Journal of Natural Gas Science and Engineering 29 (2016) 37–45

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

Investigation of gas injection flooding performance as enhanced oil recovery method

Mehdi Bayat [a], Mostafa Lashkarbolooki [b,*], Ali Zeinolabedini Hezave [a], Shahab Ayatollahi [c]

[a] *Islamic Azad University, Dashtestan Branch, Borazjan, Iran*
[b] *School of Chemical Engineering, Babol University of Technology, Babol, Iran*
[c] *School of Chemical and Petroleum Engineering, Sharif University of Technology, Tehran, Iran*

ARTICLE INFO

Article history:
Received 30 September 2015
Received in revised form
25 December 2015
Accepted 27 December 2015
Available online 30 December 2015

Keywords:
CO_2 sequestration
Deposition
EOR
Live crude oil
IFT

ABSTRACT

Asphaltene precipitation and deposition within the reservoir formation is one of the main concerns during enhanced oil recovery (EOR) processes especially during the gas injection. In the current study, different aspects of carbon dioxide (CO_2) and nitrogen (N_2) injection in the reservoir, was thoroughly examined. The feasibility of using these gases as the injection gas was explored using Bayesian network-based screening method. After recombination and preparation of the live crude oil, precipitation of asphaltene using vanishing interfacial tension (VIT) method and core flooding experimentation was examined. Besides, swelling test was utilized to investigate the effect of CO_2 and N_2 injection on the expansion of live crude oil. The obtained results showed that recovery factor (RF) of CO_2 injected method in core flood test is higher than N_2 injection due to higher swelling and better miscibility conditions. Although, VIT measurements showed asphaltene precipitation during CO_2 injection, no sign of asphaltene deposition during core flood test at near bubble point pressure was observed.

1. Introduction

The selection and implementation of any enhanced oil recovery (EOR) method requires careful studies considering possible risks concerning sweep efficiency (microscopic and volumetric) and formation damage (Green and Willhite, 1998). In general, it has been accepted that the sweep efficiency during EOR processes is highly affected by asphaltene precipitation, especially during gas injection process (Escrochi et al., 2013). In general, asphaltene precipitation is one of the major problems during petroleum production especially if the presences of the adsorbed asphaltenes do not remove from the system since it accelerates the precipitation (Vralstad et al., 2008). Asphaltene precipitation may lead to fouling, pore blockade, and wettability alteration within the formation and adversely affects the sweep efficiency (Roosta et al., 2009; Sayyad Amin et al., 2010; Mansoori and Elmi, 2010; Kord et al., 2012). In this regard, it is crucially necessary to consider the asphaltene precipitation and deposition within the formation for any application of EOR methods. Nevertheless, it is necessary to carefully monitor the oil recovery factor regardless of the oil reservoir characteristics respect to the different aspects of asphaltenes precipitation. The worth mentioning point is that there is a close relation between the possibility of asphaltene precipitation, which may affect the main oil recovery mechanisms and understanding of the different aspects of the gas injection process into the oil reservoir must be carefully investigated (Escrochi et al., 2013).

Generally, the core-flooding experiments provide applicable insights into the mechanisms of oil recovery under reservoir flow conditions. Generally, using any kind of gas may lead to different recovery mechanisms including gas dissolution into the crude oil, oil extraction, and wettability alteration of core surfaces during the gas injection, and pore block due to asphaltene precipitation and deposition. While, several researchers reported that the injection of gas into reservoir enhances the risk of asphaltene precipitation (De Boer et al., 1995; Kalantari-Dahaghi et al., 2008; Roshanaei-Zadeh et al., 2011). Respect to these facts, it is crucially recommended that a detailed investigation on any new production scenario must be carried to select proper injection fluid and operational condition consequently reduces the risk of asphaltene precipitation.

On the other hand, it is accepted that there are three different parameters namely component extractions, asphaltene precipitation, and asphaltene accumulation at the interface which are the main parameters affecting the miscibility (Escrochi et al., 2013).

* Corresponding author.
E-mail address: m.lashkarbolooki@nit.ac.ir (M. Lashkarbolooki).

http://dx.doi.org/10.1016/j.jngse.2015.12.047
1875-5100/

From the beginning, since the miscible gas injection is able to minimize the trapped oil by manipulating the capillary forces is one of the main potential EOR processes utilized worldwide. In the light of this advantage, for most of the light and medium oil reservoirs injection of carbon dioxide (CO_2) or hydrocarbon solvents is considered as the most effective EOR processes (Arshad, 2009). Regarding the several advantages of the gas injection, it is crucial to measure the minimum miscibility pressure (MMP) for an oil–solvent system with acceptable accuracy (Dong et al., 2001; Christiansen and Kim, 1987). Besides, it was in the early 1980s that the rising bubble approach gaining an increasingly attention as an efficient method to measure MMP (Christiansen and Kim, 1987). In addition, Harmon and Grigg (1988) proposed a new experimental method to measures the density of the injection-gas-rich upper phase in contact with stock tank oil as a function of pressure which was applicable for low temperatures. A similar approach was proposed years before by Orr and Jensen (1984) in which the pure solvent achieves liquid-like densities. In the light of the aforementioned method it was possible to directly measure interfacial tension of an oil–solvent mixture at reservoir conditions consequently lead to a rapid means of determining MMP (Gasem et al., 1993). Due to the necessity of measuring the MMP, researchers are always seeking for new, accurate and easy-to-perform method which is recently lead to a method called vanishing interfacial tension (VIT) of oil–solvent mixtures (Kechut et al., 1999; Zolghadr et al., 2013 a&b). This method is proposed as a new and novel method for the determination of the MMP at the end of the 20th century (Zolghadr et al., 2013 a & b; Rao, 1997; Rao and Lee, 2002; Rao et al., 2003; Ayirala and Rao, 2006). Typical non-hydrocarbon gases utilize in miscible and immiscible processes, are namely carbon dioxide (CO_2) and nitrogen (N_2). Among different EOR methods, gas injection particularly CO_2 and N_2 injection are considered as one of the most promising and attractive methods (Peterson, 1978; Christian, 1981; Clancy, 1985; Holm, 1987; Sheng, 2015). These gases are usually injected separately and have been rarely utilized together as a tertiary recovery process.

