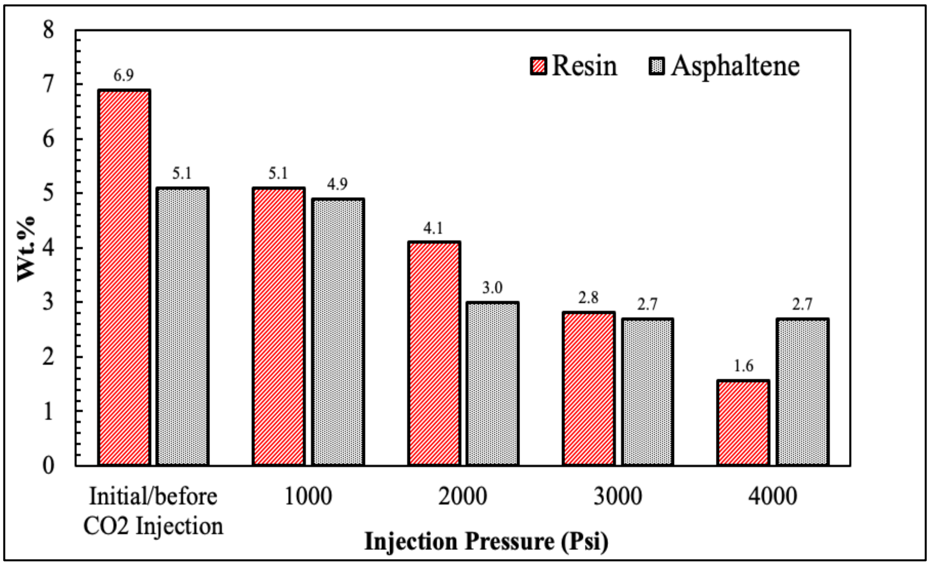

Figure 4. Weight percentage (wt.%) of resins and asphaltenes fractions of produced oil with injection pressures at 90°C.

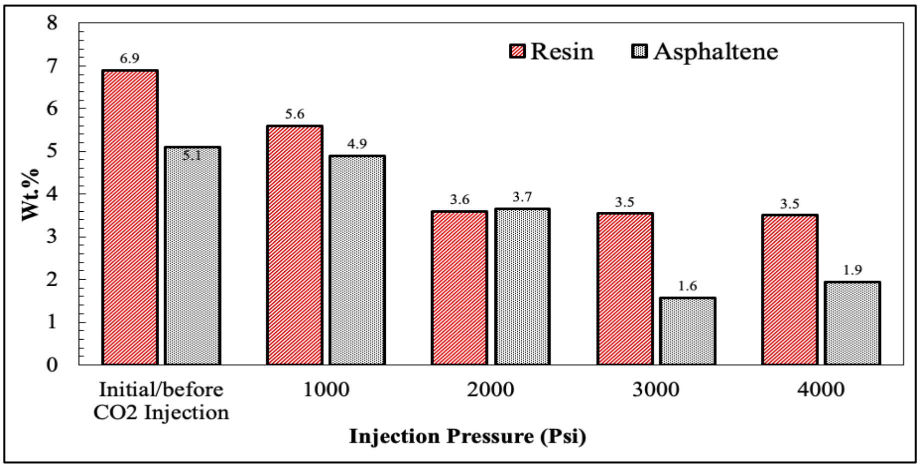

Figure 5. Weight percentage (wt.%) of resins and asphaltenes fractions of produced oil with injection pressures at 70°C.

3.3 CO_2 Displacement Performance

CO_2 floods were performed at two distinct temperatures and with varying miscible injection pressures. The performance of discplacement process was observed from the differential pressure performance, crude oil density during CO_2 flooding, and oil recovery. The oil recovery results are shown in Table 3. Table 3 shows that the oil recovery yielded from the CO_2 displacement process at a temperature of 70°C is lower than at 90°C. It indicates that asphaltene fractions were precipitated in porous media. The results align with the measured weight percentage (wt.%) of asphaltene fractions in produced oil, as shown in Figure 4 and Figure 5.

