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Practical process design for in situ gasification of bitumen

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HIGHLIGHTS

- In situ oil sands gasification processes produce energy in form of oil and syngas.
- Used comprehensive in situ bitumen gasification reaction system.
- In situ bitumen gasification model matched against field data.
- In situ gasification process is efficient, has lower emissions and water usage.

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ABSTRACT

The province of Alberta, Canada hosts an estimated 170 billion barrels of crude bitumen reserves in the Athabasca, Cold Lake and Peace River deposits. These reserves are commercially recovered through surface mining or in situ recovery methods. Most of the produced bitumen is converted in surface upgraders to synthetic crude oil (SCO), a 31–33°API oil product. Next, SCO is converted to transportation fuels, lubricants and petrochemicals in conventional refineries and petrochemical industries. In situ recovery or mining as well as bitumen upgrading and refining are energy intensive processes that generate huge volumes of acid gas, consume massive volumes of water, and are costly. Bitumen upgrading requires hydrogen, and currently most of it is produced by steam reforming of methane. Alternatively, hydrogen can be generated by in situ gasification of bitumen. In situ gasification of oil sands is potentially more energy efficient with reduced emission to atmosphere since acid gases are sequestered to some extent in the reservoir. Also, water usage is lowered and heavy metals and sulfur compounds in the bitumen tend to remain downhole since the main product is gas. The objective of this research was to understand and optimize hydrogen generation by in situ gasification from bitumen reservoirs. The central idea was to recover energy from the reservoir in the form of hydrogen and bitumen. In situ combustion has been attempted in the field, in a pilot run at Marguerite Lake. In this pilot, the produced gas contained up to 20 mole percent of hydrogen. In the current study, the Marguerite Lake Phase A main-pattern in situ combustion pilot was history-matched as a basis to understand a field-operated recovery process where in situ gasification reactions occur. Based on Marguerite Lake in situ combustion pilot observations, a new in situ bitumen gasification process, based on a Steam-Assisted Gravity Drainage (SAGD) well configuration, was designed and compared with conventional SAGD on the basis of energy investment, emission to atmosphere and water usage. The results show that the amount of energy produced per unit of energy invested for the in situ gasification process was greater than the steam alone recovery process with less than half the water usage. The cyclic injection of steam and oxygen as compared to steam injection alone can permit design of oil-alone to oil + syngas production processes.

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1. Introduction

Global estimates of the volume of heavy oil and bitumen hosted in oil sands reservoirs is greater than six trillion barrels [1,2]. Western Canada alone contains over 1.7 trillion barrels of bitumen within oil sands reservoirs [3]. This volume of unconventional oil is the third largest globally behind the conventional oil resources of Saudi Arabia and unconventional resources of Venezuela [4]. The key difficulty associated with bitumen recovery from oil sands reservoirs is its high viscosity: at original conditions, it is typically hundreds of thousands to millions of centipoise. If the reservoir is shallow enough (typically <70 m), then the oil is recovered by surface mining. For deeper reservoirs, Cyclic Steam Stimulation (CSS) and Steam-Assisted Gravity Drainage (SAGD) are used. These methods inject steam into the oil sands formation to raise the temperature of the bitumen. At over about 200 °C, the viscosity of Athabasca bitumen drops to less than 10 cP (0.01 Pa s) which enables

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it to be produced from the reservoir. In current practice, steam is generated by combustion of natural gas: as shown in Fig. 1, about 300 Sm^3 (assuming 8% heat losses in pipeline) of natural gas are required (for steam generation) per m^3 bitumen recovered for a cumulative steam-to-oil ratio (cSOR) of 2.5 m^3 per m^3. The corresponding amount of CO_2 emitted to the atmosphere as a result of this combustion is equal to about 560 kg per m^3 bitumen recovered.

On an energy basis, the energy invested by natural gas combustion in steam-based recovery processes (the energy intensity) such as SAGD and CSS, is equal to about 10 GJ per m^3 bitumen recovered at a steam-to-oil ratio (SOR) equal to about 4 m^3 per m^3. Given that the heating value of bitumen is ~43 GJ per m^3 [5], this means that in situ steam-based recovery processes are energy intensive and emit large quantities of CO_2 to atmosphere. If upgrading of bitumen and refining of synthetic crude oil is included, energy intensity and emission to atmosphere are even higher. During upgrading, roughly 180 Sm^3 of hydrogen are required per Sm^3 of synthetic crude oil (SCO) produced [6]. Given projections for increased oil sand development and consequent hydrogen consumption, there is a pressing need to develop more sustainable hydrogen production methods.

The combined motivation to (a) improve hydrogen generation and (b) increase bitumen recovery with lower emission to atmosphere and (c) lower water consumption, has driven us to study in situ gasification (ISG) of bitumen. In these types of the recovery processes, the energy vectors recovered consist of not only bitumen but also synthesis gas. The design of a process for in situ hydrogen generation by bitumen gasification requires construction of the reaction scheme together with associated kinetic parameters. Since bitumen, oxygen, and water coexist in the presence of heat during bitumen gasification, the reaction system should take into account pyrolysis (thermolysis, thermal cracking), aquathermolysis, gasification, and combustion (oxidation) reaction mechanisms.

