Journal of Petroleum Science and Engineering 154 (2017) 438–441

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

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

Editorial

Introduction to thermal Enhanced Oil Recovery (EOR) special issue

1. Introduction

Our dependency on fossil fuel increases not only because of our continuous and growing energy demand but also due to our rising need for carbon based products. Thus, the extraction of hydrocarbons from unconventional reserves is necessary to fill the growing gap between demand and production (DOE, 2016 and Conti and Holtberg, 2011). The global resources of low API gravity unconventional oil; namely, heavy oil, extra-heavy oil, and bitumen, in known accumulations amount to a total of around 9 trillion barrels. These vast resources are known as having high viscosity, low API gravity, and high asphaltenes content which make their recovery difficult in comparison to the extraction of oil from conventional reserves (USGS, 2007). The effective oil displacement for these high density oils is governed mainly by the viscosity reduction (Prats, 1982). Viscosity is defined as the resistance of a fluid to flow and is highly sensitive to temperature changes (Bird et al., 1960). As the temperature of the oil increases, due to drastic decrease in viscosity, oil mobility and consequently, oil recovery is enhanced (Raicar and Procter, 1984). Therefore, the effective extraction of these vast resources due to their high viscosity can only be achieved successfully by the application of thermal enhanced oil recovery (thermal EOR) methods.

During any thermal EOR method, heat is generated either at the surface or in-situ. The thermal EOR processes where heat is generated at the surface; mainly, hot water and steam injection processes, have wider applications due to their reliability (Sarathi and Olsen, 1992). Moreover, the implementation of different injection and production well orientations in steam injection processes make them effective in the recovery of low API gravity crude oils with all viscosity ranges. For instance, while steam is the injected EOR fluid in all steam flooding, cyclic steam stimulation (CSC), and steam assisted gravity drainage (SAGD) processes; the different well configurations used in each process make them more effective for the extraction of heavy oil, extra-heavy oil, and bitumen, respectively (Butler and Stephenes, 1981). However, since steam processes require the injection of high volume of fresh water and necessitate heating up water to generate steam by burning fuel which emits greenhouse gases (GHG); steam injection methods raise serious environmental concerns. Solvent-steam processes are proposed to mitigate the environmental footprints of steam injection processes (Hernandez and Farouq Ali, 1972 and Farouq Ali and Abad, 1976). Solvent-steam processes use less steam when compared to steam processes alone. Consequently, the reduced amount of steam generation in solvent-steam processes decreases the amount of emitted GHGs. Furthermore, solvent addition to a steam stream is expected to increase oil production due to the additional viscosity reduction maintained by the miscibility of solvents in oil. However, not all oil fractions are miscible with all kinds of solvents. Especially, the asphaltenes fraction of crude oils is insoluble in widely used solvents (CO_2, CH_4, and normal alkanes), and the asphaltenes soluble solvents (aromatics) are mainly toxic. Thus, solvent selection is critical for the success of solvent-steam processes (Hascakir, 2016).

Alternative to traditional steam injection processes, in-situ heat generation methods also show promises for the extraction of high viscosity oils. These methods are namely in-situ combustion (ISC) and electrical and electromagnetic stimulation methods. Using the ISC process, as high as 95% oil displacement can be achieved. Because the combustion front propagation is not easy to control, there are only a few successful full-field applications of ISC (Turta et al., 2005). The low success rate of ISC is mainly associated with the complicated nature of the combustion, oxidation, and cracking reactions and the highly heterogeneous nature of the oil reservoirs (Burger and Sahuquet, 1972). Electromagnetic heating methods target heterogeneous and thin reservoirs where viscosity reduction is necessary for oil displacement, but where effective oil recovery cannot be accomplished by any other thermal EOR methods; mainly due to fluid channeling in heterogeneous reservoirs, or excessive heat losses to the overburden and underburden in thin reservoirs (Chhetri and Islam, 2008). The electromagnetic heating methods are promising since the electromagnetic waves can be targeted to heat up the desired portion of a reservoir. However, controlling electromagnetic wave penetration and absorption is still a challenge.

To estimate the performance of thermal EOR methods, it is necessary to develop an understanding towards all transport phenomena concepts. Due to the involvement of heat introduction in thermal EOR methods, heat transport significantly contributes to oil displacement in porous media. However, the main heat transfer mechanism is different in each thermal EOR method; heat can be transferred by conduction, convection, radiation, or molecular level agitation. Viscosity dependence of flow in porous media can be expressed by using the fundamentals of momentum transport. Mass transport is also involved due to variation in interfacial tension, change in hydrocarbon phases (from liquid to gas, gas to liquid, liquid to solid, solid to liquid, and solid to gas), and occurrence of complex chemical reactions during the application of thermal EOR methods. Contribution of all these three complicated transport phenomena on oil displacement makes the thermal EOR processes complex and performance prediction difficult, which reduces their applicability.

http://dx.doi.org/10.1016/j.petrol.2017.05.026

Consequently, research studies on thermal EOR processes need to be strongly encouraged to capitalize on the true potential of thermal EOR methods for the recovery of low API gravity oils, and to meet future fossil fuel demands. This special issue aims to support research studies on these complicated thermal EOR methods. In this issue, we have 20 outstanding manuscripts which discuss the different aspects of thermal EOR methods.

