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Optimal placement design of inflow control valve using a dynamic optimization process based on technical and economic indicators

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ABSTRACT

The placement design of inflow control valves in petroleum wells is based on the viability of their installation to improve the flow control from the reservoir to the well. Reservoir simulation is frequently used to represent valve operation and the forecasted production results are used to evaluate the benefits. In specific cases, the high number of variables involved in this problem and the time-consuming reservoir simulation makes traditional optimization methods inefficient to solve the problem within an adequate time frame. This work proposes a dynamic optimization process that uses economic and technical indicators to speed up the process. The main goal of the method is to reduce the number of variables and the search space of the problem by prioritizing well regions where a valve operation has more technical and economic potential. To assess the effectiveness of the proposed method, its results are compared with those of an evolutionary algorithm using a simple example. The methodology is also applied in a more complex example with different geological scenarios. The results show that the proposed method achieves good results when compared with the evolutionary algorithm. The design optimization in a complex example shows that the dynamic process is able to significantly increase the NPV of the field with an acceptable number of simulation runs. It is also shown that the use of economic and technical indicators can be applied to reduce the number of variables, to define suitable constraints for each variable and to help the initial seed-guesses for the optimization method. It is concluded that the proposed methodology can be efficiently used to optimize inflow control valve design in cases in which computational resources and available time are limited.

1. Inflow-control-valve design in the petroleum industry

The installation of valves and monitoring sensors applied to specific completions of petroleum wells have been used to improve oil recovery, to increase profits, and also reduce risks of an early production of undesirable fluids. One option is the use of inflow control valves (ICV), which have surface control and monitoring mechanisms. The main idea of ICV applications is to introduce flexibility, with additional information, to manage production more efficiently. Wells which are completed with this technology are called intelligent or smart wells in petroleum field management (Aitokhuehi and Durlofsky, 2005; Almeida et al., 2010; Alhuthali et al., 2010; Doublet et al., 2009; Yeten et al., 2004).

Conventional design of petroleum wells does not include the use of ICV and downhole sensors. The wellbore and the production interval are directly connected and it is not possible to monitor and control the flow without well interventions. The new technologies to install and operate downhole equipment from the surface facilitate the application of control valves. Therefore, the evaluation of control valve application is a real procedure in companies and, due to the cost of these control valves, it is necessary to make appropriate assessment of the ICV application.

A petroleum field may have several valves installed in many wells and at different depths in a specific well. The determination of the optimum placement design of ICV is a task that involves many decision variables and a large solution space. Furthermore, the determination of ICV design depends of an adequate solution for the ICV operation while a field operates. This fact significantly increases the complexity of the problem. In general, the system formulated to solve the ICV design can be considered a large complex system from a mathematical viewpoint.

Another question related to ICV design is the multidisciplinary focus of the problem. The use of reservoir simulation to evaluate ICV may involve engineers, geologists, economists, etc. The optimization and results are evaluated for an interactive process. In addition, the determination of an optimum ICV design may be included in a larger problem of an exploitation strategy. Therefore, due to the time required for a single simulation, the integration of teams and the fact that the problem is a specific part of a larger problem, an

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Nomenclature

α	distance coefficient
λ	mobility ratio, dimensionless
Ω	set of economic parameters
C_{ICV}	discharge valve coefficient, dimensionless
C_u	cost of undesirable fluid, monetary value
CF	cash flow
$d^{i,j}$	distance between two packers that isolate the ith ICV in the jth well
d_{max}	maximum economic distance between packers (L)
d_{min}	minimum economic distance between packers (L)
F	volumetric flow rate (L^3/T)
$f(n_v, \hat{u}, \hat{v})$	the objective function that should be maximized
fm	fluid mixture index
g_j	the jth constraint from m inequality constraints
I	matrix of indicators
i	ICV index
ICV	inflow control device
j	producer index
k	time index
k_{max}	total number of considered times
m	total number of constraints
n_v	total number of ICV
NPV	net present value
ΔP	pressure drop ($M/L^2/T^2$)
PBH	well bottom hole pressure ($M/L^2/T^2$)
P_r	reservoir pressure ($M/L^2/T^2$)
PI	productivity index
p	total number of fluid phases
ph	fluid index of a mixture
R	total number of regions
r	WMR index
$s_1^{i,j}$	upper boundary position of the ith ICV in the jth well
$s_2^{i,j}$	lower boundary position of the ith ICV in the jth well
s	position point in a well trajectory
sg	specific gravity, dimensionless
t	time (T)
t_{sd}	shutdown time (T)
$\hat{u}^l$	design constraints for lower boundaries
$\hat{u}^u$	design constraints for upper boundaries
$\hat{u}$	design vector
USD	American dollars
$\hat{v}$	placement design vector
$\hat{w}$	control design vector
WT	well trajectory function
wl	well length (L)
WCT	water cut
WMR	well monitoring region
x	fraction of the valve opening, dimensionless