Here, tuning of a proposed unified kinetic scheme, originally derived from matches to laboratory experiments [7–13], was carried out by history matching the Marguerite Lake in situ combustion (ISC) pilot conducted in the 1980s [14]. Because the Marguerite Lake pilot consistently produced hydrogen during CSS followed by ISC, it serves as not only a combustion pilot but also an ISG pilot and provides a data set from the field that can be used to tune kinetic parameters of the laboratory-derived reaction scheme to values appropriate for use in a field scale model. The pilot was conducted in the Clearwater Formation, an oil sands reservoir at a depth of 450 m with gross pay thickness equal to 34 m. In this formation, the porosity and permeability of reservoir were 30% and 1–3 D (9.8692×10^{-13} to 2.9608×10^{-12} m^2), respectively and the 12°API bitumen had viscosity, at original temperature and pressure, equal to about 100,000 cP (100 Pa s) [19]. As shown in Fig. 2, during the pilot test, Wells EX T2 and EX T3 were steam fractured and operated through several CSS cycles. Then, Well EX T4 was steam fractured and operated briefly for CSS before converted to air injection. During this combustion pilot, the produced gas consistently showed the presence of up to 20 mole percent of hydrogen in produced gas from Well EX T2 as a result of air and water co-injection in Well EX T4. The main pilot consisted of four five-spot patterns (Wells EX 1–EX 13) with an additional five infilled wells (Wells EX 21–EX 25). All main pilot wells were steam fractured and operated through six cycles of CSS. Also, air and water co-injection in Well EX 4 demonstrated consistent production of up to 20 mole percent of hydrogen in the produced gas from Well EX 5 [8,14–22].

We have previously developed and tested a comprehensive reaction scheme to simulate hydrogen generation from gasification of bitumen at laboratory-scale [12]. The research described here focuses on conceptual design and simulation of a field application of ISG to examine the potential to generate hydrogen directly from

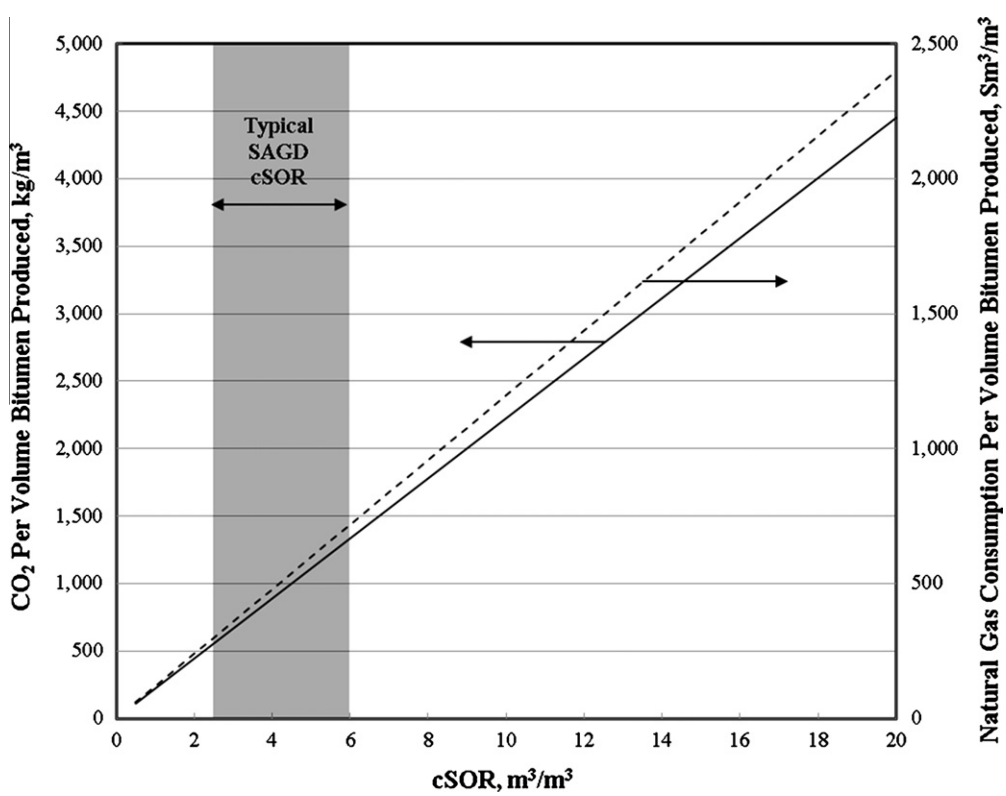

Fig. 1. Carbon dioxide emission and natural gas consumption per volume of bitumen produced versus cumulative steam oil ratio during typical SAGD operation for oil sands reservoir (assuming that thermal efficiency of steam generator is 75%). Typical cSOR for SAGD is 2.5–6 m^3 per m^3.

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