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Solar assisted method for recovery of bitumen from oil sand

Daniel Kraemer [a], Anurag Bajpayee [a], Andy Muto [a], Vincent Berube [b], Matteo Chiesa [a,c,*]

[a] Department of Mechanical Engineering, Massachusetts Institute of Technology, 77 Mass. Ave, Cambridge, MA, USA
[b] Department of Physics, Massachusetts Institute of Technology, 77 Mass. Ave, Cambridge, MA, USA
[c] Program of Material Science, Masdar Institute of Science and Technology, Masdar, P.O. Box 54115, Abu Dhabi, United Arab Emirates

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ABSTRACT

A novel concept for the recovery of bitumen from oil sands in a natural gas limited environment with and without CO_2 constraints is presented. We suggest a feasible method for the recovery of unconventional oil in an environmentally friendly and sustainable way that has the potential of eliminating the need of natural gas as a process fuel. The proposed concept involves mid temperature steam generation for stimulating an oil sand formation. The steam is generated by utilizing solar radiation. The method uses the thermal mass of the oil sand formation to allow for cyclic steam injection during solar availability while still yielding continuous bitumen recovery. Feasibility assessments of the concept from both a thermodynamic and financial point of view are presented for a scenario of development in the Athabasca region in Alberta, Canada.

1. Introduction

The worldwide oil demand for oil has more than doubled since 1965 and has grown 20% in the last two decades alone to the current level of 80 million barrels per day. This trend is expected to continue with projections of 50% growth in the next 20 years [1]. While the global oil demand continues to rise the supply from conventional sources is declining, and the depleted reserves are not being replaced with new discoveries [2]. It has been reported that the world has over twice as much supply of heavy oil and bitumen as it does of conventional oil. Excluding oil shale deposits, it is estimated that there exist 8–9 trillion barrels of heavy oil and bitumen, of which 900 billion barrels are exploitable with existing technology [3].

Canada alone, by some estimates, has 179 billion barrels of useful bitumen which make it second only to Saudi Arabia in proven oil reserves [4,5]. The oil sands of Alberta are a huge natural resource and with the price of oil rising to record levels, bitumen production has increased dramatically in the past five years [2]. Bitumen recovery from oil sands deposits involves either strip mining the sands and extracting the oil, or pumping large quantities of steam into the ground to extract the bitumen from the sand which is then pumped out of the ground for upgrading. Traditionally, the energy to produce the steam and hot water used in these processes has come from natural gas [6]. The use of increasingly large amounts of gas for oil sands recovery presents a number of economic and environmental problems. Steam generation and upgrading processes will contribute large amounts of greenhouse gas emissions while Canadian and regional environmental policies seek long term reductions [6,7]. Large planned increases in natural gas consumption will also cause western Canada to become a net importer of gas, with potentially serious impacts on regional natural gas pricing and market volatility [8]. This is likely to impact not only the profitability of the oil sands business but also the price and availability of natural gas in the region.

The presented work explores the feasibility and economics of using solar radiation to power future oil sands production activities. We propose a novel concept that utilizes solar radiation to generate mid temperature steam for the stimulation of the formation. The bitumen extraction method uses the thermal mass of the oil sand formation for heat storage to allow for cyclic steam injection during solar availability while yielding continuous bitumen recovery. Moreover, the solar steam generation plant for bitumen recovery produces no greenhouse gas emissions and dramatically reduces operating costs by substituting solar energy for natural gas as the boiler's energy source. The following chapters describe the proposed method and present the thermodynamic and economical calculations that support the use of solar steam production for bitumen recovery.

2. Energy requirements for bitumen recovery

Currently, bitumen recovery is primarily accomplished either by surface mining followed by extraction through thermal

* Corresponding author. Address: Program of Material Science, Masdar Institute of Science and Technology, P.O. Box 54115, Abu Dhabi, United Arab Emirates. Tel.: +971 2 698 8167; fax: +971 2 698 8121.
E-mail addresses: mchiesa@masdar.ae, mchiesa@mit.edu (M. Chiesa).

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processing, or by in situ means such as steam-assisted gravity drainage (SAGD) [9,10,6]. The economics of surface recovery are dominated by the cost of mining equipment, operations, and land reclamation [2]. The economics of in situ production are dominated by the cost of natural gas used to generate steam [6].

The use of enormous amounts of natural gas for steam generation makes oil sands operations large single source emitters of greenhouse gases. As concern about climate change grows and CO_2 reduction targets come into effect; considerable reduction in operational costs for oil sand production is required. Natural gas production in Alberta peaked in 2001 and has been static ever since [11]. It is likely that its requirement in the oil sands industry will be met by cutting back Canadian natural gas exports to the United States or even importing natural gas from Alaska.

