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Assisted optimization method for comparison between conventional and intelligent producers considering uncertainties

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ABSTRACT

In this article, an assisted optimization method was proposed to establish a comparison between conventional and intelligent producers, considering geological and economic uncertainties. To do this, we presented a methodology divided into three main parts: (1) well module, which deals with the optimization of each type of well and performs a deterministic decision between one type or another according to the maximum NPV reached; (2) field module, which applies the well module in each well of the field; and (3) uncertainty module, which employs the production strategy obtained in all geological models and economic scenarios, performing the probabilistic decision considering maximum EMV and risk-curve analysis, firstly considering, at the decision time, the geological models and economic scenarios as “known”, with a low degree of uncertainties, and later, as “unknown”, with high degree of uncertainties. The optimization of two types of wells was made considering the optimization of regions with completion in the conventional producer wells (CW) and optimization of number and placement of valves for intelligent producer wells (IW) before performing an appropriate decision analysis with the results of all geological models and optimized economic scenarios. The optimization process consists of a hybrid optimization method, comprising a fast genetic algorithm to perform global optimization and a nonlinear conjugate gradient method to perform local optimization. The methodology was applied to a heterogeneous reservoir model, with four horizontal producers and four horizontal injector wells. The results show a clear difference with and without the methodology proposed to establish a comparison between two types of wells. This comparison includes the results of IW with three types of control, reactive and two kinds of proactive control. The results also showed, for a low degree of uncertainties at the decision time, an advantage in using IW with at least one form of proactive control to enhance oil recovery and NPV, reducing water production and injection in most cases. For models and scenarios with high degree of uncertainties, IW with any type of control were not recommended, showing to be essential, especially for proactive controls, have good knowledge of reservoir characteristics in order to exploit the benefits of these wells.

1. Introduction

The development of an oil field involves many challenges, among them: (1) maximizing profit, (2) increasing oil recovery, (3) decreasing high water flow, since high flow can be a limiting factor in oil production, (4) reducing the number of interventions in the wells, as this process temporarily paralyzes production and has high costs and operational risks, and (5) reducing project risk, since at the beginning of developing the field there are many uncertainties about the characteristics of the reservoir, about economic factors at the time of production, and also the operational factors involved.

One of the possible technologies used in this process and that has been an option for the development of a field is the IW, which has sensors that receive production data in specific sectors of the well, and inflow valves that control the flow of production according to the data received by the sensors. This type of completion allows greater operational flexibility, enabling us to perform actions over the course of production and overcome the challenges described above, mitigating the uncertainties in this complex activity. Because this is a more expensive technology than a conventional well, these wells require more careful evaluation, since

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the potential benefits need to be estimated in the context of uncertainties, and a possible increase in cash flow may occur after some years of production.

However, the lack of a methodology for comparing between IW and CW often creates difficulties in the evaluation process, and therefore in the implementation of these wells. Another problem is an unfair comparison between two options, due to fact that IW and CW are not optimized in the best way before being compared. The CW is not optimized in terms of completion and the IW is not optimized in terms of number and placement of valves (Silva and Schiozer, 2009; Almeida et al., 2010). This is due to the fact that an evaluation of valve operation in the early stage of the field, in the phase of development planning, involves a large number of variables when representing future operations, which in turn leads to greater difficulty in solving the problem through classical optimization methods. This phase is the focus of this article. This complexity increases with the number of valves in the well and the number of IWs evaluated in the simulation model, which is used to estimate possible gains.

The objective of this work is to create a methodology to optimize IWs and CWs, only producers, in order to realize an appropriate comparison between both types, establishing an optimized production strategy with IWs and CWs in an oil field. To do this, the development of an efficient optimization process was required to allow for a fair comparison between wells, seeing as how many works of literature employ valves with arbitrary number and placement, probably being used in a non-optimal condition, thus compromising the comparison. This procedure also led to a reduction in the number of variables and possibilities studied, evaluating only the optimal number and placement of the valves in the IW and zones with completion in the CW.

