APPLICATIONS OF CARBON DIOXIDE FOR HEAVY OIL ENHANCED OIL RECOVERY VIA VAPOUR EXTRACTION PROCESS

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To My beloved wife and daughter

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ABSTRACT

Recently production of heavy oil and bitumen is become an interesting subject for petroleum engineers to enhance oil recovery from these reservoirs. Vapor extraction (VAPEX) is a promising enhanced oil recovery (EOR) technique that has not been performed in an oil field. Infeasibility of VAPEX process in large scale applications is due mainly to economic issues. Conventional used solvents such as propane and butane in this process are priceless components and utilizing them on a large scale is not considered economical. One attractive option to reduce the process cost is utilizing carbon dioxide (CO_2) with the solvents. The high solubility of CO_2 in heavy oil provides a higher reduction in oil viscosity. Methodology which has been used in this project is experimental and simulation. By making sandpack and using, different solvent mixtures including propane, methane, and CO_2 is tried to investigate the behavior of CO_2 as non-condensable carrier gas, co-solvent, and solvent in laboratory condition (ambient temperature and 7 bar). Also all same situation is assumed for simulation by CMG (Computer Modeling Group) In contrast of previous studies, it was found that CO2 is not a good candidate as non-condensable carrier gas for the VAPEX. However, CO_2 behavior is similar to propane. Hence, CO_2 can be considered as a good alternative for the priceless solvents to extract heavy oil and also the use of CO_2 provides substantial environmental benefits.

ABSTRAK

Pada masa ini, pengeluaran minyak berat dan bitumen dari reservoir minyak melalui proses perolehan minyak tertingkat (EOR) menjadi subjek yang menarik kepada Jurutera Petroleum. Ekstraksi wap (VAPEX) adalah teknik EOR yang mempunyai harapan tetapi masih belum dilaksana di lapangan minyak. Ketidaklaksanaan proses VAPEX dalam penggunaan berskala besar adalah terutamanya disebabkan isu ekonomi. Penggunaan pelarut konvensional seperti propana dan butana, yang merupakan komponen berharga, dalam proses ini dan penggunaanya dalam skala besar adalah dianggap tidak ekonomi. Salah satu pilihan menarik bagi mengurangkan kos proses adalah melalui penggunaan karbon dioksida (CO2) yang dicampur bersama pelarut. Kebolehlarutan yang tinggi CO2 dalam minyak berat menyebabkan pengurangan yang banyak pada kelikatan minyak. Kaedah yang digunakan dalam projek ini adalah terdiri daripada kajian eksperimen dan simulasi. Dengan menggunakan padatan pasir dan campuran pelarut berbeza, termasuk propana, metana dan CO2, telah digunakan untuk mengkaji sifat CO2 sebagai gas pembawa tak boleh mampat, co-pelarut dan pelarut yang dijalankan dalam sekitaran makmal (suhu bilik dan tekanan 7 bar). Dengan menggunakan situasi yang sama, kajian simulasi juga digunakan dengan menggunakan CMG. Terdapat perbezaan berbanding kajian terdahulu iaitu didapati CO2 bukanlah pilihan yang baik sebagai gas pembawa tak mampat untuk VAPEX. Namun begitu, didapati sifat CO2 adalah mempunyai kesamaan dengan propana. Dengan demikian, CO2 boleh dianggap sebagai pilihan yang baik kepada pelarut berharga untuk menekstraksi minyak berat. Disamping itu juga, penggunaan CO2 akan memberi faedah kepada alam sekitar.

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SOR	A function of the ratio of the net injected volume of the liquid solvent
V	volume of the displaced oil
ν	The vaporized solvent fraction in the reservoir
α	The net amount of cumulative SOR depends on rock and fluid Properties
Q	Drainage rate
K	function of the permeability
g	Acceleration due to gravity
H	Drainage height
φ	Porosity
ΔS_O	The oil saturation change
N_S	VAPEX dimensionless number
$\Delta\rho$	Density difference between the pure solvent and the mixture
μ	Mixture viscosity
Ds	Solvent diffusion coefficient in the mixture
C_S	Solvent concentration
Cmax	Maximum solvent concentration, volume fraction
Cmin	Minimum solvent concentration, volume fraction
Csf	Concentration of suspended solid in the oil phase
Pop	Approach pressure

CHAPTER 1

INTRODUCTION

1.1 Research Background

With increasing energy demand and declining oil production from conventional oil reservoirs, attention has turned to production from heavy oil and bitumen resources and to enhanced oil recovery (EOR) techniques that are suitable for these types of reservoirs. Heavy oil and bitumen comprise approximately 70% of the hydrocarbon resources in the world (Motahhari *et al.*, 2011). These resources are globally distributed. However, most resources have been reported in Canada, 2.5 trillion barrels (bbls), Venezuela (1.5 trillion bbls), Russia (1.0 trillion bbls), and the U.S. (180 billion bbls) (Foo *et al.,* 2011). Natural oil recovery from these resources does not exceed 6 to 8% of initial oil inplace because of high oil viscosity and low oil mobility (Butler and Mokrys, 1991; Yazdani and Maini, 2005; Roopa and Dowe, 2007).

