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Heat recovery optimization in a steam-assisted gravity drainage (SAGD) plant

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ABSTRACT

Pinch Analysis was used to improve the energy performance of a typical steam-assisted gravity drainage (SAGD) process. The objective of this work was to reduce the amount of natural gas used for steam generation in the plant and the associated greenhouse gas emissions. The INTEGRATION software was used to analyze how heat is being used in the existing design and identify inefficient heat exchanges causing excessive use of energy. Several modifications to improve the base case heat exchanger network (HEN) were identified. The proposed retrofit projects reduced the process heating demands by improving the existing heat recovery system and by recovering waste heat and decreased natural gas consumption in the steam production unit by approximately 40 MW, representing approximately 8% of total consumption. As a result, the amount of glycol used to transfer energy across the facility was also reduced, as well as the electricity consumption related to glycol pumping. It was shown that the proposed heat recovery projects reduced natural gas costs by C$3.8 million/y and greenhouse gas emissions by 61,700 t/y of CO_2.

1. Introduction

One of the most energy-intensive processes in Canadian industry is the extraction and processing of bitumen from oil sands, which produces approximately 4% of Canadian greenhouse gas (GHG) emissions [1]. In-situ techniques such as steam-assisted gravity drainage (SAGD) are used for approximately 45% of bitumen extraction [2]. These processes have high bitumen production rates, in some cases exceeding a 65% recovery factor. However, they have higher energy consumption and higher associated GHG emissions in comparison with other extraction methods [3]. The SAGD process requires large amounts of high-pressure (HP) steam to be injected continuously into the ground to heat the bitumen, thereby reducing its viscosity and allowing it to be extracted more easily. The mixture of bitumen and condensate is then pumped out for further separation [1,4]. The steam used in the process is produced in once-through steam generator (OTSG) boilers, and the energy required for steam generation – predominantly natural gas – represents more than 90% of the plant's total energy requirements [5].

In recent years, environmental concerns, together with national and international agreements and regulations to reduce GHG emissions, urged industrial sectors to invest in heat management measures and new technologies to improve their energy efficiency [6]. Among the possible heat management techniques, Process Integration is a powerful approach that is used in various industrial processes such as petroleum refining, chemical, food and beverage, petrochemical, and pulp and paper industries to improve the efficiency and optimize the use of energy and other resources [7,8]. Process Integration can notably be used to find the best design options to minimize the use of thermal energy in a process. Pinch Analysis, a simple yet powerful Process Integration technique, applies thermodynamic principles to optimize heat recovery systems in industrial facilities [9]. In conducting Pinch Analysis, the engineer looks at all the ways in which heat is being used, where it can be recovered, and how that heat can best be applied across the process. In retrofit situations such as this work, Pinch Analysis comprises a diagnosis phase, where potential for improvement is determined, followed by an optimization phase, where heat recovery projects that improve energy efficiency are identified.

Despite the fact that Process Integration has several benefits and leads to significant reductions in energy use and GHG emissions, its potential is not fully leveraged in the oil sands industry. Jacobs

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Nomenclature

BFW	boiler feed water
BPD	barrels per day
COSIA	Canada's Oil Sands Innovation Alliance
CPF	central processing facility
Dilbit	diluted bitumen
HEN	heat exchanger network
HP	high-pressure
HR	heat recovery
Hx	heat exchanger
MP	medium-pressure
NG	natural gas
LP	low-pressure
OTSG	once-through steam generator
PFD	process flow diagram
SAGD	steam-assisted gravity drainage
WLS	warm lime softener

Consultancy [6] studied energy efficiency aspects in a typical SAGD facility and evaluated the impact of different measures to reduce energy use and GHG emissions. In their study, the base case scenario was improved by considering different configurations involving operational changes and heat recovery using Pinch Analysis. Nadella [10] also employed Pinch Analysis to improve the energy use of in-situ oil recovery facilities. This work studied a typical SAGD facility and calculated the minimum energy requirement by direct heat recovery to heat boiler feed water (BFW). The heat exchanger network (HEN) was developed using a grassroots approach meaning that no existing heat exchanger was considered in the analysis. In another study, Carreon et al. [5] used Process Integration principles to evaluate energy efficiency options in a SAGD facility to improve the central processing facility (CPF). In order to increase environmental and economic savings they modified the process to make better use of medium-pressure (MP) steam. They directly mixed flashed MP steam with BFW to maximize heat recovery, but, at the same time, the new design increased raw make-up water and wastewater production. Here again, the HEN was developed using a grassroots approach.

