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Data availability and development of a decision support system for heavy oil production prediction

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ABSTRACT

This paper has the dual objectives of (1) presenting an approach for overcoming the problem of data availability by combining experimental and simulation studies for generating a large data set, and (2) presenting a case study in which this integrated and interdisciplinary approach was adopted for tackling the problem of selection of enhanced oil recovery or EOR technology for heavy oil production. This paper describes development of a decision support system that can predict heavy oil based on different sequential applications of EOR techniques and the reservoir and operation parameters of oil viscosity, reservoir pressure, reservoir size, original oil in place, initial oil saturation, reservoir permeability, water-flooding, CO_2 flooding, injection pressure, percentage recovery using the first EOR technique, and a given time frame. Based on the constraints defined by the set of experimental data, a larger set of data was generated using a simulation software. The larger dataset in turn provided the basis for developing the correlation models for the decision support system. An oil production prediction system was developed which can predict oil production over time for a given EOR sequence. However, if a prediction is made beyond the domain of parameter values specified in the experiment, the prediction system performs poorly. The approach illustrated by the case study can potentially be applicable for tackling data modeling studies for which data availability is a problem.

1. Introduction

Data analysis can be defined as a process of inspecting, cleaning and modeling data to discover underlying information or knowledge, with the objective of developing a better understanding of the studied domain, and support a variety of activities such as prediction and decision-making (Bowen and Weisberg, 1980). Data analysis studies have been widely applied to business, social science, medical, engineering and science domains. They typically have both descriptive and predictive purposes, and the objectives often involve determining or modeling some relations among the studied parameters and investigating how these relations can be manipulated or interpreted. The models derived from a data analysis study can support prediction of some target variables or an enhanced understanding of the studied domain. Data analysis has conventionally involved statistical procedures. However, as real-world data often cannot satisfy the ideal assumptions of mathematical statistics, data analysis currently encompasses a much broader range of methodologies and techniques, such as the soft computing techniques of artificial neural network (ANN) and fuzzy logic. For some of these techniques, such as ANN, the availability of a large dataset for modeling is a prerequisite for application of the techniques. This issue of data availability is an important consideration in any data analysis study because obtaining data for this type of problem can be difficult or costly, or both.

This paper presents a data analysis study, which tackles the issue of data availability by adopting an integrated and interdisciplinary approach. The study investigates the effect of alternative sequential applications of water flooding and carbon dioxide injection on heavy oil production. The integrated and interdisciplinary approach adopted involved: (i) conducting physical experiments that investigate the effect of sequencing EOR techniques on heavy oil production, (ii) using the experimental data for providing the framework for running the simulation program of CMG© (Trademark of Computer Modeling Group Ltd.), which generated a large dataset on effect of sequential applications of EOR techniques on heavy oil production; (iii) using the larger data set developed for building three different correlation models using the artificial neural network or ANN technique, (iv) assessing and selecting the best among the three correlation models developed;

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(v) incorporating the best correlation model in a decision support system that models the impact of alternative sequential applications of water-flooding and carbon dioxide (CO_2) injection for heavy oil production. The entire process of experimentation, generating simulation data, and developing correlation models and the decision support system contributes to: (i) overcoming the problem of insufficient data in a data modeling study, and (ii) enhancing our understanding on sequential application of EOR techniques and its effect on heavy oil production. The decision support system for heavy oil production prediction is also useful for assisting the field operator in the selection of an appropriate EOR sequence for a given oil field.

The paper proceeds as follows. Section 2 gives some background on the problem domain of sequential application of EOR for heavy oil production. Section 3 presents the methodology of this study, which includes: (1) the experimental study which focused on investigating the sequential application of the two EOR techniques on heavy oil production, (2) the generation of the larger dataset using the commercial simulation program of CMG, and (3) the development of the correlation models based on the generated dataset. Section 4 shows the results of this study, which includes the assessment of the developed models and some details about the developed decision support system (DSS). Section 5 presents a discussion and suggests some limitations of the developed decision support system; Section 6 gives the conclusion and suggests some directions for future work.