The first study provides a review of the world total heavy oil and bitumen reserves and the importance of geology on their recovery. Then, four studies on steam injection processes (CSS, SAGD, and solvent-steam), eleven studies on in-situ heat generation methods (in-situ combustion, electromagnetic heating, kerogen extraction, and coal gasification), three studies on phase behavior, and one study on drilling of thermal wells follow up. Most of the studies in this issue include both experimental and numerical approaches, which enable the potential readers to develop an understanding towards the fundamental aspects of every thermal EOR method and important parameters affecting their performance for the field scale application. Synopsis of each manuscript is given below with a brief description.

2. World low api gravity and high viscosity hydrocarbon potential

1. Geology of bitumen and heavy oil: An overview: This paper discusses main heavy oil and bitumen reservoirs in the world and provides important information on hydrocarbon formation and their geological characteristics. Not only information but also visual review of different heavy oil and bitumen deposits are given with pictures.

3. Steam injection processes

2. Structuring an Artificial Intelligence Based Decision Making Tool for Cyclic Steam Stimulation Processes: This study shows the important screening criteria for the modeling of cyclic steam stimulation (CSS) into heavy oil reservoirs by considering an artificial neural network (ANN) based simulation. It has been found that among all reservoir parameters; permeability, residual oil saturation, and oil density and among all operational parameters for application of CCS; steam injection duration, steam injection rate, and process cycles affect most the cyclic steam performance.
3. SAGD Pad Performance in a Point Bar Deposit with a Thick Sandy Base: This research discusses the impact of reservoir heterogeneities due to presence of multi-layer shale/siltstone interbeds on SAGD performance to extract a Canadian bitumen. These interbeds inhibit the formation and effective growth of steam chamber. The performed numerical studies show that steam access can be enabled in multiple oil bearing formations by placing the well pairs across the shale layers.
4. Performance of Multiple Thermal Fluids Assisted Gravity Drainage Process in Post SAGD Reservoirs: Steam Assisted Gravity Drainage (SAGD), Steam-and-Gas-Push (SAGP) with CO_2, and multiple thermal fluids assisted gravity drainage (MFAGD) were tested experimentally for the recovery of a heavy oil from China. The experimental results presented in this work were produced through a three-dimensional SAGD experimental set-up. Experimental results were first modelled and simulation results were then upscaled to the field dimension. It has been found that MFAGD as a follow up to SAGD provided the greatest oil recovery due to well-established communication between injection and production well during SAGD period.
5. Experimental study and numerical simulation of a solvent-assisted start-up for SAGD wells in heavy oil reservoirs: In this experimental study, an asphaltenes soluble solvent was used to establish the communication between injection and production well for the SAGD initiation period. Injected solvent was soaked for a period of time and experimental results were simulated numerically. It has been observed that optimization of solvent soaking time is critical to maintain the best communication between the wells for greater oil recovery.

4. In-situ combustion, reaction kinetics, and other in-situ thermal methods

6. Crude Oil Characterization Using TGA-DTA, TGA-FTIR and TGA-MS Techniques: In-situ combustion is a very successful process, however, the complicated nature of the chemical reactions involved in this process limits its application. Thus, this study concentrates on finding the chemical reaction kinetics parameters by using two Arrhenius based kinetic models for four different crude oil samples through Thermogravimetric Analyzer- Differential Thermal Analysis (TGA-DTA), Thermogravimetric Analyzer- Fourier Transform Infrared (TGA-FTIR), and Thermogravimetric Analyzer- Mass Spectroscopy (TGA-MS) techniques.
7. Thermal Characterization of Crude Oils in the Presence of Limestone Matrix by TGA-DTG-FTIR: During in-situ combustion, not only crude oils react at elevated temperatures with injected air, but also reservoir rock can be reactive at elevated temperatures. Limestone decomposes at oil combustion temperatures (~400–450 °C). This paper discusses how endothermic reactions due to limestone decomposition affect the performance of in-situ combustion. Two crude oils are blended with limestone, and the change in the reaction kinetics parameters were defined through Thermogravimetric Analyzer-Derivative Thermogravimetry- Fourier Transform Infrared (TGA-DTG-FTIR) analyses.
8. Aquathermolysis of Heavy Oil Using Nano Oxides of Metals: During oxidation of hydrocarbons, every reservoir component contributes to the success of in-situ combustion. This paper discusses the contribution of initial water saturation experimentally. Furthermore, the increase in combustion performance was presented experimentally because of the addition of nano metal oxides as catalysts.
9. Interaction between saturates, aromatics and resins during pyrolysis and oxidation of heavy oil: It is neither feasible nor practical to study the reaction kinetics of every single hydrocarbon molecule that exists in crude oils. Therefore, in this study, crude oil components are grouped under three fractions; Saturates, Aromatics, and Resins (SAR), and their kinetics were studied to understand their mutual interaction on crude oil oxidation and cracking.
10. Variations in In-Situ Combustion Performance due to Fracture Orientation: Combustion tube experiments are the most validated technique to determine the operational parameters for the full field application of in-situ combustion. This study shows two combustion tube experimental results and discusses the impact of high permeability zones and their orientations to air injection direction on in-situ combustion performance. Furthermore, the crude oil oxidation is explained with the chemical changes observed in displaced oils' SARA (Saturates, Aromatics, Resins, and Asphaltenes) fractions through the Fourier Transform Infrared (FTIR) spectroscopy analyses.
11. Combustion Assisted Gravity Drainage - Experimental and Simulation Results of a Promising In-Situ Combustion