Table 3. Oil recovery results at temperature of 90°C and 70°C

Injection Pressures (Psi)	Recovery Factor (%) at 90°C	Recovery Factor (%) at 70°C
1000	45.84	47.48
2000	64	64.18
2500	76.3	-
3500	90.6	86.46
4000	-	87.93
5000	93.49	89.09

The CO_2 displacement process yields the recovery factor, which also indicates the MMP. The determination of the MMP is based on the studies conducted by Hudgins et al. (1990) and Glaso (1990) [15], [16]. The MMP results from the CO_2 displacement process at operating temperatures of 90°C and 70°C are ~3300 Psi and ~3100 Psi, respectively, as shown in Figure 6. It shows that for this case, even though the asphaltene fraction is more precipitated at lower temperatures, the MMP for higher temperatures (90°C) is higher than at temperatures of 70°C. Based on the MMP correlation developed by Orr and Jessen [23], the MMP results at operating temperatures of 90°C and 70°C are 3133 Psi and 2267 Psi, respectively. The MMP results between slim tube test and Orr and Jessen's correlation at 90°C shows a small discrepancy. This significant difference may occur due to the precipitation of asphaltene in the porous media, which interferes with the slim tube MMP measurements.

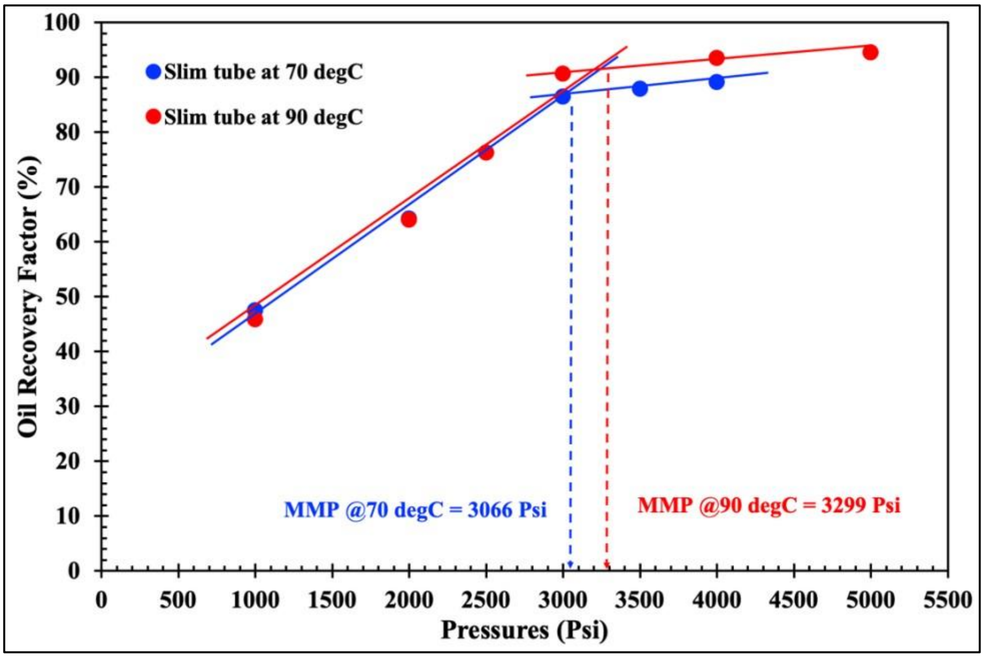

Figure 6. Minimum miscibility pressure (MMP) approximation from slim tube at 90°C and 70°C

4. Conclusions

The following are the conclusions based on the experimental findings.

1. The higher the CO_2 displacement pressure, the more resins and asphaltene are precipitated in porous media. Crude oil becomes unstable due to the decreasing in the resin and asphaltene components.

