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Research paper

Evaluation of energy efficiency options in steam assisted gravity drainage oil sands surface facilities via process integration

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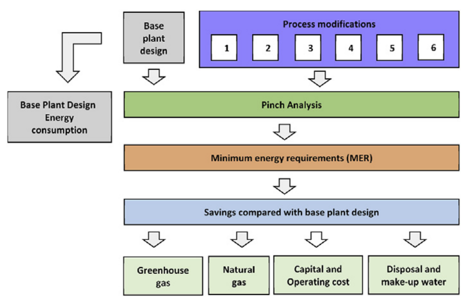
HIGHLIGHTS

- Pinch analysis performed for unconventional oil recovery process to identify inefficiencies.
- Both the removal of pinch violations and process modifications lead to savings.
- Effect of energy savings on water consumption for the process is considered.
- Greenhouse gas emissions reduction and economic benefit are estimated for the studied cases.

GRAPHICAL ABSTRACT



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ABSTRACT

While new technologies are being developed for extracting unconventional oil, in the near term economic benefits and footprint reduction can be achieved by enhancing the energy efficiency of existing facilities. The objective of this work is to evaluate energy efficiency opportunities for in situ extraction of Canada's oil sands resource using pinch analysis. Modifications to an original plant design are analyzed in order to estimate utility savings beyond those obtained for the initial process configuration. The modifications explored in this paper are estimated to deliver energy savings of up to 6% beyond 'business as usual'. This corresponds to GHG emissions reduction of approximately 5%. However, in some cases, this increase in energy savings comes at the cost of increasing demand for make-up water and volume of disposal water. Surplus generation of steam beyond heating requirements in the water treatment system leads to energy inefficiencies. Additional cost and energy savings are obtained by reducing or eliminating the use of glycol in the cooling circuit.

1. Introduction

Canada is rapidly expanding production of its large reserve of extra/ultra-heavy oil referred to as oil sands (a mixture of clay, sand, water and oil or bitumen). In 2013, bitumen production was reported as 1.9 million barrels per day (bpd) [1], and it has been forecast to grow to 5 million bpd by 2030 [2]. This rapid development will bring significant economic benefits to the province of Alberta and Canada. However, it has also raised global scrutiny including concerns over environmental impacts such as those from greenhouse gas (GHG) emissions that are typically higher for oil sands than conventional oil [3]. As such, research and development activities are currently underway to develop technologies

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Nomenclature

BAU	business as usual
BFW	boiler feedwater
CHP	combined heat and power
CPF	central process facility
FWKO	free water knockout
GHG	greenhouse gas
HEN	heat exchanger network
HP	high pressure
HLS	hot lime softening
MER	minimum energy requirements
MP	medium pressure
OTSG	once through steam generator
SAGD	steam assisted gravity drainage
SOR	steam to oil ratio
TDS	total dissolved solids
WAC	weak acid cationic exchange

to reduce the impacts of both current and future oil sands projects. Biological solutions, carbon capture, using zero/no-emissions electricity are all long-term solutions, potentially with significant emission reductions. This study, however, evaluates near term incremental solutions, namely different energy efficiency measures for an in-situ facility that could lead to reductions in energy consumption, and consequently GHG emissions, using pinch analysis.

Bitumen is extracted using two main methods; surface mining techniques are used to recover bitumen at depths up to 80 m and in situ techniques are used to recover bitumen at depths greater than 80 m. The most commonly deployed in situ technique today is steam assisted gravity drainage (SAGD) [4] that involves generation of high pressure (HP) steam (between 8 and 14 MPa) to be injected in the reservoir which heats the bitumen and reduces its viscosity, allowing it to flow to the surface then on to the central process facility (CPF). The bitumen is then separated from water and in most cases diluted before being shipped by pipeline to refineries where it is further refined into final products such as transportation fuels. Typically, more than 90% of the energy consumed in producing a barrel of bitumen using SAGD is used to generate the steam that is injected into the bitumen reservoir [5]. In existing oil sands operations, energy cost savings and/or CO_2 emissions reductions can be accomplished through a number of retrofit measures, such as, fuel switching [6], more efficient heating by use of combined heat and power (CHP) plants [7], reduction of hot and cold utility usage by increased heat exchange and optimization of the heat exchanger network [8].

Pinch analysis is a design approach that aims to minimize energy consumption with implications for operating and capital costs [9]. The methodology tool allows for a systematic assessment of the cost, energy and GHG emissions implications of a set of energy efficiency opportunities within a large scale industrial facility. Pinch analysis does not directly reduce emissions. Rather, it is a tool to assist and facilitate the prioritization of energy efficiency technologies and processes on the basis of their cost and GHG emissions. Pinch analysis was initially proposed by Hohmann in 1971 [10,11], and further developed by Linnhoff and Umeda in 1978 [12]. Due to the demonstrated insights pinch analysis has provided in a variety of industrial applications, it has been widely accepted both in academia and industry [13] as an efficient and reliable tool in process and retrofit design [14]. Pinch analysis has been applied in a variety of industries such as chemical, petrochemical, pulp and paper, food and beverage, steel making and power generation [12,14], but can be applied to any industrial process involving heat transfer between two process streams or between a process stream and a utility stream [15]. Applications of this method around the world have resulted in estimated average energy savings of up to 45% [16].

Despite the benefits of pinch analysis to identify and prioritize energy savings and emissions reductions, the application of pinch analysis in oil sands operations has received little attention to date. To the authors' knowledge, Nadella [17] is the only study to apply pinch analysis to the oil sands industry that has been reported in the academic literature. In this study, the minimum energy requirement calculations for a SAGD CPF are demonstrated as part of a simplified illustrative example. A pinch analysis is performed and a heat exchanger network proposed. However, options to modify the process are not explored and changes to the heat exchanger network are not presented.

Jacobs Consultancy [18] was commissioned by Alberta Innovates to assess the energy efficiency of a typical SAGD facility with different technologies and operating strategies to identify the most economic means to reduce energy consumption and associated GHG emissions. Improvements to the base case were successively considered, where the heat recovery potential was estimated using pinch analysis. An interesting finding in this report is the energy inefficiency of glycol systems (the current industry standard) compared to air as a cooling medium for heat exchange throughout the facility. While they demonstrate that pinch analysis can be an effective tool, they do not present how the energy savings are obtained (e.g., from which process streams). They also only investigate pinch analysis of the base plant design and do not explore any further possible process modifications.

Another study conducted by Jacobs Consultancy and Suncor Inc. assessed the energy efficiency and GHG emissions reduction potential of a range of technology options for mining, in situ and upgrading stages of oil sands operations using a life cycle approach [8]. A pinch analysis was also conducted as part of this study for operating projects owned by Suncor leading to proposed capital investments in the HEN, resulting in 3.5% savings of energy consumption and 2.5% of GHG emission reduction. However, further modifications are not explored and no heat exchanger network to achieve these energy savings is presented. Again, energy savings from the pinch analysis of the base plant design are calculated but further modifications are not explored and no improved heat exchanger network to achieve these energy savings is presented.

The objective of this paper is, therefore, to apply pinch analysis techniques to a specific, but representative, SAGD oil sands project design, to investigate opportunities for energy efficiency improvements in the CPF for existing or new projects. In this study, energy efficiency measures are presented and ranked by effectiveness to better inform investment and operational decisions in the in situ oil sands industry.

2. Methods

Pinch analysis uses analytical and graphical tools to analyze the heat content of every stream (fluid flow) within a system to identify opportunities to exchange heat between hot and cold streams to recover additional energy. The pinch method can then be used to design heat exchanger networks (HEN) which maximize the energy