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Gasflooding-assisted cyclic solvent injection (GA-CSI) for enhancing heavy oil recovery

Xinfeng Jia, Fanhua Zeng *, Yongan Gu

Petroleum Systems Engineering, Faculty of Engineering and Applied Science, University of Regina, Regina, Saskatchewan S4S 0A2, Canada

HIGHLIGHTS

- A new process to improve cyclic solvent injection performance in heavy oil recovery.
- This process combined the advantages of both continuous solvent injection and cyclic solvent injection process.
- Extensive laboratory experimental studies suggested the oil production rate can be improved by 3 times.

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ABSTRACT

Cyclic solvent injection (CSI) process has showed great potential to enhance heavy oil recovery because it takes advantages of solution-gas drive and foamy oil flow for oil production. However, CSI suffers from solvent release during the production period so that the viscosity of the solvent-diluted heavy oil is re-increased and its mobility is re-decreased. How to effectively recover the solvent-diluted heavy oil becomes a key technical challenge in a CSI process. This paper first experimentally analyzed a conventional CSI process that used a solvent injector as an oil producer alternately. It is found that foamy oil was induced and flowed to the producer during the production period of a cycle but some foamy oil was pushed back by solvent during the solvent injection period of the following cycle. Such "back-and-forth" movement of foamy oil seriously hindered the productivity of the CSI process. On the basis of this knowledge, this study proposed a new process, gasflooding-assisted cyclic solvent injection (GA-CSI), to enhance the performance of CSI. In a GA-CSI process, the solvent injector and the oil producer were placed horizontally apart. An additional solvent gasflooding process was applied immediately after the pressure drawdown process to produce the foamy oil that lost its mobility due to solvent release. The experimental results showed that the oil production rate of the newly proposed GA-CSI process is 3–4 times of that for a conventional CSI process.

1. Introduction

A large number of heavy oil and bitumen reserves exist in thin reservoirs in western Canada, such as the Lloydminster area. Cold heavy oil production with sands (CHOPS) is a major primary production method for these reservoirs, which only recovers approximately 5–15% of the original-oil-in-place (OOIP) of heavy oil reservoirs in western Canada [1,2]. Afterwards, CHOPS reaches its economic limit due to quick reservoir pressure depletion or severe water encroachment to the production well [3]. How to effectively recover the residual oil left in these thin heavy oil reservoirs becomes a major technical challenge. Thermal-based techniques, such as steam-assisted gravity drainage (SAGD) [4], cyclic steam stimulation (CSS) [5], and in-situ combustion (ISC) [6], are not suitable for these thin heavy oil reservoirs due to large heat losses to the overburden and underburden formations. Some solvent-based techniques, such as cyclic solvent injection (CSI), emerge and show great potential to be a follow-up process of CHOPS in recent years.

The conventional CSI process uses a single well alternately as the solvent injector and as the oil producer to produce heavy oil in a huff-n-puff mode [7]. A typical CSI cycle consists of three periods: solvent injection, soaking, and oil production periods. First, a vaporized solvent is injected into a heavy oil reservoir to dilute heavy oil through solvent dissolution during its injection and soaking periods. Then the solvent injector is converted into an oil producer and the reservoir pressure is drawn down continuously to induce the so-called solution-gas drive and foamy oil flow, which move the solvent-diluted heavy oil to the producer. Various

* Corresponding author. Tel.: +1 (306) 337 2526; fax: +1 (306) 585 4855.
E-mail address: Fanhua.Zeng@Uregina.Ca (F. Zeng).

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experimental and simulation studies have been conducted to evaluate the potential of the CSI process [1,3,8,9].

Previous studies show that a major technical limitation of the conventional CSI process is the oil viscosity regainment due to solvent release and the associated oil mobility loss during pressure drawdown in the production period. To overcome this technical shortcoming, some variations of CSI, such as enhanced cyclic solvent process (ECSP) [10] and cyclic production with continuous solvent injection (CPCSI) [11], have been proposed and studied in recent years. In the ECSP process, two solvent gases were used: one was more volatile (methane) and the other was more soluble (propane). The purpose of the ECSP was to use the volatile gas to provide expansion and the soluble one to keep the oil viscosity low during the production period. However, experiments showed that the operation scheme of ECSP was effective only during the early stage of the production period. Composition analysis of the produced gas in a CSI test with a solvent mixture (28 vol.% propane + 72 vol.% carbon dioxide) [3] showed that propane outweighed carbon dioxide in molar percentage during the early stage of the oil production period. This suggested that propane might not stay in the oil to keep its low viscosity as expected in the ECSP. The CPCSI intended to produce the solvent-diluted heavy oil by a gasflooding process. During its production period, a small pressure difference between the injector and the producer was maintained to control the solvent exsolution and oil viscosity regainment. The major technical merit of CPCSI is that it applied a stronger driving force (solvent gasflooding) for oil production. However, other important heavy oil recovery mechanisms, such as solution-gas drive and foamy oil flow, were not fully incorporated in the CPCSI, since both mechanisms require a large pressure drawdown to take place.