2. The amount of asphaltene fractions in produced oil has decreased because more asphaltene precipitation occurs at a miscible CO_2 displacement pressure.
3. Temperatures have a significant impact on asphaltene precipitation. The lower the operating temperature, the more potential to cause the precipitation of asphaltene in porous media.
4. At a lower temperature, the recovery factor obtained from the CO_2 displacement process is lower than that obtained at a higher temperature.

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by Kartika Hartono

Characterization of Produced Oils in the Miscible CO_2 Displacement Process

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Abstract. CO_2 flooding is one of the enhanced oil recovery methods that has been successfully proven to increase oil production by altering the properties of the hydrocarbon fluid. One of the fundamental mechanisms of the interaction between CO_2 and hydrocarbon fluid by miscible CO_2 injection is the extraction phenomenon of light to intermediate hydrocarbon by dense CO_2. It leads to changing the properties of produced and residual oils. This study aims to investigate the characterizations of produced oil during the CO_2 displacement process. It is crucial to forecast any possible problems that occur due to miscible CO_2 flooding, such as asphaltene deposition. In this study, a light-dead oil sample taken from an Indonesian oil field was used. The miscible CO_2 displacement process was conducted by a slim tube experiment at a temperature of 90°C, which represents the reservoir temperature and re-conducted at 70°C, which is the average temperature of the surface and the reservoir in the field. The properties of produced oil were further characterized by analyzing the composition based on its polarity (saturates, aromatics, resins, and asphaltenes). The results show that increasing injection pressures decrease resin and asphaltene fractions in produced oil. In addition, the asphaltene and resin fractions in the oil produced at a lower temperature significantly decrease compared to those at a higher temperature. This study provides an understanding of the properties changes of produced oils due to the displacement process during the CO_2 injection process.

Keywords: *CO_2 flooding, slim tube, asphaltenes, displacement process, extractions*

1. Introductions

CO_2 flooding is one of the enhanced oil recovery methods that has been successfully proven to increase oil production by altering the properties of the hydrocarbon fluid [1]–[3]. One of the fundamental mechanisms of the interaction between CO_2 and hydrocarbon fluid by miscible CO_2 injection is the extraction phenomenon of light to intermediate hydrocarbon by dense CO_2 [4]–[6]. When the CO_2 is injected into the fluid reservoir, the phase behavior of the reservoir fluid changes. It changes the properties of produced and residual oils [7]. Therefore, it has the potential for instability of crude oil that leads to asphaltene precipitation and deposition. Ashoori et al. (2017) investigated the relationship of crude oil compositions based on its SARA fractions to instability of crude oil. However, they did not investigate the effect of CO_2 flooding to the properties of produced and residual oils [8]. Sarma (2003) and Alimohammadi et al. (2019) reported that asphaltene problems can occur easily due to CO_2 injection [9], [10]. The asphaltenes deposition problems have a negative impact on the performance of production systems and cause a decrease in the efficiencies of the recovery, both upstream and downstream. For instance, blockage of pore throats, alteration of reservoir wettability, and decreased reservoir permeability are deleterious effects of asphaltene precipitation and deposition. Furthermore, asphaltene precipitation/deposition in the downstream portion results in the blockage of flow facilities, the formation of solids in storage containers, and the fouling of safety valves [11], [12]. Therefore, this study aims to investigate the characterizations of produced oil during the CO2 displacement process. Understanding the characterizations of produced oil during the CO_2 displacement process is important to forecast and predict any possible problems due to miscible CO_2 flooding, such as asphaltene deposition and CO_2 Enhanced Oil Recovery (EOR) implementation. In order to achieve this objective, the CO2 displacement process was conducted using a slim tube experiment at miscible conditions and operating temperatures representing reservoir temperature. The produced oils were then analyzed by their saturates, aromatics, resins, and asphaltenes (SARA) fractions.

