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Prediction of steam-assisted gravity drainage steam to oil ratio from reservoir characteristics

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ABSTRACT

Forecasts suggest that production of bitumen from oil sands reservoirs will increase by a factor of at least 2.5 times over roughly the next 15 years. Although a significant economic benefactor to the Canadian economy, there are challenges faced by oil sands operators with respect to greenhouse gas emissions and water consumption. For the Athabasca deposit, the current oil recovery process of choice is the SAGD (steam-assisted gravity drainage) method where high temperature and high pressure steam is injected into the oil sands formation. At present, there are more than ten SAGD operators in Alberta, Canada and results to date reveal that the geology of the reservoir impacts SAGD performance. Given the growth of the SAGD industry in Alberta, forecasting tools are required that can predict performance versus reservoir characteristics. Here, we present a neural network-based model to predict the SOR (steam-to-oil ratio) in oil sands reservoirs by using log and core data to characterize the reservoir porosity, permeability, oil saturation, depth and thickness. Our analysis confirms that the lower the porosity, permeability, and oil saturation of the reservoir, the worse the performance of the operation. In other words, the lower the quality of the reservoir, the lower the oil rate, and the higher the SOR. Our analysis also shows that well performance (i.e., SOR), is predictable with a relatively high degree of accuracy (R^2~0.80) using log and core data via a neural network model. These results imply that the depth of the reservoir, gamma ray readings, and permeability are the most important determinants of the variation in SOR.

1. Introduction

With over 1.7 trillion barrels of oil in place of which ~10% is considered recoverable with current technology and current market conditions, oil sands reservoirs in Western Canada are among the largest petroleum volumes globally [1]. The key technical issue that challenges production of oil sands reservoirs is the viscosity of the bitumen, which can range from 100,000 up to several million cP (conventional oil is typically in the range of between several thousand up to tens of thousands of cP) [2]. To produce these reservoirs, the viscosity of the oil within the reservoir must first be lowered to a value low enough so that conventional forces, such as solution gas drive or gravity, can move the oil within the reservoir to a production well [2].

One such recovery process that enables recovery from the relatively shallow, low solution gas content Athabasca oil sands reservoirs in Northeastern Alberta is the SAGD (steam-assisted gravity drainage) process [3]. In SAGD, high pressure saturated steam injected into a depletion chamber of the oil sands formation releases its latent heat at the edge of the chamber heating the oil sands [3]. As a consequence, its viscosity falls by up to six orders of magnitude, typically <10 cP, and it drains to the bottom of the chamber where a horizontal production well removes steam condensate, formation water, and mobilized oil to surface. There have been several studies on the impact of geological heterogeneity on the performance of SAGD. Most SAGD operations have targeted the Middle McMurray Formation which is heterogeneous since it consists of sedimentological elements such as point bar deposits. These elements are comprised of IHS (inclined heterolithic strata) of sandwiched sand-shale/siltstone layers and abandoned mud channels [4]. Due to the presence of shale layers, the performance of SAGD, which relies largely on gravity drainage, suffers [5]. Although past studies have focused on single well or pad scale heterogeneity, none has dealt with all of the SAGD well pairs in Alberta to evaluate the relationship between performance and reservoir characteristics.

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A critical measure of the energetic and economic success of SAGD is its injected steam (typically expressed as CWE (cold water equivalent)) to produced oil ratio (SOR). Steam is an important process cost since it consumes fuel, in nearly all cases, natural gas, which is combusted to generate the steam [6]. Produced oil is the process revenue. Thus, the SOR roughly represents the cost-to-revenue ratio [7]. If the SOR is high, process costs can exceed revenues and the process is rendered uneconomic.

Oil sands operations generally produce more greenhouse gas emissions than that of conventional oil [8] with energy returns lower than that of conventional oil [9]. This also results in generally higher levels of CO_2 emissions [10]. Thus, there are mounting social pressures for oil sands operators to lower their SOR. Previous work has demonstrated that SOR is the key determinant of GHG (greenhouse gas) emissions performance of in situ projects [11] using models that characterize the contributions of each component of the process to GHG emissions [12]. Therefore, measurement and prediction of SOR is directly linked to GHG emissions per unit of oil produced as well.

Over the next 15 years, the growth of SAGD operations is forecast to increase production from ~1.9 million bpd (barrels per day) to over 4.8 million bpd [13]. There are several key issues that confront industry with this expansion. One key challenge is potential worsening of the SOR due to a trend towards thinner and lower quality oil sands reservoirs (e.g. reservoirs with thief zones such as bottom water and top gas/water zones) and more heterogeneous reservoirs [4]. As yet, there are no simple tools available to rapidly predict SOR given the characteristics of the reservoir. Here, we describe a new tool to estimate the SOR given reservoir properties derived from publicly available production and evaluation well data (well logs and core data) [14].