This paper conducted a series of laboratory experiments with two types of physical models. The conventional CSI process was first investigated and its disadvantages were analyzed and summarized. Accordingly, a new process, namely, gasflooding-assisted cyclic solvent injection (GA-CSI), was proposed. In comparison with CSI, GA-CSI used two-well configuration and a stronger oil production mechanism to recover the foamy oil, which would lose its mobility due to solvent release in CSI. The detailed experimental results showed considerable superiority of GA-CSI over CSI in terms of both the average oil production rate and the ultimate oil recovery factor.

Table 1
Properties of the dead oil @ 1 atm and 20.2 °C.

Oil	Plover lake
Dead oil viscosity (cP)	5875
Dead oil density (g/cm^3)	0.976
Dead oil molecular weight (g/mol)	477
Dead oil asphaltene content (wt.%)	17.96

2. Experimental section

2.1. Materials

The crude heavy oil sample was collected from Plover Lake reservoir and its physical properties are given in Table 1. Propane with a stated purity of 99.5 mol.% (Praxair, Canada) was used as an extracting solvent. Standard industrial glass beads (Manus Abrasive, Canada) were used to pack the physical models.

2.2. Experimental set-up

Fig. 1a schematically shows the experimental set-up used in this study, which is comprised of four major operating units: a solvent injection unit, a physical model, a fluids production unit,

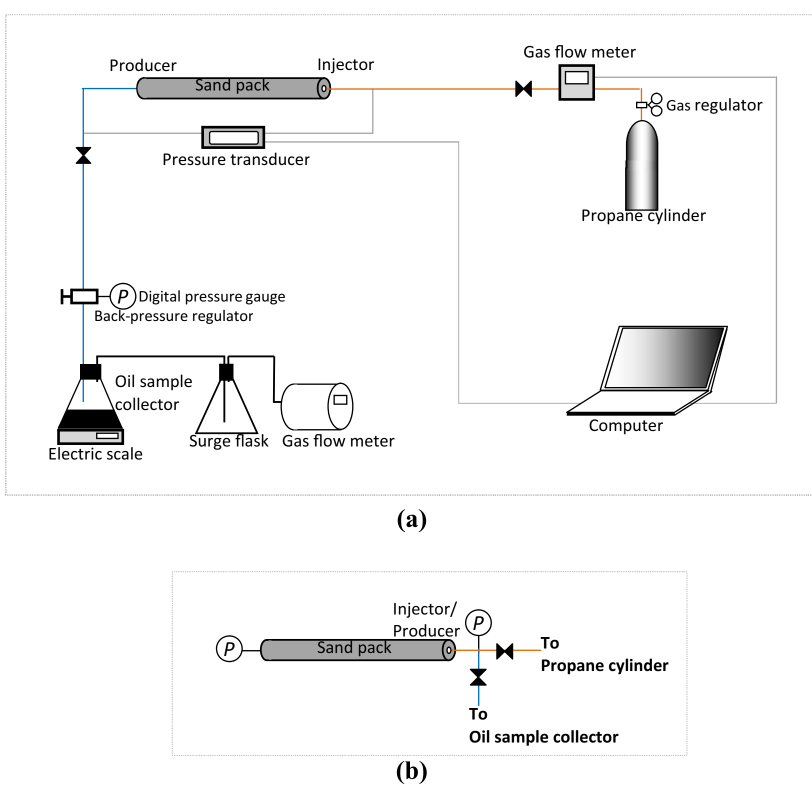

Fig. 1. Schematic diagrams of (a) experimental set-up with a cylindrical physical model and two-well configuration and (b) experimental set-up with a cylindrical physical model and one-well configuration.