2. Materials and Methods

2.1 Materials

The crude sample used in this study was light dead crude oil and collected from Indonesian oilfield. It has specific gravity of 36.4°API and density of 810.26 kg/m^3, measured under ambient conditions at a standard temperature of 15.5°C (60°F). The average reservoir temperature was 90°C and the average temperature of the surface and the reservoir of the field was 70°C. The composition of crude sample as shown in Table 1 was analyzed using Gas Chromatography. The crude sample was also analyzed based on its polarity to show the saturates, aromatics, resins, and asphaltenes fractions (SARA) using IP-143 method. the SARA fraction of crude sample is shown in Table 2.

Table 1. Compositional crude oil sample

Carbon No.	mol (%)	Carbon No.	mol (%)
nC_6	0.00	nC_{24}	3.42
nC_7	2.26	nC_{25}	3.24
nC_8	3.85	nC_{26}	2.77
nC_9	7.28	nC_{27}	2.63
nC_{10}	9.13	nC_{28}	1.87
nC_{11}	6.58	nC_{29}	1.69
nC_{12}	5.30	nC_{30}	1.02
nC_{13}	4.75	nC_{31}	0.90
nC_{14}	4.62	nC_{32}	0.50
nC_{15}	4.57	nC_{33}	0.42
nC_{16}	4.10	nC_{34}	0.16
nC_{17}	3.97	nC_{35}	0.11
nC_{18}	3.95	nC_{36}	0.00
nC_{19}	4.23	nC_{37}	0.00
nC_{20}	4.04	nC_{38}	0.00
nC_{21}	4.25	nC_{39}	0.00
nC_{22}	4.31	nC_{40}	0.00
nC_{23}	4.10	Total	100.00
Molecular Weight (g/mol)			187.66

Table 2. SARA Fractions of Crude Oil Sample

Component	JTB
Saturate (wt.%)	61.6
Aromatic (wt.%)	26.4
Resin (wt.%)	6.9
Asphaltene (wt.%)	5.1
Total (wt.%)	100.00

2.2 Experimental Apparatus

The CO_2 displacement process experiment used a slim tube apparatus with a silica sand pack calibrated 230-310 μm silica with a maximum pore volume of 120 mL. The slim tube system used in this study can test the dynamic displacement process at reservoir conditions with a maximum pressure of 10000 Psi and a maximum temperature of 150°C. The average porosity of sand pack is 0.35. The length and extrenal diameter of tube is 24 m and ¼ inch, respectively. The schematic diagram of slim tube apparatus is shown in

Figure *1*.

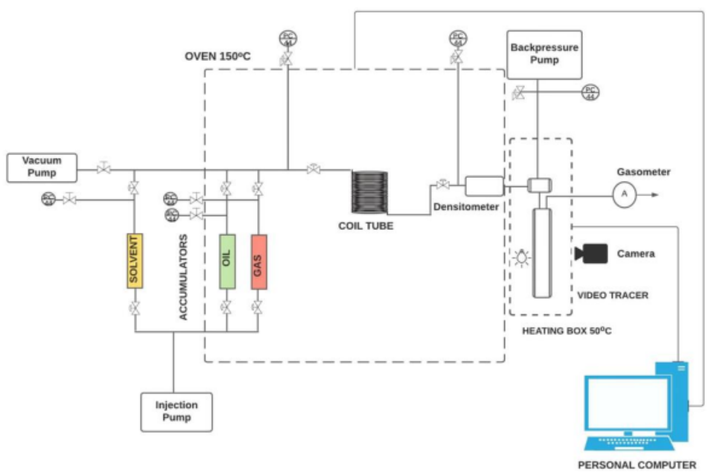

Figure 1. Schematic Diagram of Slim tube Apparatus

2.3 Experimental Procedures

The general procedures and steps of the experiments are shown in Figure 2. Compositional analyses in this study were conducted to observe the extraction phenomena of the light hydrocarbon component and the composition based on SARA fractions. The CO_2 displacement process was conducted using a dynamic slim tube test. The output of the slim tube experiment was recovery performance at each injection pressure. The produced oil from the slim tube test was then analyzed its compositions by gas chromatograph and its SARA fractions.