efficient optimization plan must to be developed to reach a reliable solution in a suitable time.

2. Objective

The objective of this work is to propose a dynamic optimization process to optimize inflow control valve placement design. The main goal of the proposed optimization process is improve the performance of alternatives evaluations for an environment where the available time and the computational resources are limited. The process is based on the generation of technical and economic information to identify and select more plausible alternatives. The process obtains the best solution through the use of serial procedures associated with optimization methods. It aims to find a good solution with a low number of simulations instead of the high number that are generally required when traditional mathematical methods are used.

3. Evaluation of inflow-control-valve design

Several scientific studies have been developed to evaluate ICV optimization problems using reservoir simulation and applying different methods. In this section, the main forms proposed in the literature to evaluate ICV are shown and the need for a new methodology to solve practical problems of industry to determine ICV placement design is discussed.

Considering reservoir engineering aspects, ICV problems can be classified in two different types: control optimization and placement design optimization. Basically, control optimization is used to determine the best operation for valves in a specific time and placement design optimization is a tool to select the best number and position of valves. However, the selection of the placement design also includes the control optimization, even in a more simplified way, due to ICV value only can be estimated based on the future benefits provided by an adequate control. Hence, control optimization aspects are important in studies of placement design.

In general, ICV optimization problems have a high number of decision variables involved. The problem description and the proposed methods to solve it may lead to hundreds of decision variables in a single well evaluation, due to the flexibility that allows the continuous change of a valve operation in time and the many possibilities of positioning them in the wells (Aitokhuehi and Durlofsky, 2005; Almeida et al., 2010; Alhuthali et al., 2010; Doublet et al., 2009; Yeten et al., 2004; Zandvliet et al., 2007). Considering cases with several wells, the problem may be quite computational expensive and its cost may be prohibitive for reservoir simulation use. Therefore, the development of methodologies to select ICV placement design must consider large-scale problem aspects.

Some works have proposed improvements and adaptations in mathematical methods such as gradient-based (Aitokhuehi and Durlofsky, 2005; Almeida et al., 2010; Yeten et al., 2004; Zandvliet et al., 2007) evolutionary algorithms (Alhuthali et al., 2010), based on Kalman filters (Doublet et al., 2009; Nævdal et al., 2006), among others, to speed up control optimization. Even though they could be solved with the proposed methods, they would require thousands of simulation runs and, in certain cases, it cannot be done. Other tested alternative is the use of experimental design and surrogate models, or meta-models, to imitate reservoir simulation response to avoid time consuming reservoir simulations (Yin et al., 2012; Zubarev, 2009). However, the process may also require a high number of simulation runs to create a reliable response surface and generate a surrogate model. In addition, the surrogate methodologies are not sufficiently tested in ICV studies.

Placement design problems are generally solved considering a fixed strategy for number and position of ICV and carrying out a control optimization to evaluate if the strategy is economically viable (Dehdari and Oliver, 2012; Doublet et al., 2009; Emerick and Portella, 2007). Therefore, in practice, only control optimization methods are used to evaluate a few numbers of alternatives of placement design. The strategy is based on geological aspects and reservoir engineering experience. It can be a suitable methodology