2. Background on sequential application of EOR for heavy oil production

Traditionally, the three stages of primary, secondary, and tertiary production are considered for conventional oil reservoirs. Primary production of oil usually includes the use of solution–gas drive, gas-cap drive, water drive and gravity drive. For heavy oil systems, the primary production of conventional oil is usually rather low and generates only 5–15% of the heavy oil (Lu et al., 2010). The secondary production of oil typically involves utilization of immiscible gas, water, or a combination of both as injection fluid. For heavy oil reservoirs, immiscible gas injection is not an efficient recovery technique, especially when oil viscosity is very high. This is mainly due to the unfavorable mobility ratio which results from the viscosity contrast between oil and the injected gas. In contrast to immiscible gas injection and depending on the oil viscosity, waterflooding is typically useful for recovering considerable amount of heavy oil. For example, after studying waterflood results from viscous oil fields around the world, Beliveau (2009) concludes that simple water flood operations should be used as the base process for improved oil recovery for viscous oil, and recovery could be improved by reducing well spacing and injecting larger volumes of water. Enhanced or tertiary recovery methods refer to techniques applied for recovery other than the ones adopted in the primary and secondary stages. Among these, thermal recovery is one of the primary enhanced methods for heavy and extra-heavy oil; and thermal recovery includes the processes of cyclic steam injection, steam flood, in-situ combustion, and hot water injection (Lu et al., 2010).

The choice of oil recovery strategies is critical for a successful field development. Hence, the selection of EOR technique is important. This process of selection of oil recovery method is referred to as screening and the decision should be made in the early stages of planning for field development. Taber et al. collected and presented the typical criteria for EOR technique screening in a variety of tables and graphs (Taber et al., 1997); the information was gleaned from the literature, or obtained from laboratory experiments, reservoir simulations and past project experiences. Software tools are also available for supporting the screening process. For example EORgui (Petroleum Solutions Ltd., 2012) is a publicly available software, which supports generating a ranking of the appropriate EOR methods based on the fluid properties of a given reservoir. The screening criteria in EORgui are largely based on the criteria available in (Taber et al.,1997).

The conventional recovery of oil is typically conducted by applying primary, secondary and enhanced methods in that order. In terms of application of enhance oil recover (EOR) techniques, however, there has been a lack of study on the effective sequence of applications of EOR techniques and the effect of one technique on the performance of the subsequently applied technique. This is especially true for production of heavy oil. In general, the literature on the concept and process of sequencing of EOR techniques is scarce. In the research work on EOR techniques, it was noted by Mohammadpoor and Torabi (2012) that “the effectiveness or the consequences of the sequence of the application of enhanced oil recovery (EOR) processes have not been adequately identified for light and medium oils, let alone heavy oils”.

To address this gap in research, this paper presents a study that has the objective of building a decision support system that can aid an oil patch operator in selecting an appropriate sequence of application of EOR techniques, with the objective of enhancing heavy oil production. The research approach involved combining an experimental study, a simulation study, and a modeling study, a software system development process. This integrated and interdisciplinary approach was necessary primarily because of the scarcity of data available for describing the problem domain. The integrated approach adopted can be potentially useful for other investigations for which available data are not adequate.

3. Methodology

This study adopts an integrated approach, which includes the processes of: (i) conducting physical experiments for investigating the effect of sequencing of EOR techniques on heavy oil production, (ii) using the experimental data as the basis for generating a large dataset on effect of sequential applications of EOR techniques on heavy oil production using CMG© (Trademark of Computer Modeling Group Ltd.); (iii) conducting modeling of the larger data set and developing three correlation models using the ANN technique, (iv) assessing and selecting the best among the three correlation models developed; (v) incorporating the selected correlation model in a decision support system that models the impact of alternative sequential applications of water-flooding and carbon dioxide (CO_2) injection for heavy oil production

3.1. Experimental study

This section presents details of the experimental set up and procedures that were used for investigating the effect of applying different sequences of waterflooding and CO_2 injection on heavy oil production. The experimental study provided the basis for subsequent development of the simulation model useful for generating a large data set, which was modeled for developing the correlation models and building the automated prediction system.

The first hypothesis to be tested in the experimental study was that the eleven characteristics or parameters about the reservoir and production operation affect the production performance of heavy oil. The eleven parameters are considered the predictors and the production of heavy oil for a given time frame is the predicted parameter. Specifically, the eleven predictor variables of the experiment include: (i) oil viscosity, (ii) reservoir pressure, (iii) reservoir size, (iv) original oil in place, (v) initial oil saturation, (vi) reservoir permeability, (vii) waterflooding, (viii) CO_2 flooding, (ix)