The dynamic CO_2 displacement process was conducted using a dynamic slim tube test at the operating temperature of 90°C, representing reservoir temperature and under the miscible condition. The operating pressures used in the displacement process are 1000 psi, 2000 Psi, 3000 psi, 4000 psi, and 5000 psi. The detail experimental procedures of the dynamic slim test refer to the author previous work [2]. The produced oil from CO_2 displacement was further analyzed based on their polarity components, which contain saturates, aromatics, resins, and asphaltenes fractions (SARA) to investigate the effect of the extraction light to intermediate hydrocarbon by dense CO_2 on the change composition of crude oil. The asphaltene content of the produced oil was measured by following the American Society for Testing and Materials method ASTM D6560, also known as IP-143 [13], [14]. Furthermore, the Minimum Miscibility Pressure (MMP) was determined from a distinct point of maximum curvature at an oil recovery of 1.2 PV gas injected and was plotted against pressure [15], [16] or near maximum recovery in a series of displacements [17]. The CO_2 displacement experiment was re-conducted at a temperature of 70°C, representing the average temperature of the surface and the reservoir of the field.

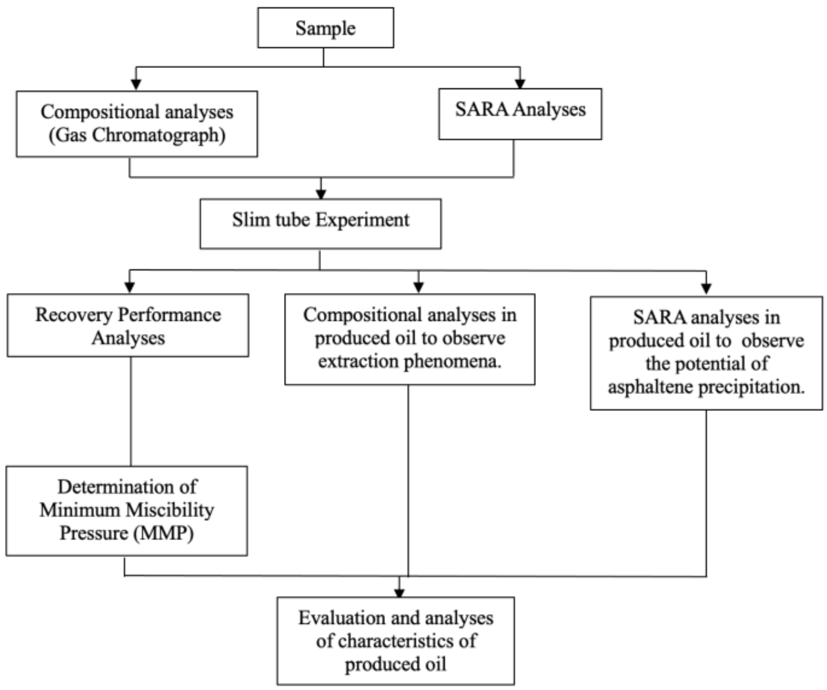

Figure 2. The Steps of the Experiments

3. Results and Discussions

3.1 The Extraction of Intermediate Hydrocarbon Component by Dense CO_2

The CO_2 displacement process leads to the extraction phenomenon of some component hydrocarbon, exceptionally light to intermediate components of hydrocarbon [4], [18]. The extraction phenomena of the intermediate component hydrocarbon by dense CO_2 can be seen from the compositional analysis of the original crude sample with various CO_2 displacement pressures at a temperature of 90°C, as shown in Figure 3. It is clear from Figure 3 that the mole percentage of intermediate components (C6-C9) reduces with increasing CO_2 displacement pressures. However, the component of C24-C30 showed slightly higher with increasing CO_2 injection pressures than the original oil sample. The reduction of lighter hydrocarbon components from the oil causes an increase in the density of the fluids. It is possible for more asphaltene can enter the solution when the crude oil loses its light hydrocarbon components [11], [19]. Therefore, it requires further analysis of the produced oil's composition based on its SARA fractions. The discussion about compositions of produced oil based on its polarity will be discussed in the following chapter.

