Journal of Petroleum Science and Engineering 157 (2017) 917–929

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

A model-based decision analysis comparing water and polymer flooding in the development of a heavy oil field

V.E. Botechia [*], M.G. Correia, D.J. Schiozer

CEPETRO/University of Campinas, PO BOX 6052, 13.083-970, Campinas, São Paulo, Brazil

ARTICLE INFO

Keywords:
Polymer flooding
Decision analysis
Risk analysis
EOR
Numerical simulation

ABSTRACT

Polymer flooding is an effective means to recover oil although the method creates conditions absent in traditional water flooding, mainly due to the physical phenomena related to this technique, such as adsorption of polymer molecules and non-Newtonian behavior. This work aims to guide the selection, through a decision analysis methodology, of the best strategy option using comparisons between water and polymer flooding projects in a heavy oil field development, under uncertainty, through a risk-return analysis.

The methodology is based on a complete risk evaluation and decision analysis process presented by Schiozer et al. (2015), including the generation of uncertain scenarios, selection of representative models (RM), production strategy optimization for the RM, combination of the strategies in all scenarios, risk-return and risk curves analysis and the selection of the best strategy. The case study is representative of a heavy oil and high heterogeneous reservoir. We combined geological, economic and polymer uncertainties. We use Expected Monetary Value (EMV) as the objective function to measure economic return and Net Present Value (NPV) semi-deviation to measure risk.

The results show that simplified comparisons between these two recovery methods, by only changing the injection fluid may lead to ill-informed decisions, and therefore, pre-planning is needed to realize the advantages from additional polymer costs to choose an optimal strategy. Furthermore, the results suggest that polymer flooding may be a viable alternative in the heavy oil field studied in this work.

1. Introduction

In the oil exploration and production phase (E&P), decisions are made taking into account the inherent risks through assessing the impact of uncertainty on the performance of the oil fields, increasing the probability of success, quantifying potential losses and identifying opportunities (Costa et al., 2008). Decision analysis is an effective tool to guide decision makers through a thorough and logical evaluation of alternative strategies. Its use in oil industry has increased significantly in the past few decades (Evans, 2000).

Uncertainty, to varying degrees, is inherent in all decision-making processes. Including the possibility of loss, resources and information are used to minimize this possibility. When using more advanced technology, such as EOR techniques (e.g. polymer flooding, CO_2 injection, steam injection, spontaneous imbibition) (Lake, 1989; Babadagli, 2003) the complexity and number of uncertain variables are even higher. Several factors may be influenced by EOR; for instance, the wettability for oil-wet or mixed-wet rocks can be changed using chemicals, inducing imbibition (Kathel and Mohanty, 2013).

In the specific case of polymer flooding, which is subject of this work, there are several phenomena related to this technique that are absent in water flooding, such as adsorption (Hirasaki and Pope, 1974; Szabo, 1975; Farouq Ali and Thomas, 1996; Carpita et al., 2006) and non-Newtonian behavior (Lake, 1989; Sorbie, 1991).

The combination of reservoir uncertainties and advanced recovery techniques, with their impact on the performance of the project, allows project risk to be better quantified. Hence, a risk assessment is important to manage risk and increase the probability of success by identifying actions to reduce the probability of outcomes with low return and high exposure (Goodyear and Gregory, 1994).

Most of published screening criteria for polymer flooding recommend that this technique should be used in reservoirs with oil up to 150 cP (Taber et al., 1997; Green and Willhite, 1998; Al-Bahar et al., 2004). However, in recent years, polymer flooding has been studied as suitable recovery alternative for heavy oil reservoirs (Wang and Dong, 2009; Wassmuth et al., 2009; Brooks et al., 2010; Gao, 2011; Kamaraj et al.,

* Corresponding author.
E-mail address: botechia@dep.fem.unicamp.br (V.E. Botechia).

http://dx.doi.org/10.1016/j.petrol.2017.08.014
Received 24 May 2016; Received in revised form 2 August 2017; Accepted 3 August 2017
Available online 5 August 2017
0920-4105/

2011), since it can reduce water cut and improves the displacement sweep efficiency of heavy oil via lowering the mobility ratio and reducing viscous fingers (Levitt et al., 2011).

Decision-making regarding enhanced techniques such as polymer flooding and its comparison with other recovery techniques are complex tasks and must involve a detailed and complete procedure in order to avoid taking wrong decisions. The objective of this paper is to guide the decision maker, through a decision analysis methodology comparing water and polymer flooding, using numerical simulation and economic analysis, in choosing the best recovery strategy in a heavy oil field development in uncertain scenarios, considering risk and return.

The methodology is based on a 12-step decision analysis methodology presented by Schiozer et al. (2015) summarized in Fig. 1a below. This methodology is based on a closed-loop reservoir management (CLRM) (Jansen et al., 2009; Morais et al., 2017), showed in Fig. 1b. The colors of the boxes in Fig. 1a relate to the colors in Fig. 1b.