Among the aforementioned gases, N_2 can be more desired due to low cost, and availability compared with the CO_2, but the vital point is the miscibility of used gas which enhance the chance of CO_2 application in oil recovery process. In addition, the global concern about the greenhouse gas effect on the global warming makes CO_2 as a proper injecting agent to recover trapped oil which gives benefits from CO_2 storage point of view (Hussen et al., 2012; Karimnezhad et al., 2014). Also, supercritical fluid extraction has received wide attention during the past few decades for different potential application (Ahmadi Sabegh et al., 2012; Lashkarbolooki et al., 2011 & 2013). Carbon dioxide is one of the most important supercritical solvents that widely is used for practical applications due to its unique and green features including non-toxic, non-flammable, cheap, high availability, low critical temperature and pressure that make it a good candidate for EOR processes (Rajaei et al., 2013; Zeinolabedini Hezave et al., 2013).

Considering the aforementioned facts, in the first step, the feasibility of gas injection (N_2 and CO_2) was initially explored using Bayesian network-based screening method. After that, the obtained results during the injection of supercritical CO_2 (SC-CO_2) and supercritical N_2 (SC-N_2) were compared to find which method is the best. With the best knowledge of the authors, the majority of the performed core flooding experiments are involved with gas injection (CO_2 and N_2) into the systems containing dead oil. However, in the current study, the gas injection was performed on the systems containing live oil which more the results toward more realistic conditions. Beside the core flooding tests, asphaltene precipitation during CO_2 and N_2 injection was investigated with the assist of VIT method. furthermore, to examine the impact of oil swelling mechanism during the SC-CO_2 and SC-N_2 injection as a tertiary oil recovery method on additional oil recovery, several oil swelling tests on the live-crude oil using a PVT apparatus were performed as well.

1.1. Screening

Generally, EOR processes are divided into four categories: thermal, gas, chemical, and other (Green and Willhite, 1998). Higher oil prices and concerns about future oil supply are leading to increase interest in EOR around the world. So, extensive researches have been conducted to develop various EOR methods, evaluate their applicability and optimize operation conditions (Chukwudeme and Hamouda, 2009; Zerafat et al., 2011). But, since EOR projects are generally more expensive and involve higher front end costs than conventional secondary projects, one of the principal areas is to develop an effective tool for selection of a suitable EOR method according to oil field characteristics (Zerafat et al., 2011). Screening criteria was initially presented in a series of tables and simple graphs (Taber et al., 1997 a & b; Taber and Martin, 1983; Goodlett et al., 1986; Adsani and Bai, 2011). In recent years, simulation methods, artificial intelligence and neural networks have improved the EOR screening methods. For this purpose, intelligent screening method based on Bayesian network (based on Zerafat et al., 2011 method) was used to find the proper EOR methods. Bayesian network quantitative learning technique was applied to different data combinations from the data bank to train the network which is to serve as the expert system. A full description of the used method is given elsewhere (Zerafat et al., 2011).

2. Experimental section

2.1. Materials

CO_2 (purity > 99%) and N_2 (purity > 99%) were supplied from Abughadareh Industrial Gas Company, Iran. The composition of the live crude oil and the properties of the corresponding oil field used in this work are listed in Table 1 and Fig. 1, respectively. The cores used in this study were prepared from outcrop of the target formation rock in south of Iran. The majority of the rock content was determined to be dolomite based on the XRD test analysis. The porosity of the cores was measured using Porosimeter, Vincci Tech. Company, France. The porosity of the used core was obtained 17.3 and 16.9 for CO_2 and N_2 injection test, respectively. In addition, permeability of the rock samples used in this study was determined using Darcy's law for the flow of fluids in porous media. The

Table 1
The properties of crude oil and the oil field.

Porosity (core analysis)	3.4–18.7	%
Density	31.2	API
Bubble point pressure	1879	Psi
Oil gradient	0.32	Psi/ft
Water gradient	0.47	Psi/ft
Oil pressure (datum = 2311 m.S.S)	4345	Psi
Temperature (datum = 2311 m.S.S)	212	Deg. F
Salt (Standing)	150,000	Ppm
K (fracture)	9–350	Md
Average Oil Saturation	21	%
Formation Type	Carbonate	–
Layer Thickness	500	M
Solution gas oil ratio (GOR)	601	Scf/STB
Oil viscosity	0.74	CP
Oil formation volume factor @ sat. pressure	1.4245	Rbbl/STB
Oil formation volume factor @ res. pressure	1.3897	Rbbl/STB