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Sidetrack and recompletion risk evaluation — Waterflooded reservoir

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ABSTRACT

Sidetrack or recompletion time (t_R) is optimized for the pair of a production and injection well simultaneously under uncertainty with respect to expected monetary value (EMV) or risked net present value (NPV) as the objective function to properly understand and shed more light on the critical parameters influencing t_R. The option to sidetrack or not is also evaluated. Analysis is aided by a recent time dependent analytical waterflood performance model with respect to cumulative injected water for adequate economic analysis. There exist two zones, a productive and lower zone and a lesser producible upper zone that has low recoverable reserves, of which both zones are penetrated by both wells. The injection well enhances oil production in the production well by the displacement mechanism of waterflooding. Though sidetrack is simultaneous considering negligible time interval between sidetrack of both wells, it is actually a sequential operation with regards to the decision tree schematic. A possible outcome is, if sidetrack to produce from the upper zone fails, then no sidetrack to the upper zone through the injection well.

Decision tree analysis is brought to fore considering the probability of success (POS) of continual production (injection) from (to) the producing zone and production (injection) commencement possibility for the upper zone. Uncertainty of parameters including POS in evaluating the objective function, EMV, is made possible by probable values using distributions for Monte Carlo simulation run. EMV and t_R are optimized for each run by constraining t_R to either, after water breakthrough time to the lower zone or from time 0. The objective function is solved with a constrained non-linear generalized gradient optimization scheme.

Significant match was obtained for waterflood performance, and NPV of each terminal branch of the decision tree between the analytical approach and reservoir simulator generated data. Notably, optimal t_R obtained through the analytical approach is highly dependent on POS of production and injection from (to) the upper zone. Evaluation of possible dependencies of POS is essential as regards to the sequential operation brought largely by geological uncertainties and may be to a lesser extent by the sidetrack operation based on the influence of probable pathways. Other criteria for selection of optimal time are more suitable for selection of an optimal range and not a single value. These criteria in essence, boost the EMV and cannot stand alone as an optimization tool.

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1. Introduction

Lerche and Noeth (2004) extensively covered sidetrack and recompletion risks in oil fields. The compendium of papers commenced first with relative contributions to uncertainties for reserve estimation to geological uncertainty of potential leaks due to the uncertainty of fault existence for resource estimation and then to maximizing profits of oil field development using net present value (NPV) solely based on exponential oil decline as previously applied by Nind (1981).

Earlier on, Johnson and Mather (1991) evaluated recompletion time based on enhanced recovery by steam flooding of sequential production from multiple zones without considering commingling or simultaneous production from the zones. This was a deterministic approach that lacked possible sidetrack operation outcomes or uncertainties of key parameters. That of Lerche and Noeth (2001a) evaluated the uncertain parameters affecting risked NPV or expected monetary value (EMV) and the means of ascertaining the choice of sidetrack (recompletion) over no sidetrack as a decision analysis problem. The optimal recompletion time was also considered through the maximization of risked NPV (Lerche and Mudford, 2001; Lerche and Noeth, 2001b, 2001c). While the evaluation of Johnson and Mather (1991) is based on multiple wells of a single flood pattern unit, Lerche and Mudford (2001) focused on primary recovery of a production well under exponential decline as utilized by Nind (1981) for maximizing field development. The subsurface configuration by Lerche and Mudford (2001) was of 2 separate zones with a lower productive zone and an upper, less producible zone with the possibility of commingled or simultaneous production

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from both zones. However, in sidetracking (recompleting) the well to produce from the upper zone for simultaneous production of both zones, the possibilities of killing production from the lower zone and the success of sidetrack (recompletion) of the upper zone are considered. This leads to the application of decision tree and optimization scheme application.

Another view of sidetrack is that of real time evaluation of a drilling operation by tying the probability density function of productivity and injectivity of a geothermal reservoir to cost as a means of deciding to sidetrack from the particular zone under evaluation (Grant, 2009). This application neither considers geological and operational uncertainties, nor NPV.

This study bridges the gap between Johnson and Mather (1991) and Lerche and Mudford (2001), but, focuses on sidetracking (recompleting) a pair of production and injection well simultaneously. Water injection is considered and performance data from a synthetic-field (syn-field) is used. Oil production is hinged on waterflood performance with a direct link to injection rate, though uniform rate. Production performance is based on a nascent analytical production decline model for water displacement (Yang, 2009) that incorporates estimation of volumetric sweep efficiency where cumulative liquid production is approximately equal to cumulative water injected with adjustment catered for by voidage replacement ratio (VRR).

