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A new solvent-based enhanced heavy oil recovery method: Cyclic production with continuous solvent injection

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HIGHLIGHTS

- We tested a new enhanced heavy oil recovery technique, named cyclic production with continuous solvent injection (CPCSI).
- 1-D and 2-D experimental tests were conducted to test the performance of this process.
- The oil recovery factor for this process can reach 80%.
- Compared with the classical VAPEX process, the oil recovery factor is increased by 11%.

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ABSTRACT

This paper presents a new enhanced heavy oil recovery (EHOR) process, Cyclic Production with Continuous Solvent Injection (CPCSI). In this process, a vapourized solvent near its dew point is continuously injected into the reservoir to maintain reservoir pressure and also supply extra gas drive to flush the diluted oil out through an injector that is located on the top of the reservoir; while a producer, which is located at the bottom of the reservoir, is operated in a shut-in/open cyclic way. A series of experiments have been conducted to evaluate the CPCSI performance. The recovery factors (RFs) are up to 85% of original oil in place (OOIP) in 1-D tests, and the RF is improved by 11% by using the 2-D lateral CPCSI, compared with the traditional 2-D lateral VAPEX. Well configurations and the producer shut-in/open scenarios are key optimization factors that affect the CPCSI performance. Experimental results show that the foamy oil flow and solvent trap are the two major EHOR mechanisms for enhancing the oil production rate during the production period. In comparison with continuous injection process, such as vapour extraction (VAPEX), and cyclic injection process, such as cyclic solvent injection (CSI), CPCSI offers free gas driving, and the reservoir pressure is maintained during the producer opening period so that the diluted oil viscosity is kept low. This work shows that CPCSI could be an alternative optimization production scenario for applying solvent based in situ EHOR techniques for heavy oil reservoirs in Western Canada.

1. Introduction

Heavy oil and bitumen resources are key to fulfilling increasing demand for hydrocarbon fuels consumption all over the world. The untapped heavy oil and bitumen deposits are over five times greater than the remaining conventional crude oil reserves, and are estimated at 5.6 trillion barrels [1]. Canada contributes about 50% of these untapped heavy hydrocarbon deposits, which are located in Western Canadian Sedimentary Basin. Thermal methods, such as cyclic steam stimulation (CSS) and steam-assisted gravity drainage (SAGD), have been widely applied to produce heavy oil or bitumen from reservoirs with thick net-pays. However, for reservoirs in thin formations, with the presence of bottom water zones and/or with high water saturation in the pay zone, the thermal methods tend to be neither effective nor economical due to significant heat loss and large heating and water source requirements [2–4].

Non-thermal methods, including surface mining, cold heavy oil production (CHOP) or cold heavy oil production with sands (CHOPS), and solvent injection, are the other main techniques that are used to recover heavy oil. Surface mining is effective but it is only economically applicable to those reservoirs with a depth of less than 70 m. Only about 5% of the heavy oil reservoirs can be recovered with this technique [5]. CHOP/CHOPS can recover approximate 5–10% of the initial heavy oil in place, before becoming uneconomical because the pressure depletion and water encroachment [6]. Solvent injection techniques, such as vapour extraction (VAPEX) and cyclic solvent injection (CSI), use a vapourized solvent to extract heavy oil or bitumen deposits. A pure light hydrocarbon or a mixture of several light hydrocarbons or CO_2 is

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usually used as the solvent. The injected solvent is dissolved into the heavy oil to reduce the oil viscosity, in situ de-asphalting, so that the diluted oil can be produced by gravity drainage or pressure depletion [2,6,7].

VAPEX is analogous to the SAGD process where the steam is replaced with vapourized hydrocarbon solvent. The solvent vapour is injected through the upper horizontal well to create a solvent chamber, then dissolve into the heavy oil and the diluted oil will be produced from the lower horizontal well. VAPEX process has been extensively studied by many researchers [2,3,5,7–9]. It is reported that VAPEX process uses approximate 3% of the energy consumed by SAGD for the same production rate. It also cuts down the greenhouse gas emission by 80% [10,11]. Using vapourized solvent close to its dew point could provide a higher driving force for gravity drainage rather than liquid solvent [9]. However, the low production rates were observed in the field tests, particularly during the early stage, the slow mixing of solvent and heavy oil causes a extremely low initial rate [12]. For the thin reservoirs, the lack of gravity drainage also limits this process. To address those problems, a VAPEX configuration of laterally separated well pattern was introduced and tested to improve the VAPEX performance for thin reservoirs [4,13,14].