Steps 1 and 2 (green steps) are related to model construction and the numerical consistency. In order to have precise risk quantification, it is necessary to rely on the response of the model for each scenario created. Therefore, it is necessary to calibrate the simulation model to have a fast and robust response.

Steps 3 through 5 (red steps) relate to calibration of the model using history data, uncertain scenarios generation and reduction of these through dynamic data. Possible approaches in these steps are probabilistic history adjustments and seismic integration (Maschio et al., 2010; Davolio et al., 2013).

The Steps 6 to 11 (blue steps) are related to production forecast and decision analysis, passing through the optimization of the production strategy of the base model, elaboration of an initial risk curve, selection of representative models and selection of the production strategy under uncertainties. In these steps, final evaluations are also carried out in order to improve the strategy, for example, with integration with production facilities, value of information and value of flexibility and robustness. The final step (12) consists of the final decision analysis.

For this work, the simulation model was already calibrated and hence the calibration of the model (Steps 1–2) and the history matching (Steps 3–5) are not scope of this study. This is a continuation of the work presented by Botechia et al. (2016), which focused on Step 6. We focus here on prediction steps (Steps 7 to 12) of the aforementioned methodology.

2. Methodology

Since we are not concerned here with the calibration of the model and the history matching, we describe only steps 7 to 12 below. Details of the steps that are not addressed here can be consulted in Schiozer et al. (2015) and Botechia et al. (2016).

Step 7 – Quantification of the initial risk.

Botechia et al. (2016) shows the deterministic optimization for the base case (Step 6), highlighting the importance of considering the recovery mechanism in the optimization process. Thus, through the base case two production strategies were generated, one considering polymer flooding and other one considering water flooding.

From Step 7 onwards, the analysis becomes probabilistic (uncertain parameters are included in the process). In Step 7, we first estimate risk curves (graphs linking decreasing values of the objective function with their associated cumulative probabilities) using both optimized production strategies presented in the aforementioned work. The risk curves are built separately for each strategy.

To generate the risk curves, we perform the following procedure:

- Create uncertain scenarios (simulation models) by combining geological uncertainties using probabilities distributions and statistical techniques;
- Simulate the production strategies (in the case of this work, two production strategies so far) in each simulation model;
- Calculate the NPV resulting from each simulation and sort them by descending order with their respective probability of occurrence.

In this work, we consider that the uncertain scenarios have the same probability of occurrence. The Application Section of this paper shows the uncertainties used and how they were combined. In this step, all scenarios are simulated with the base case strategies.

Step 8 – Representative models (RM) selection.

According to Santos and Schiozer (2003), in a risk analysis process it is important to consider the production strategy as a variable, because there is no guarantee that the optimal strategy of the base case is the best for all uncertain models. The complete procedure should optimize a strategy for each model generated by the combination of uncertain attributes and apply them in all models, checking which strategy is best for all scenarios. However, this procedure requires high computational cost and effort, sometimes making the process unfeasible.

Thus, one way to maintain the quality of the results and reduce the computational effort is using *Representative Models* (RM), which can represent the variability of the geological model, combining uncertainties in a small number of simulation models, significantly enabling the analysis (Schiozer et al., 2004; Costa et al., 2008; Marques et al., 2013; Schiozer et al., 2015).

The representative models are selected based on the models that

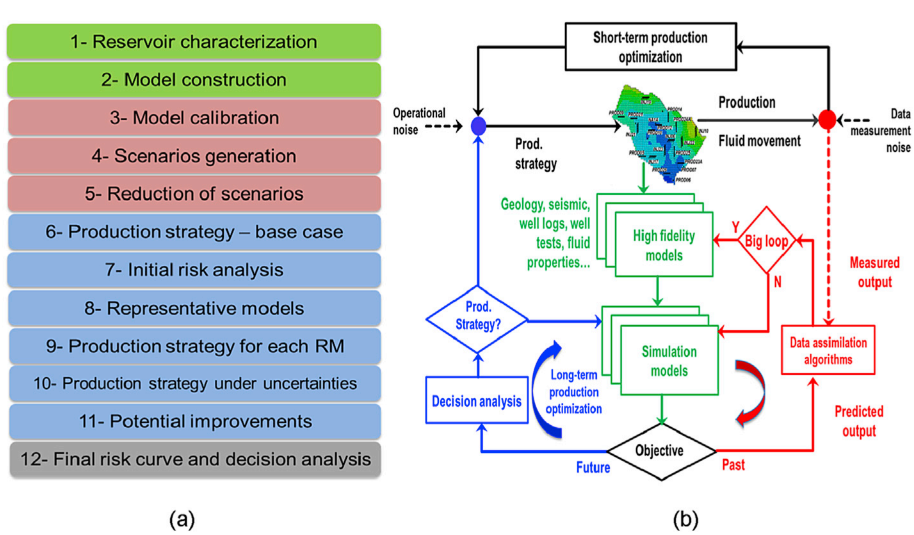

Fig. 1. (a) 12 steps methodology proposed by Schiozer et al. (2015) (b) Closed-loop reservoir development and management (Adapted from Jansen et al., 2009; Morais et al., 2017).