SAGD is a major breakthrough in the oil sand recovery technology. It is cheaper than similar steam-assisted production methods, and recovers up to 60% of the available oil. The steam requirements for SAGD fields vary significantly [6]. The desired steam generation pressure and temperature are affected by the geological characteristics of the area, the distance over which the steam must be transported, and the depth and quality of the bitumen reserve. The steam temperature varies in the range of 250–350 °C, while the steam pressure is limited by the fracture pressure of the formation. Saturated steam is produced at sufficient pressure to support control, distribution and injection processes. A typical steam to oil ratio (SOR) measured in barrels of cold water to produce a barrel of bitumen is between 2 and 4. The actual SOR for any given well depends on the quality of the deposit and the specific geology in the region [6]. The present analysis assumes saturated steam production at 6–10 MPa with a related SOR of 3. Thus one barrel of bitumen is recovered for every three barrels of cold water equivalent of steam injected. In situ SAGD recovery uses about 1.0–1.5 Mcf of natural gas for each barrel of bitumen recovered [12,13]. An SOR of 3.0 corresponds to a natural gas intensity of 1.3 Mcf/bbl.

3. Energy efficient method for the recovery of bitumen

The proposed bitumen recovery method harnesses solar radiation to generate mid temperature steam that is used to stimulate the formation. Solar thermal power plants employ point focusing (solar tower) or line focusing (solar trough) systems to concentrate sunlight as heat to generate steam which is then converted to electricity [18]. Line focusing systems can achieve concentrations of 70–100 times and operating temperatures in the range of 350–550 °C. On the other hand point focusing systems use a field of distributed mirrors called heliostats that individually track the sun and focus the sunlight at the top of a tower concentrating the sunlight 600–1500 times and delivering temperatures of about 550 °C. In either case the solar energy is often absorbed by a heat storage fluid such as molten salts and then used to generate high temperature steam for the power cycle [14].

The proposed recovery method employs solar thermal power technology where both the line focusing and the point focusing techniques may be used. Unlike conventional solar thermal systems, our method generates steam directly at mid-level temperatures of 230–350 °C. Decreased radiation losses due to lower temperatures at the receiver and the possibility of direct steam generation with no intermediate heat storage fluid would enhance the overall thermal efficiency of the system [14]. The use of mid temperature steam allows for the use of the proposed technology even in locations with relatively low solar radiation such as Alberta. This mid temperature steam generated throughout concentrating system is injected into the oil sand formation where the bitumen is extracted from. The required steam needed to stimulate the formation will be injected at high rates during times of peak solar radiation while little or no steam will be available during nights. In a scenario of daily oil production of 10,000 barrels about 30,000 barrels of water need to be converted to steam and be injected into the formation.

The injected thermal energy is absorbed by the formation, thus causing the bitumen to decrease in viscosity and enabling it to be pumped out. The formation acts as a large thermal mass with a response time much longer than a day. Previous work on economic implications of intermittent steam injection in the SAGD process suggests that short term variations in steam injection have negligible impact on formation chamber pressure and temperature [17]. Thus as long as enough energy is injected during the period of solar availability the system may be operated continuously to extract the desired daily amount of bitumen. Similarly the larger thermal mass of the injection chamber allows for continuous operation in the wake of seasonal changes. Work by Birrel et al. [17] supports the feasibility of intermittent steam injection based on seasonal variations. It is shown for a plant that has been in operation for one year, upon a 100% steam injection shut-down for 60 days, the decline in daily bitumen production is only 0.83%. For shut-down periods of 15 and 30 days, the reductions are about 0.4% and 0.6%, respectively. Since the steam injection is reduced (insolation values in the months of November, December, and January are about 50%, 31%, and 47% of the average insolation, respectively [16]) and not completely shut-down and since the low injection period is relatively short, the effect on bitumen production due to seasonal variations will be negligible.

The proposed method uses a similar well configuration as the conventional SAGD with some variations. First, in order to account for the variation in steam generation rates the steam injecting well(s) allows for varying flow rates and/or has a larger flow cross section area than that of the bitumen recovery well(s). Secondly, the proposed configuration employs local steam injection as close as possible to the location where the steam is generated and a centralized oil producing facility where the oil is produced from multiple horizontal wells. Schematics for the entire proposed system and the upgrading processes without natural gas are depicted in Fig. 1.

3.1. Thermoelectric electricity generation

The energy required to inject the steam into the formation and to recover the bitumen from the formation is a small fraction compared to the energy necessary to generate steam. We thus propose to generate the power necessary to run various pumping equipment by means of Solar Thermoelectric Generators (STG). These STG's are installed at the solar focus point on the surface of the boiler as illustrated in Fig. 2. It must be reiterated that this will not significantly affect the overall system performance as the electrical power required here is only 5% of the total power supply. Thermoelectric Generators are a robust, low maintenance option and are easy to install as compared to a full blown steam turbine system including a heat storage fluid [15]. STG's may also be able to utilize other secondary sources of cold and hot fluid streams without significant modification. Although the conversion efficiency of a solar thermoelectric generator (STG) is relatively low compared to the state of the art photovoltaic modules, the major advantage of using this technology lies in the cogeneration of electric work and heat [15]. The STG module is directly mounted on the boiler therefore the excess heat which is transferred through the module is used to generate steam. The installation of an STG module represents an additional thermal resistance between the solar radiation and