Oil production techniques from heavy oil reservoirs are divided into two main groups: thermal and non-thermal processes. Thermal processes are the first option to enhance heavy oil production because the viscosity of oil is very temperature-sensitive. In-situ combustion (ISC), hot water injection, steam-assisted gravity drainage (SAGD), and cyclic steam stimulation (CSS) are famous processes used to extract heavy oil and bitumen resources. However, these techniques are not sufficiently feasible for many heavy oil reservoirs from economic or operational perspectives. For example, steam injection is not suitable for deep reservoirs or reservoirs with a very thin pay zone, a low thermal conductivity of the rock matrix, a bottom water zone, an overlying gas zone, and high water saturation. Furthermore, converting water to steam and using special pumps and casings incurs operational expenditures that are not economically practical anymore. Therefore, the development of new extraction techniques has become essential.

Over the past twenty years, many researchers have attempted to develop novel techniques with greater applicability and lower cost investments. The vapor extraction (VAPEX) process, which was developed by Butler and Mokrys (1989), is such a technique. VAPEX is a non-thermal process that has become an attractive alternative for the recovery of heavy oils because of lower capital costs, low environmental pollution, low energy consumption, applicability to thin reservoirs or reservoirs with bottom water, and in situ upgrading compared to thermal processes (Das, 1995; Luhning *et al.*, 2003; Karmaker and Maini, 2003; Azin *et al.*, 2005; Vargas-Vasquez; Romero-Zeron, 2007). The process is analogous to the SAGD process. However, VAPEX reduces the heavy oil viscosity by mass transfer phenomena via a light hydrocarbon solvent, such as propane (C_3) or butane (C_4), instead of heat transfer phenomena via steam. The VAPEX process consists of a pair of production and injection wells that are horizontally drilled into the heavy oil zone. The selected solvent is injected through the injection well into the reservoir and creates a chamber above the injection well. This chamber continues to expand until the cap rock (or a barrier bed) is reached, after which the chamber continues to spread along the cap rock (see Figure 1.1a). When the solvent chamber along the cap rock is sufficiently large in size, the solvent is driven downward into the production well by the gravity force. The expansion of the solvent chamber during the VAPEX process is shown schematically in Figure 1.1b.

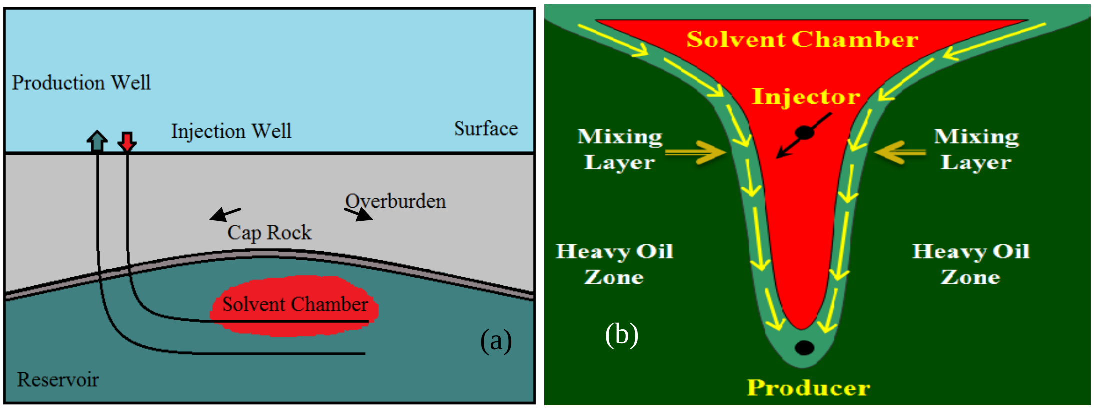

Figure 1.1 (a) Schematic of the layout of the production and injection wells in the VAPEX process; (b) Vertical cross section of the VAPEX process showing solvent chamber, horizontal producer and injector

The VAPEX process has not yet been applied in an oil field and all VAPEX studies were performed in small cells under laboratory conditions. It is believed that the unfeasibility of the VAPEX process in large scale applications is due mainly to economic issues followed by operational issues. Both problems are caused by the use of pure solvents such as propane and butane which are priceless components and utilizing them on a large scale is not considered economical. Furthermore, the vapor pressure of propane and butane, 930 and 642.7 kpa at 23.9° c, respectively, is much lower than the average pressure and temperature of many oil reservoirs. As a result, these solvents condense at pressures greater than their vapour pressures. Solvent condensation during the process results in increasing the amount of solvent required and decreasing the process efficiency to extract heavy oil (Azin *et al.*, 2008; Das, 2008; Derakhshanfar *et al.*, 2009).

