



Full Length Article

Comparing the effects of CH₄, CO₂, and N₂ injection on asphaltene precipitation and deposition at reservoir condition: A visual and modeling study



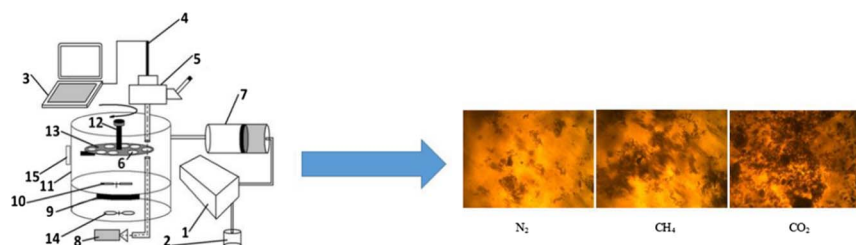
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GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:

Asphaltene precipitation
Enhanced oil recovery
Carbon dioxide injection
Nitrogen injection
Methane injection

ABSTRACT

Enhanced Oil Recovery (EOR) through various methodologies has been an active research for many years seeking efficient methods to increase the crude oil recovery efficiency from oil reservoirs. Among different gas injection scenarios, carbon dioxide (CO₂), natural gas (mainly methane (CH₄)) and nitrogen (N₂) injection are considered as promising EOR agents. Asphaltene precipitation and deposition during EOR methods cause severe problems, which affect the recovery efficiency and increase the cost of the incremental oil production. This study is aimed to investigate the effects of CH₄ and N₂ injection compared with CO₂ injection on asphaltene precipitation and deposition. The different mole percent of the mentioned gases were introduced into the high-pressure cell, then the amount of precipitated asphaltene was measured at the reservoir condition. The evolution of asphaltene deposition was monitored through a high-resolution microscope. Moreover, Image processing software was utilized to check the amount of deposited asphaltene and its size distribution under different conditions. The most apparent finding to emerge from this study is that both CO₂ and natural gas increase the amount of precipitated asphaltene whereas the nitrogen as an inert gas has no considerable effect on the amount of precipitated asphaltene. According to the results, the increment of precipitated asphaltene by CO₂ is much higher than natural gas. Further, the thermodynamic solid model used in this study reasonably predicted the trend of asphaltene precipitation process for the mentioned EOR scenarios.

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Nomenclature

Abbreviations

ASTM	American society for testing and materials
CH ₄	methane
CO ₂	carbon dioxide
EOR	enhanced oil recovery
g	gas
l	liquid
MW	molecular weight
N ₂	nitrogen
OOIP	original oil-in-place
P	pressure
SARA	saturated hydrocarbons, aromatics, resins and asphaltenes
T	temperature
v	vapor
V	volume

Symbols

b _i	equation of state parameter for component i
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d _{ik}	interaction coefficient between i and k
e	adjustable parameter
f _{ij}	fugacity of component i in phase j with translation
f _{ij} ^{eos}	fugacity of component i in phase j without translation
f _s	fugacity of pure solid
f _s [*]	reference fugacity of pure solid
n _c	number of components
P [*]	reference pressure
P _c	critical pressure
P _{ci}	critical pressure of component i
R	gas constant
s _i	dimensionless volume shift parameter for component i
T _c	critical temperature
T _{ci}	critical temperature of component i
V _c	critical volume
v _{ci}	critical volume of component i
v _{ck}	critical volume of component k
v _s	molar volume of pure asphaltene
v _j ^{eos}	EOS molar volume without volume shift
y _i	mole fraction of component i
Ω _b	dimensionless EOS parameter

1. Introduction

Crude oil mainly consists of various fractions such as resins, aromatic hydrocarbons, saturates, waxes and asphaltenes. Asphaltenes are one of the heaviest fractions in crude oil. On the basis of solubility, asphaltene is not soluble in light hydrocarbon solvents (n-alkenes), but can completely be dissolved in light aromatic hydrocarbons such as toluene, benzene, and xylene [1–4]. From the structural point of view, asphaltenes are polycyclic organic compounds with high molecular weight composed of aliphatic and aromatic structures [5–10].

Asphaltene precipitation and deposition pose significant problems which affect the production efficiency and increase operating costs [11]. It mostly changes the wettability of the reservoir rock from water-wet to the oil-wet condition that reduces the effectiveness of oil recovery [12–14]. Because of the naturally complex structure of asphaltene, it is difficult to thoroughly investigate the effects of asphaltene structure on the precipitation and deposition process. However, some recent studies have indicated that the tendency of asphaltenes to aggregate and precipitate on rock surface is mainly referred to their complex structure [12,15,16]. Speight et al. reported the effects of the aromaticity (hydrogen/carbon atomic ratio) and molecular weight of asphaltene on the amount of asphaltene precipitation [3]. Thus far, it has argued that the process of asphaltene precipitation from crude oil is an irreversible process [17,18]. A Proper understanding of the condition of asphaltene instability in different oil reservoirs can result in avoiding precipitation and deposition problems. There have been several methods to maintain the well flow during asphaltene precipitation in oil reservoirs. The expensive cost of treatments to remove the asphaltene deposition results in more attention of the industry and academic researchers finding the solutions to inhibit or reduce asphaltene precipitation in recent years [9,12,15,16,19]. It is essential to predict the onset and amount of asphaltene precipitation and deposition due to pressure, temperature and composition changes in oil reservoirs. It is worth mentioning that the changes in crude composition could happen during different enhanced oil recovery (EOR) methods.

The residual oil saturation after primary and secondary recovery is about 50–60% of the original oil in place (OOIP) [20,21]. EOR methods have become the most common approach after the primary and secondary oil recovery to enhance the recovery of heavy hydrocarbon from a reservoir [22–24]. The main mechanisms of EOR processes can contribute to 1) improving the sweep efficiency by decreasing the mobility

Table 1
SARA tests of the crude oil used in this work.

Test name	Results (wt%)
Saturates	38.74
Aromatics	50.59
Resins	6.17
Asphaltene	4.25

Table 2
Specifications of synthetic oil components.

Components	Synthetic oil (mol%)
C ₇ H ₈	75
n-C ₇	23
Asphaltene	2
Total	100

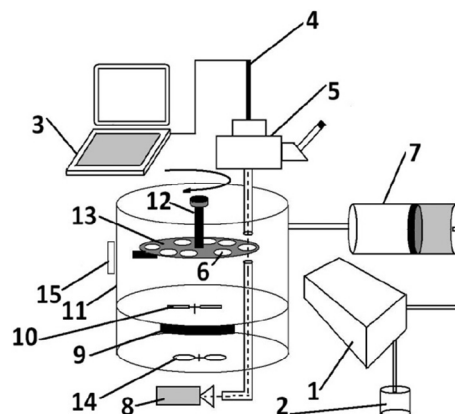


Fig. 1. Schematic diagram of the designed high-pressure experimental set-up [15]: (1) peristaltic pump, (2) distilled water reservoir, (3) computer, (4) CCD camera, (5) microscope, (6) sight glass, (7) piston-cylinder, (8) cold light source, (9) heater, (10) magnetic mixer, (11) high-pressure cell, (12) rotator, (13) metal disc, (14) fan, (15) magnetic device.

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