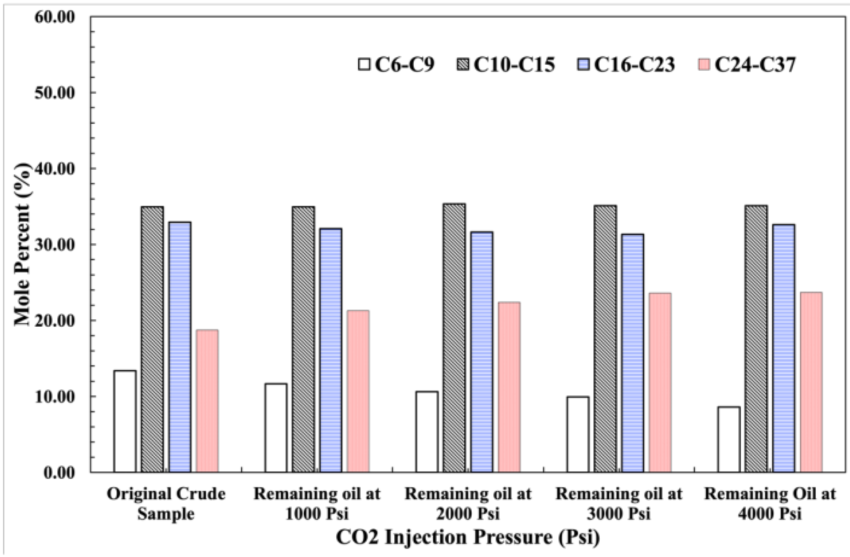

Figure 3. The Extraction of Hydrocarbon Component by Dense CO_2

3.2 Characterization of Produced Oil

In the CO_2 displacement process, CO_2 not only can extract light and intermediate hydrocarbon components, as shown in Figure 3, but also can lead to the precipitation of asphaltenes. Hence, the properties and characteristics of the produced and residual oil can change over production time. Figure 4 and Figure 5 show the measured saturates, aromatics, resins, and asphaltenes fractions (SARA) of produced oil collected from the outlet of the slim tube after CO_2 breakthrough under different miscible injection pressures and temperatures of 90°C and 70°C, respectively. The SARA fractions of produced oil are also compared to that of the original crude sample. It can be seen in Figure 4 that the weight percentage of resins and asphaltene in the produced oil decreased with the increasing displacement pressures. The decrease of asphaltene fractions in produced oil can be attributed to the fact that more asphaltene precipitation occurs under a miscible CO_2 displacement pressure. These results have the same observation with Wang et al. (2015) [7]. In such cases, resins are a peptizing agent [9], [20]. When the CO_2 is injected into the fluid reservoir, the phase behavior of the reservoir fluid changes [7], [21]. Therefore, as the injection pressure increases, the asphaltene precipitated in porous media increases.

Figure 5 shows the same trend as Figure 4, that resins and asphaltenes fractions decrease with the increasing CO2 injection pressures. However, it can be seen in Figure 5 that the weight percentage (wt.%) of asphaltene fraction in produced oil at a temperature of 70°C are lower than the weight percentage (wt.%) of asphaltene fractions in produced oil at a temperature of 90°C. It indicates that asphaltenes tend to precipitate at lower operating temperatures. It can be occurred because of the relationship between temperature and viscosity. As the mixture's viscosity decreases with increasing temperature, the effective diffusivity of the particles increases [22]. Therefore, at higher temperatures, the lower viscosity causes the asphaltene to become more stable in crude oil.