Over the past few years, a novel methodology was proposed by CanmetENERGY [11] and tested successfully for retrofitting heat exchanger networks in industrial plants. The proposed methodology is based on the Network Pinch approach – a step-by-step method proposed by Asante and Zhu [12] and further developed by Varbanov and Klemes [13] – with additional methodological improvements capable of handling different practical constraints in a systematic way and reducing the number of retrofit options. Based on this novel methodology, CanmetENERGY developed the INTEGRATION software [14], a powerful Process Integration software package that includes the most recent advances from several research activities, combined with years of practical experience in improving industrial heat recovery systems [15]. Aside from the common Pinch tools, the INTEGRATION software introduces many practical and novel features: the concept of effluent streams with a final temperature that is not fixed; flexibility in process stream target temperatures (soft targets); the possibility of linking the soft target temperature of a stream with the supply temperature of another stream; the possibility of using different minimum temperature approaches for each stream; as well as utility switching and relocation of heaters and coolers, when required.

With INTEGRATION, improving an existing heat recovery network is performed step-by-step, one modification at a time, as per the Network Pinch approach. At each step, the software identifies the structural modifications that would best improve heat recovery, taking into account the limitations of installed equipment. However, the users maintain full control over the number of modifications they wish to make. In a retrofit situation, where the process already exists, INTEGRATION compares the energy targets (i.e. the minimum energy consumption if heat recovery is optimum) with the actual energy consumption, so that the potential for energy saving through improved heat recovery can be calculated. Through detailed analysis of how heat is being used within the process, the software identifies inefficient heat exchangers and unrecovered waste heat streams that cause excessive energy use. Furthermore, INTEGRATION includes several models to estimate the temperature level (i.e. quality) and the amount of waste heat (i.e. quantity) from industrial boilers, air compressors, and refrigeration systems, so that a comprehensive heat recovery analysis considering process and utility systems can be performed using the same software [14].

In this study, INTEGRATION was used to analyze and optimize heat recovery in a typical SAGD facility. The existing heat recovery system was retrofitted step-by-step, and the energy savings after each step was calculated. The base case data were obtained from material and energy flow diagrams developed by Canada's Oil Sands Innovation Alliance (COSIA). In addition, the software was used to model the steam production system (i.e. several OTSGs), as well as to calculate the amount of waste heat available in the flue gas, the natural gas consumption, and the GHG emissions both for the base case and the improved designs.

2. Typical steam-assisted gravity drainage (SAGD) plant

In SAGD operations, a number of wells are drilled into the reservoir. These wells are drilled horizontally in pairs: one to inject steam and the other to extract bitumen and condensate [16]. To do this, large amounts of HP steam are produced in the CPF, transported to the injection well pads, and then injected into the reservoir. The HP steam condenses and heats the earth, reducing the bitumen viscosity enough to make it fluid. Gravity helps the condensed water and oil flow to the production well, located below the injection well. The hot mixture, an emulsion of water and bitumen, is extracted from the reservoir and sent to the CPF for separation. Once separated, the bitumen is diluted to be pipelined to market, and the water is treated to be reused in the steam generation system.

In this work, we have selected a standard in-situ extraction facility, developed by COSIA for use in evaluating new technologies, with the following design conditions [17]:

- Production capacity: 33,000 BPD (5247 m^3/d)
- Steam-to-oil-ratio: 3.0
- Gas-to-oil-ratio: 5.0
- Water losses in reservoir: 10%
- Steam generation: 6 OTSG boilers
- Steam quality: 77% before the high-pressure steam/liquid separator at 310 °C and 99 bar
- Emulsion extraction: Mechanical lift (submersible electric pumps used for lifting the bitumen emulsion from the reservoir)
- Water treatment: Warm lime softener (WLS)

The CPF is comprised of several integrated process units designed for heat recovery and water conservation, as shown in Fig. 1. In this simplified process flow diagram (PFD), major process streams and heat exchangers within the CPF are illustrated. This base case configuration was used to analyze and improve heat