Journal of Petroleum Science and Engineering 133 (2015) 862–868

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

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

Effect of bitumen viscosity and bitumen–water interfacial tension on steam assisted bitumen recovery process efficiency

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ARTICLE INFO

Article history:
Received 18 March 2014
Accepted 2 April 2015
Available online 11 April 2015

Keywords:
Steam assisted bitumen recovery
Solvent injection
Viscosity reduction
Bitumen–water interfacial tension
Biodiesel surfactant

ABSTRACT

Over 80% of Athabasca, Alberta, Canada oil sands deposits are suitable for in-situ bitumen recovery processes. Steam assisted gravity drainage and cyclic steam stimulation processes are commercially implemented with current bitumen production capacity of about 850,000 bbl/d, which is projected to exceed 5000,000 bbl/d in the next two decades. Efficiency of these processes would be improved by reducing the steam-to-bitumen ratio. For this purpose addition of light hydrocarbons into steam as a solvent to reduce bitumen viscosity has been studied for decades with a limited commercial success. As an alternate strategy to solvent co-injection with steam, reduction of bitumen–water interfacial tension by co-injection of a surfactant, such as biodiesel (fatty acid methyl esters), with steam was proposed (Babadagli et al., 2009. Use of biodiesel as an additive in thermal recovery of heavy-oil and bitumen. In: Paper 049 Presented at the Canadian International Petroleum Conference (CIPC), 16–18 June, Calgary, Alberta, Canada; Babadagli and Ozum, 2012. Oil Gas Sci. Technol.: Rev. IFP Energies Nouvelles 67 (3), 413–421). The present study focuses on three issues: (i) viscosity of bitumen in the neighborhood of the edge of the steam chamber using heat conduction models, where bitumen mobility should be controlled by viscosity and bitumen–water interfacial tension; (ii) generate bitumen recovery data, operating the steam chamber as a pressure cooker; where bitumen mobility should be controlled mainly by viscosity rather than bitumen–water interfacial tension, since the influence of the creeping flow of water-condensed steam is marginally small; and, (iii) measure bitumen content at different heights of the pressure cooker test spent core samples to predict bitumen mobility and permeability. Pressure cooker tests were performed using steam, steam and pentane as a solvent at 5%, 10% and 15% of bitumen by mass, and steam and biodiesel as a surfactant additive at 0.2% and 0.3% of bitumen by mass dosages. Our test results showed that solvent, such as pentane, addition reduced bitumen recovery as the dosage of solvent addition increased from 5% to 15% of bitumen. This observation is interpreted that while solvent addition reduces bitumen viscosity it also increases bitumen–water interfacial tension; the overall effect of which results in reduction of bitumen recovery efficiency. When biodiesel was used as a surfactant additive at 0.2% and 0.3% of bitumen by mass dosage, a slightly increase in bitumen recovery efficiency was observed. Bitumen mobility and bitumen permeability values predicted in this study were one order of magnitude smaller than that of the values reported in the literature; probably resulting from reduced bitumen–water interfacial tension, by the activation of natural surfactants contained in bitumen, promoting bitumen mobility in the field operations. Result of the present study suggests that further tests and modeling studies are needed to understand effects of bitumen viscosity reduction by solvent co-injection and bitumen–water interfacial tension reduction by surfactant co-injection with steam on the efficiency of steam assisted bitumen recovery processes.

1. Introduction

Oil sands in Alberta, Canada are the third largest hydrocarbon reserve in the world. In Alberta, bitumen is commercially produced from oil sands by either mining the sands for an ore-water slurry based extraction or by thermal in-situ processes, at about 1300,000 bbl/d and 800,000 bbl/d capacities, respectively.

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http://dx.doi.org/10.1016/j.petrol.2015.04.001
0920-4105/

One of the main obstacles to produce bitumen from deep formations is the high viscosity of bitumen, usually of over 10,000 mPa s at reservoir conditions. Bitumen viscosity is reduced by heating the reservoir with steam, electric heating or combustion methods as well as injecting diluents such as light hydrocarbons with steam. Several in-situ bitumen recovery processes have been developed; however, Cyclic Steam Stimulation (CSS) and Steam Assisted Gravity Drainage (SAGD) processes have had the most successful commercial application (Butler and Mokrys, 1989, 1991; Al-Bahlani and Babadagli, 2009; Nenninger and Gunnewiek, 2009; Stark, 2013; Zhao et al., 2005; Gupta and Gittins, 2006, 2012; Ayodele et al., 2009; Sharma and Gates, 2011; Jha et al., 2012).