The traditional CSI process is also known as solvent huff-n-puff process, which comprises of several cycles and each cycle has three periods: an injection period, a soaking period and a production period [6,15–17]. The light hydrocarbon gas is injected into the reservoir to increase the reservoir pressure, part or portion of which is dissolved into the heavy oil to reduce the oil viscosity, and then the reservoir pressure is depleted to produce the diluted oil. The problems of this process are that: (1) the pressure drops rapidly so that the diluted oil may regain its viscosity while the dissolved solvent is released from the diluted oil, and also, (2) the severe formation energy loss during the pressure depletion. In addition, it needs a longer time for injecting and soaking, which might cause the average production to be relatively low in this process.

This study proposed an enhanced solvent injection EHOR technique for heavy oil recovery, called cyclic production with continuous solvent injection (CPCSI). The performance of CPCSI process was experimentally examined through 1-D and 2-D sand-pack physical models. The experimental results suggest that the RFs are up to 85% of OOIP in 1-D tests, and in the 2-D tests, the RF can be improved by 11% by using the CPCSI compared with classic lateral VAPEX.

2. Experimental section

2.1. Materials

In this study, the heavy oil sample obtained from an oil field located in Western Central Canada was used in all tests. The measured density and viscosity of this dead oil sample were $\rho_o = 980\ \mathrm{kg/m^3}$ and $\mu_o = 8411$ MPa s at atmospheric pressure and constant room temperature of 21 °C, respectively. Asphaltene content of the original heavy oil sample was measured by using the standard ASTM D2007 with No.5 Whatman filter paper with a pore size of 2.5 μm and found to be 18.88 wt%. Pure propane (Praxair, Canada, 99.99 mol%) was used as a solvent to extract the heavy oil. The experiments were performed at the room temperature (21 °C) and solvent injection pressure is generally maintained around 800 kPa, under which condition, the propane is in vapour phase close to propane's dew point at 21 °C. Potters glass beads with an average pore size of 90–150 μm was used to pack the physical sand-pack models homogeneously.

2.2. Experimental setup

Two different types of physical models were used in this study: small cylindrical physical models with different lengths; and a visual rectangular sand-pack high pressure physical model. The cylindrical models were with 3.8 cm in inner diameter and 34 cm, 63 cm and 93 cm in length, respectively. Two caps machined with 1/8 in. NPT ports to provide well placement. The visual rectangular model had a chamber size of $40 \times 10 \times 2\ \mathrm{cm^3}$ with a thin polycarbonate see-through plate and a thick acrylic glass plate to provide the visual observation during the test. The schematic diagrams of the experimental setup were shown in Figs. 1–3. The experimental tests were performed in different scenarios, which include 1-D vertical CPCSI, 1-D horizontal CPCSI, 2-D lateral VAPEX and 2-D lateral CPCSI.

The solvent injection system consisted of a propane cylinder, a pressure reducing regulator, a digital pressure gauge, a solvent injection valve and an injector. The gas reducing regulator was set to the constant operating pressure for all tests and the propane cylinder was left open to provide continuous propane vapour during the entire test. A digital scale with a large scale range (KILO TECH, KWS 301) was used to measure the amount of the solvent injection for the entire test run. The sample collection system was consisted of a producer, a back-pressure regulator (BPR), a ball valve and a sample collecting flask. The back pressure regulator (Equilibar, EB1ZF1) was adjusted to maintain the pre-specified operating pressure. Another digital scale with a small scale range was used to measure the weight of produced cumulative oil. A high-precision digital pressure transducer (HEISE, PM1L, PPM-2-DIGPSI 3000A Sensors) was connected to the model to precisely measure the pressures of both injector and producer simultaneously.

2.3. Experimental preparations

To conduct the experimental test, physical model was first packed with dry Potter glass beads. After a proper sand-pack model was established, the porosity was measured, and a leakage test was conducted using CO_2. Distill water was then injected to displace the CO_2. The permeability of the physical model was also measured at this time. Then, heavy oil sample was injected into the sand-pack model to displace the distill water. In this way, the condition of initial water and initial oil saturations was established in the

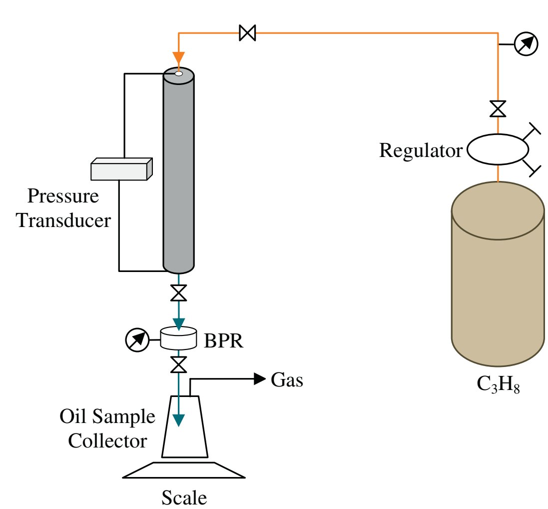

Fig. 1. Schematic diagram of 1-D vertical CPCSI (V-CPCSI) setup.