2. Methods

Here, we first introduce our sources and types of data followed by a detailed explanation of the methods used for analysis.

2.1. Data collection and processing

In this study, we focus on SAGD operations in Alberta, Canada with publicly available data associated with individual production and evaluation wells reported to the energy regulator in Alberta up to 1/1/2013. This data contains 415 evaluation wells and 365 production/injection wells posted by IHS Inc [14]. Evaluation wells are wells drilled to learn about the characteristics of the reservoir from core analysis and wire line logging. Production and injection wells comprise SAGD well pairs. Several small data processing and filtering steps are applied to the raw data to obtain variables used in the analysis. First, immature wells (that have not yet reached peak oil rate) have been excluded in addition to wells with extreme SOR values (lower than two or larger than fifteen). Also, the wells with missing observations have been excluded from the study. Then, necessary calculations are made on raw data to obtain variables that can be directly used in the analysis.

The main objective of our study is to investigate the influence that reservoir properties have on SAGD well pair performance. As yet, there are no studies that have examined a large number of SAGD well pairs together with their adjacent reservoir characteristics, as measured from log and core data, to understand the impact of reservoir properties on SAGD performance. As described above, the key measure of the thermal efficiency of SAGD is given by the SOR. Therefore, we set cSOR (cumulative SOR) as our dependent variable, one of the key industry well performance indicators. While there are many models that have been developed that use detailed proprietary data, our focus is on developing a model using publicly available information. Therefore, data availability was our limitation in the determination of predictors representing reservoir characteristics. Companies carry out "core analysis" by taking samples from evaluation wells to assess reservoir characteristics. Porosity, permeability, and oil saturation of the reservoir are determined through these core analyses and are important reservoir characteristics. Therefore, we included these three reservoir properties as predictors. Also, Gamma Ray well log readings give information about the lithology of the reservoir formation. Thus, we included Gamma Ray readings as the fourth predictor in our analysis. The thickness of the reservoir is also included as a predictor in our analysis because it is directly related to volume of oil in the reservoir. We also wanted to investigate the influence of the reservoir depth on SAGD performance. Thus, true vertical depth of the reservoir is also included in our analysis as a predictor. As a result, seven variables are used in the study, one dependent and six independent. Note that, the dependent variable is the cSOR that is calculated by dividing the total cold water equivalent steam injected up to a specific time point to the total oil produced up to the same time. The following are short descriptions of the model predictors:

- TVD (True Vertical Depth): The vertical depth of the reservoir (m) (production wells).
- Thickness (H): Average thickness of reservoir (m) (evaluation wells).
- GR (Gamma Ray): Amount of natural gamma radiation emitted by the reservoir (API units) (evaluation wells).
- Porosity (ϕ): The ratio of pore space to the total space in reservoir (dimensionless) (evaluation wells).
- Permeability (k): Ability of the reservoir rock to transmit fluids (m^2) (evaluation wells).
- Oil Saturation (S_o): The fraction of oil volume in the pore space (dimensionless) (evaluation wells).

Reservoir characteristics at the locations of the production and injection wells are not known and are estimated from the evaluation well data. The 365 production and injection wells contain cSOR and TVD (True Vertical Depth) data of the reservoir. The thickness of the reservoir, H, is calculated as the distance between the lower and upper bound of the reservoir where $\phi S_o > 0.2$. Using this formula, we neglect the parts of the reservoir with poor bitumen content. Furthermore, the number of evaluation well measurements that contain GR, ϕ, k, and S_o data are 415, 327, 295, and 276, respectively.

2.2. Estimation of unmeasured variables using regression trees

In order to conduct statistical analysis to predict reservoir performance, estimates of geological properties are required at production and injection well locations. Evaluation wells where data are known are not co-located with the production wells. In typical field development, the production wells are positioned in what is believed to be the most productive parts of the reservoir. This determination is informed by evaluation well data. A special type of interpolation method, called spatial interpolation, is required to estimate the values of the geological quantities at production well locations. Spatial interpolation is a method to investigate spatial correlation between spatially distributed objects. Therefore, we derive functions that model the statistical relationship between formation variables and position (longitude, latitude, and depth of the reservoir) from the evaluation well data. Then, estimates are calculated from the functions of the values of formation variables at the production well positions with their given LAT (latitude), LON (longitude), and depth.