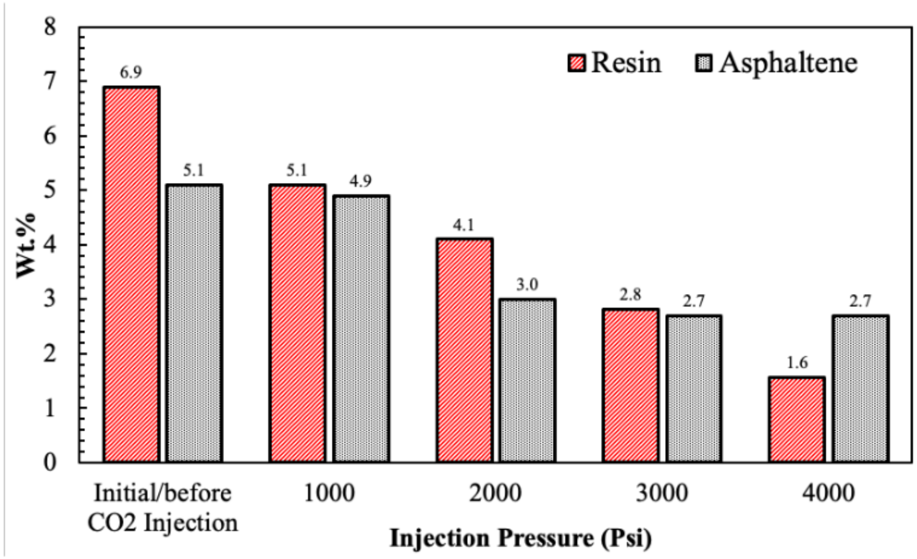

Figure 4. Weight percentage (wt.%) of resins and asphaltenes fractions of produced oil with injection pressures at 90°C

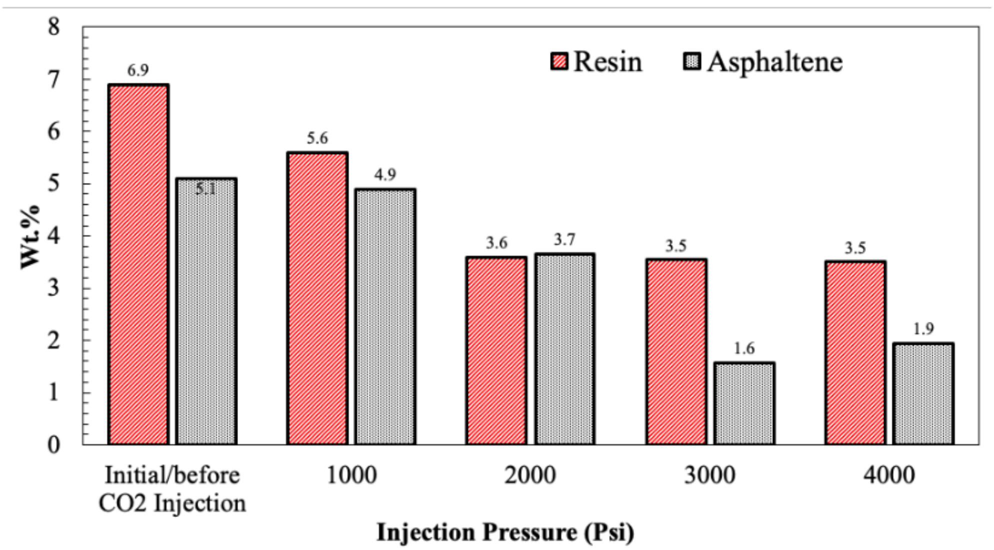

Figure 5. Weight percentage (wt.%) of resins and asphaltenes fractions of produced oil with injection pressures at 70°C

3.3 CO_2 Displacement Performance

CO_2 floods were conducted under different miscible injection pressures and two different temperatures. The performance of discplacement process was observed from the differential pressure performance, crude oil density during CO_2 flooding, and oil recovery. The oil recovery results are shown in Table 3.