The efficiency of the optimization algorithm is due to the fact that the fast genetic algorithm (FGA), used in this work, uses various genetic operators described in the literature as being the most advanced and that provide greater efficiency in the search for the global solution. For local optimization, nonlinear conjugate gradient (NCG) was chosen to be one of the most efficient methods. However, this work does not test the increase of efficiency, although it is widely supported in references.

Therefore, the main result was an appropriate analysis of these wells in a context of economic and geological uncertainties. Through the proposed method, we can also analyze the economic feasibility of putting valves in the producer wells.

2. Literature review

Many optimization methods have been proposed, but their use is impractical in the initial development of the field. Thus, many studies attempted different optimization methods to solve this problem, but most studies employed simple cases: simulated annealing (Kharghoria et al., 2002), conjugate gradient (Kharghoria et al., 2002; Yeten et al., 2002), gradient-based methods (Aitokhuehi and Durlofsky, 2005; Sarma et al., 2005; Van Essen et al., 2009; Yeten et al., 2004), direct search (Emerick and Portella, 2007), ensembles (Su, 2009), Lagrangian augmented method (Doublet et al., 2009), among others. Although some of these studies have shown certain advantages of one method over another, many of these are based on gradients, presenting difficulty in finding a global solution because a local solution can easily reach the stopping criteria.

An important advance was achieved by employing evolutionary computation methods such as genetic algorithms (Alghareeb et al., 2009; Almeida et al., 2010), an efficient method of global optimization in sweeping for the optimal solution, or very close to it, in a feasible computational time but still dependent on the complexity of the reservoir model, the number of variables used (number of valves), and the computational power available. Despite being an efficient global optimization method in scanning for solutions, genetic algorithms are not efficient in finding the local maximum. Thus, only using these algorithms can generate an unreliable result, because results do not guarantee the optimal solution, but only a good solution that is close to the optimal solution (depending on the parameters used, if genetic convergence was reached). Therefore, it becomes necessary to refine the best solution found by another type of algorithm.

The operation of inflow control valves (ICV) can be done basically in two different ways: proactive (defensive) or reactive control. The first operates to prevent an undesired future event; and in the second, the control reacts to a specific undesirable past event to guide the ICV operation (Brouwer, 2004; Ebadi and Davies, 2006; Addiego-Guevara et al., 2009). In theory, proactive controls should yield better results, because they are a type of control that operate before an undesired event occurs. There is no consensus in the literature about the definition of proactive control; in this work, the undesirable event is a negative cash flow (for the valve) and the term proactive is used in order to close the valve at any time before this event. However, this type of control is only possible when there is a good knowledge of the reservoir and confidence in prediction tools, but this is very appropriate to evaluate the potential of production of an oil field, mainly in the phase of strategy selection.

3. Methodology

The methodology was elaborated to allow for a comparison between CWs and IWs, both optimized in the best possible way, and to establish one production strategy considering both types of wells in an environment of geological and economic uncertainties.

3.1. General methodology

First, before applying the “Well Module,” it was necessary for us to determine the order in which the analyses would be carried out well to well. To do this, valves are placed in all blocks in all wells of the model, and the optimization of valves was performed via reactive control. With the optimal closing time of each of the valves in each of the wells, we find what use of valves has the most potential to bring the greatest benefit relative to conventional completion. This happened in wells where there is an uneven distribution of closing among valves occurs unevenly and not too late, demonstrating a potential for the use of valves. Taking this into account, we create a list of wells that will be optimized one by one.

3.1.1. Step 1: well module

This step consists in optimizing one well in the field, firstly as a CW, and afterwards as an IW, choosing between the two options. For a CW, optimization involves finding the best arrangement of completions to be performed along the well, then to maximizing the NPV in order to find the water cut limit. Optimization of the IW starts with the optimized result found for the CW, because the valves are only tested in regions with completion resulting from the optimization performed. As for the IW, optimization involves finding the number and placement of valves that maximizes NPV, using reactive control to optimize the operation of valves. After optimization of the two types of wells, a deterministic analysis was carried out to decide between putting valves in the well or not. Fig. 1 shows the well module flowchart.

This article uses as project variables the regions with completion in the CW and the number of valves in the IW, and as control