Butler *et al.* (1995) recommended the use of non-condensable gases, such as methane, nitrogen or carbon dioxide (CO_2), in combination with pure solvents to solve both economic and operational problems. According to Butler *et al.*, there are three advantages to applying a non-condensable gas. First, the process would become more economically feasible by minimizing the solvent requirements. Second, solvent diffusion rate would be promoted, which could lead to oil upgrading during the process. Third, the higher the density difference between the solvent mixture and the heavy oil would improve gravity drainage during the VAPEX process.

The CO_2 is considered to be the major greenhouse gas (GHG) contributing to global warming (Lei *et al.,* 2011) and increasing in the atmospheric concentration since the industrial revolution. There seems to be general agreement to reduce the GHG emissions and alternative solutions for coping with the increased GHG emissions must be sought (Talbi and Maini, 2003). The use of greenhouse gases (GHGs) for EOR has significant impact in reduction of these emissions. CO_2 has the greatest contribution to global warming over other GHGs. The use of CO_2 based VAPEX for the EOR is one of the EOR applications. CO_2 is considerably more soluble in heavy oil than methane and is known to provide greater viscosity reduction on its own (Talbi and Maini, 2003).

In some research studies CO_2 was used as a non-condensable carrier gas (Talbi and Maini, 2003; Badamchi-Zadeh *et al.,* 2008; Derakhshanfar *et al.,* 2009; Javaheri and Abedi, 2011). However, operational pressures and temperatures as well as porous media features applied in these studies could not represent the conditions of most of heavy oil reservoirs. In addition, no attempts have been made to apply CO_2 as a co-solvent or even as a solvent during the VAPEX tests. In all previous VAPEX studies in which CO_2 was used, it is assumed that CO_2 considers as a non-condensable carrier gas. In this study, VAPEX process is run in an unconsolidated sandpack to determine the CO_2 behavior as non-condensable carrier of gas, co-solvent, and solvent.

1.2 Problem statement

VAPEX is a promising enhanced oil recovery (EOR) technique that has not been performed in an oil field. Infeasibility of VAPEX process in large scale applications is due mainly to economic issues. Conventional used solvents such as propane and butane in this process are priceless components and utilizing them on a large scale is not considered economical. One attractive option to reduce the process cost is utilizing carbon dioxide (CO_2) with the pure solvents. In some research studies CO_2 was used as a non-condensable carrier gas (Talbi and Maini, 2003; Badamchi-Zadeh *et al.,* 2008; Derakhshanfar *et al.,* 2009; Javaheri and Abedi, 2011). However, no attempts have been made to apply CO_2 as a co-solvent or even as a solvent during the VAPEX tests.

1.3 Objectives

In this study, two objectives have been considered:

1. To evaluate CO_2 behavior as non-condensable carrier gas for extraction of heavy oil compared to methane.
2. To determine the CO_2 behavior as co-solvent and solvent in the VAPEX process.

1.4 Scopes

For this study the following scopes are considered:

1- Preparation of a cubic sandpack with 38.1*2.54*15.24 cm dimensions in terms of length, width, and height.
2- Sandpack characterization (determination of porosity and permeability).
3- Using propane and methane as solvent and carrier gas, respectively.
4- Applying Heavy crude oil from the Soroosh oil field in tests.
5- Using CO_2 as a co-solvent and solvent.
6- Running VAPEX tests at the ambient temperature.
7- Increasing pressure up to 7 atm.
8- To evaluate the obtained experimental data using a commercially available software, Computer Modeling Group (CMG).
9- Finding an optimum solvent mixture for extraction of heavy oil via VAPEX.

1.5 Significance of study

Heavy oil and bitumen reserves represent a considerable portion of worldwide energy resources. It is estimated that these reservoirs contains six trillion barrels of original oil inplace (OOIP) which is much further than the total conventional oil reservoirs. Highly energy consumption and demands cause the attention turn to exploration from heavy oils and bitumens. In optimum conditions, the primary recovery of these reservoirs would not exceed 10 percent of the OOIP. Thus, utilizing some new techniques to produce oil from heavy oil reservoirs are essential. VAPEX as good technique can help to produce heavy oils with higher quality. However, due to economic problems this technique has not been performed in an oil field. Using CO_2 along the conventional solvents such as propane and butane cause the process would become more economically feasible by minimizing the solvent requirements. Furthermore, presence of CO_2 in the solvent mixture can produce heavy oils with higher qualities and provide substantial environmental benefits.

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