Fluids flow in the reservoir exclusively by laminar viscous creeping flow mechanism which is correlated by the Darcy's equation (Hubbert, 1956), where $\underline{v}_j$, K_j and μ_j are the velocity (m/s), permeability (m^2) and viscosity (Pa s) of the jth fluid and ∇P is the pressure gradient (Pa/m):

$$\underline{v}_j = -\frac{K_j}{\mu_j}\nabla P \quad (1)$$

Steam assisted bitumen recovery processes are designed by assuming that bitumen mobility ($\underline{v}_B$) is controlled primarily by bitumen viscosity and gravity is the only force field. As a result, it is commonly accepted that solvents such as light hydrocarbons injected with steam would reduce bitumen viscosity and increase bitumen mobility. Significant work has been completed in laboratory and field scale tests and computer simulations on enhanced oil recovery (EOR) processes using solvents with limited commercial success.

Our experience with bitumen extraction in oil sands ore-water slurry systems prompted us to investigate the potential role of bitumen–water interfacial tension on the performance of SAGD processes (Babadagli et al., 2008). Our research was inspired by the fact that in SAGD processes two immiscible liquids, about 1 volume of bitumen and 3 volumes of water-condensed steam, flow in the pores of oil sands reservoir; therefore, bitumen–water interfacial tension should affect bitumen mobility.

We measured viscosity of bitumen and bitumen–pentane mixtures, and interfacial tension (IFT) between bitumen, bitumen–pentane (hydrocarbon solvent) mixtures and process water with and without biodiesel (*BD*, surfactant) additive (Argüelles-Vivas et al., 2012). In these tests both bitumen and process water samples without any chemical treatment were received from a SAGD plant in Alberta, Canada. Continuing from these studies, the present study focuses on three issues: (i) bitumen viscosity in the neighborhood of the edge of steam chamber by heat conduction models; (ii) steam assisted bitumen recovery tests using pentane as a solvent and using *BD* as surfactant additives, operating the test unit as a pressure cooker; and, (iii) interpretation of the spent ore bitumen content profile to predict mobility ($\underline{v}_B$) and permeability (K_B) of bitumen. The purpose of the present study is to redirect oil industry's attention on the potential role of bitumen–water interfacial tension on steam assisted bitumen recovery process efficiency.

2. Unsteady-state heat conduction model

Upon the tapping of the reservoir by steam and/or solvent injection, physical properties of the reservoir fluids start changing. Changes in the physical properties of the fluids result in alterations of the static (capillary forces versus pressure and gravity forces) and the dynamic (flow or mobility) characteristics of the fluids.

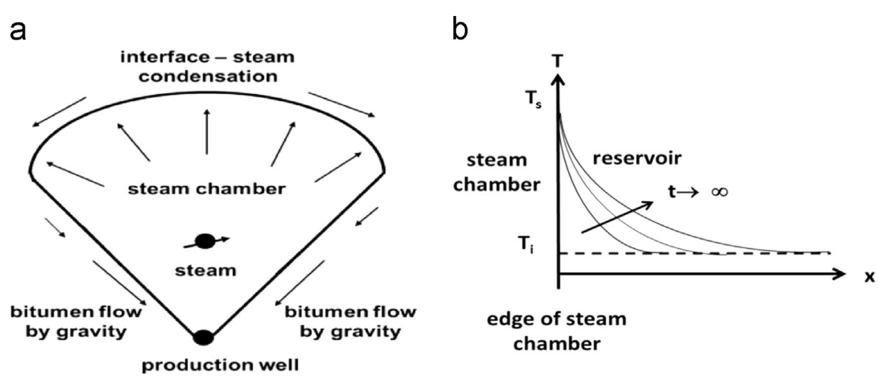

Fig. 1. Heat conduction in SAGD reservoir.

Table 1
Unsteady heat conduction predictions.

x (m)	*T*=60 °C (*ψ*=0.25) *η*=0.81			*T*=95 °C (*ψ*=0.43) *η*=0.50			*T*=180 °C (*ψ*=0.85) *η*=0.13		
	t (d)	Q_{Total} (kJ/m^2)	M_{Steam} (kg/m^2)	*t* (d)	Q_{Total} (kJ/m^2)	M_{Steam} (kg/m^2)	*t* (d)	Q_{Total} (kJ/m^2)	M_{Steam} (kg/m^2)
0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0
0.1	0.1	23,887	12.9	0.2	38,697	20.8	2.4	148,835	80.1
0.2	0.3	47,774	25.7	0.7	77,394	41.7	9.8	297,670	160.2
0.3	0.6	71,661	38.6	1.5	116,091	62.5	22.0	446,505	240.3
0.4	1.0	95,548	51.4	2.6	154,788	83.3	39.1	595,340	320.4
0.5	1.6	119,435	64.3	4.1	193,485	104.1	61.1	744,175	400.5
0.6	2.3	143,323	77.1	6.0	232,183	125.0	88.1	893,010	480.6
0.7	3.1	167,210	90.0	8.1	270,880	145.8	119.8	1041,845	560.7
0.8	4.0	191,097	102.9	10.6	309,577	166.6	156.5	1190,680	640.8
0.9	5.1	214,984	115.7	13.4	348,274	187.4	198.1	1339,515	720.9
1.0	6.3	238,871	128.6	16.5	386,971	208.3	244.6	1488,350	801.0