Yang's model is based on 1-D Buckley–Leverett equation and applicable to performance of water-cut (f_w) above 50%. Hence the method is not particularly adapted for intralayer heterogeneity within a zone without some considerations. The model is applied for time above water breakthrough to avoid determining the time at which water-cut is equal to 0.5. So, instead of an approach to estimation of performance from beginning of production to f_w of 0.5, average production rate is applied from the beginning of production to water breakthrough time (t_{BT}). This is based on 1-D displacement efficiency. The average production rate is the ratio of cumulative production at breakthrough time to breakthrough time. Hence for intralayer heterogeneity an average breakthrough time is applicable ensuring that the average performance from this can be modeled by the model. In support of prediction from t_{BT} by using Yang's model, Lausten (1996) highlighted the need for significant water breakthrough prior to oil decline curve fitting for the case of pressure supported reservoir and multi-layer. The reduction approach of complex 2-D to 1-D as explained in Dake (2001) for layers with vertical pressure equilibrium within a zone, multilayer can be averaged by 1-D. For lack of communication between the layers, an equivalent average can be computed using the Stiles or Dykstra–Parsons method as elaborated in Dake. This approach is commonly applied to the generation of pseudo relative permeability for simulation study. For high accuracy, optimal sidetrack time may be evaluated with a constraint of sidetrack time being equal to or higher than water breakthrough time for cases that deviates from 1-D. In addition, the reliability of the Yang's model as a prediction tool shall be compared with production performance from a commercial reservoir simulator. This shall be based on a syn-field.

Optimal sidetrack (recompletion) time is sought for production well under waterflood displacement from an adjacent well that both penetrates an existing producing zone (Zone-B) that is isolated from a producible Zone-A. Both zones are homogeneous. Sidetrack is required for both wells simultaneously. Zone-A is on an upper horizon compared to Zone-B in a lower horizon. Furthermore, the zones are not in vertical communication and are independent entities as shown in Fig. 1. The zones are assumed separated by impermeable shale with no pressure communication. Hence, this approach is suitable for multiple zones without pressure communication.

In evaluating the optimal sidetrack time, simultaneous sidetrack is used and not sequential sidetrack of both the production and injection wells. The word simultaneous is used due to neglecting the time interval between sidetrack of both wells. However, sequential

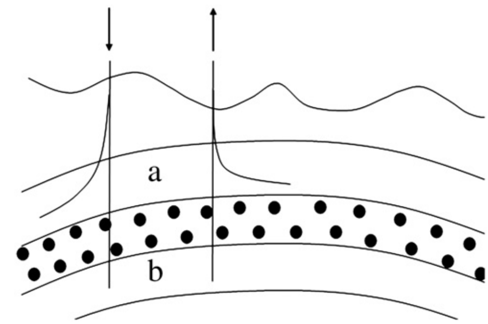

Fig. 1. Subsurface illustration of multiple zones of productive Zone-B and possible recompletion (sidetrack) into producible reserves of Zone-A.

makes room for dealing with uncertainties as modeled in a decision tree schematic that has only one decision node of either to sidetrack or not (Fig. 2a–b). The sequential chance nodes due to uncertainties is as a consequence of the probability of not killing production from the lower zone and that of significant or no production from the upper zone to be brought on stream. The others are probability of not killing injection into the lower zone and failure of water injection into the upper zone is also considered (see Fig. 1). Injection failure either to the upper zone or lower zone calls for oil production performance prediction by Arps' rate–time decline model due to pressure decline as the major production mechanism. This is further elaborated under the Production forecast subsection.

Optimal sidetrack time is by maximizing the risked NPV (or EMV). Optimal time is not only based on EMV (risked NPV) but also on statistical tools of volatility which is related to deviation from EMV to know for a fact that computed EMV is useful for sidetrack time estimation. The other is probability of profitability of sidetrack over the no sidetrack option to know if sidetrack is necessary and the range of admissible t_R. Critical parameters shall be evaluated and the uncertainties of parameters in the model are represented by a distribution of likely estimates for Monte-Carlo simulation. In addition, the NPV of each terminal branch (Fig. 2a) shall be evaluated by the analytical method presented in this study and production performance from a reservoir simulator for comparison.

The probability of success of injection to the upper zone and producible oil from the upper zone lies on geological uncertainty related to estimated reserves, communication between injector and producer, potential leaks (uncertainty of fault), compartmentalization and ill-defined reservoir heterogeneity (Lerche and MacKay, 2004; Newendorp and Schuyler, 2000; Suslick and Schiozer, 2004; Zabalza-Mazghani et al., 2004).

2. Recompletion (sidetrack and recompletion) time

2.1. Decision tree

Lerche and Mudford (2001) presented a decision tree for sidetrack or recompletion time analysis based on a production well. This case extends the application to the scenario of a production well under water displacement from an injection well. The wells configuration and decision tree schematic is as shown in Figs. 1 and 2a–b.

The well configuration shows two zones, A and B, with Zone-B being of more commercial benefit as a result of its high producible reserves and Zone-A of less reserves or below commercial exploitable reserves due to current technology or otherwise. The decision tree as compared to that of Lerche and Mudford (2001) adds on the probability of success (POS) of continued injection to Zone-B and the success of injection into horizon-B for production enhancement by

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