Table 3 shows that the oil recovery yielded from the CO_2 displacement process at a temperature of 70°C is lower than at 90°C. It indicates that asphaltene fractions were precipitated in porous media. The results align with the measured weight percentage (wt.%) of asphaltenes fractions in produced oil, as shown in Figure 4 and Figure 5.

Table 3. Oil recovery results at temperature of 90°C and 70°C

Injection Pressures (Psi)	Recovery Factor (%) at 90°C	Recovery Factor (%) at 70°C
1000	45.84	47.48
2000	64	64.18
2500	76.3	-
3500	90.6	86.46
4000	-	87.93
5000	93.49	89.09

The recovery factor obtained from the CO_2 displacement process also shows the minimum miscibility pressure (MMP). As mentioned, the determination of the MMP refers to Hudgins et al. (1990) and Glaso (1990) [15], [16]. The MMP results from the CO_2 displacement process at operating temperatures of 90°C and 70°C are 3299 Psi and 3066 Psi, respectively, as shown in Figure 6. It shows that for this case, even though the asphaltene fraction is more precipitated at lower temperatures, the MMP for higher temperatures (90°C) is higher than at temperatures of 70°C. Based on the MMP correlation developed by Orr and Jessen [23], the MMP results at operating temperatures of 90°C and 70°C are 3133 Psi and 2267 Psi, respectively. The MMP results between slim tube test and Orr and Jessen's correlation at 90°C shows a small discrepancy. This significant difference may occur due to asphaltene precipitation in the porous media, which interferes with the slim tube MMP measurements.

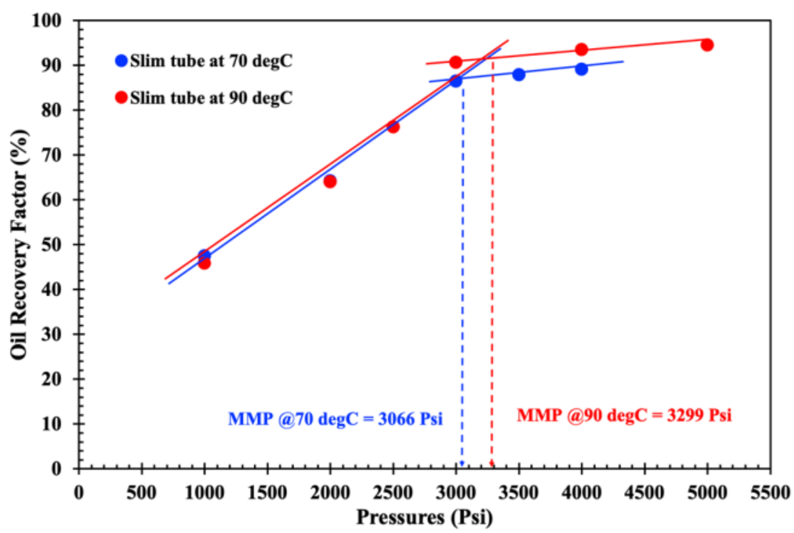

Figure 6. Minimum miscibility pressure (MMP) estimation from slim tube at 90°C and 70°C

4. Conclusions

According to the experimental results, the conclusions reached from this study are shown below.

1. The higher the CO_2 displacement pressure, the more resins and asphaltene are precipitated in porous media. The decreased resin and asphaltene fractions in crude oil causes the crude oil to become unstable.
2. The decrease of asphaltene fractions in produced oil can be attributed to the fact that more asphaltene precipitation occurs under a miscible CO_2 displacement pressure.
3. Temperatures have a significant impact on asphaltene precipitation. The lower the operating temperature, the more potential to cause the precipitation of asphaltene in porous media.
4. At a lower temperature, the recovery factor obtained from the CO_2 displacement process is lower than that obtained at a higher temperature.

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