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Optimisation of the wells placement in gas reservoirs using SIMPLEX method

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Abstract

This paper presents novel optimisation model to evaluate the optimal number of wells for underground gas storage operations. More specifically, generalized well-placement scheme has been formulated to minimize the total number of wells required to fulfil prescribed multiple constrains including wells interference. The scheme integrates nonlinear models of reservoir and well performance. The optimization problem has been formulated mathematically and solved by iterative use of the SIMPLEX method. The method is dedicated to gas reservoirs or underground gas storages management. The method may be useful as a base for more detailed numerical reservoir simulation. The paper is illustrated by a field example related to optimisation of the production cycle of the underground gas storage in Poland.
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Keywords: Reservoir simulation; Optimization; Well placement; Simplex method

1. Introduction

The problem of optimal well management and placement for underground reservoir exploitation up to date remains not fully solved. Well-known solutions are applied to so-called ground water management problem (Gorelick, 1983; Kinzlbach, 1986), where the optimisation is usually reduced to maximizing the total rate of production over given set of wells or water intakes. Only rates of individual wells, intakes or grid blocks are optimised whereas the well number and locations are not a subject of a full optimisation. Usually linearized mathematical models are used and from a mathematical point of view, the problem may be reduced to a linear programming application. A similar approach was presented by Fang and LO (1996) in application to gas/oil reservoirs. The problem of determination of the optimum position of several wells, producing from a two-dimensional closed-boundary reservoir, to maximize the cumulative production was investigated by Camacho et al. (1996). The solution presented in that work is based on analytical flow model and may be applied for homogeneous reservoirs. In practice, the problem of optimal well number and placement is usually solved by use of the trial and error procedure in combination with multi-variant reservoir simulation. An example of this method applied to the underground gas storage was presented by Siemek et al. (1997). Gharbi (2004) used similar approach to optimize the oil recovery from a carbonate reservoir. McVay and Spivey (2001) presented the procedure using multiple simulations to determine the maximum performance of the gas

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storage with a minimal number of simulation runs. Hazlett and Babu (2003) addressed the problem of optimal well placement in heterogeneous reservoir.

In their paper, a reservoir was decomposed into interacting regions, each with its own reservoir properties and associated semi-analytic flow solution. Optimal well position was determined using gradient search routine to iterate on well position until drawdown per unit of fluid withdrawn, was minimized. Davidson and Beckner (2003) addressed the problem of well rates setting in a facility network of a reservoir simulator so that production objectives are optimized. Their paper is focused on the modelling of the production facilities (the wells, flow lines, separators etc.). Handley-Schachler et al. (2000) provided iterative approach for the optimization of gas production networks using sequential linear programming. In this approach, the first step was to build a linear approximation to the original mathematical model that was solved using the SIMPLEX method. If this solution fulfils the nonlinear constrains, the process is terminated, else it is continued by building a new linear approximation to the original mathematical model. Similar approach is presented in the present paper, but in relation to the optimization of the wells placement in gas reservoir. Montes et al. (2001) and Guyaguler and Horne (2001) used genetic algorithms to optimize the objective function related to the well placement problem. Recently, Ozdogan and Horne (2004) proposed modified hybrid genetic algorithm to find the optimum locations of the wells using time-dependent information. Norrena and Deutsch (2002) presented geostatistical approach based on the simulated annealing method, particularly well suited to optimizing highly combinatorial problems such as the static problem of selecting wells locations. The static problem does not account for the dynamics of fluid flow. The static plan may be adjusted to a dynamic plan with the aid of a flow simulator. The process is iterative and similarly as the methods mentioned above, requires multiple simulations. This process can be expensive in terms of professional and CPU time.

In this paper the alternative technique is proposed which is based on the physics of fluid flow in porous media. In outline, the method proposed in this paper is based on the following assumptions:

1. the reservoir is divided into N zones of uniform parameters e.g. by introducing the coarse grid
2. each zone may include or not a number of wells
3. mass transfer between zones and wells interference is taken into consideration
4. the objective is to minimize the number of wells
5. constraints are as follows: total rate required Q_t, minimal and maximal pressures ($P_{\min,j}$ and $P_{\max,j}$), minimal and maximal number ($N_{\min,j}$, $N_{\max,j}$) of wells acceptable in the j-th zone, $j=1,\ldots, N$
6. optimisation model is linear but mass transfer model is not linear
7. the method is to be useful for gas reservoirs or underground gas storages.

2. Mathematical model of gas reservoir

According to assumption 1 the reservoir may be represented by a set of vectors of the form X_j, where X_j represents a particular property of reservoir e.g. permeability or maximal number of wells acceptable in the j-th zone. The schematics of conceptual model of reservoir is sketched in Fig. 1.

Assuming the no-flow boundary conditions, the mass balance equation for the j-th zone at each time step is:

$$\mathrm{Vg}_j^t + \sum_{i \in I_j} W_{j,i}^t \Delta t - Q_j^t \Delta t = \mathrm{Vg}_j^{t+\Delta t} \tag{1}$$

where the second term represents the total flow from the j-th cell into neighbouring cells I_j, (obtained by summing over the cells neighbouring to j-th cell) and:

Vg_j^t, $\mathrm{Vg}_j^{t+\Delta t}$ Volume of gas at reservoir condition in the j-th zone, at the time t and $t+\Delta t$ respectively
$W^t{}_{j,i}$ Volume of gas flowing for the period $[t, t+\Delta t]$ from the zone j-th to the zone i-th, where i refers to j neighbourly zones
Q_j^t Change of gas volume in the zone j-th per time Δt, related to the acting of an external source,

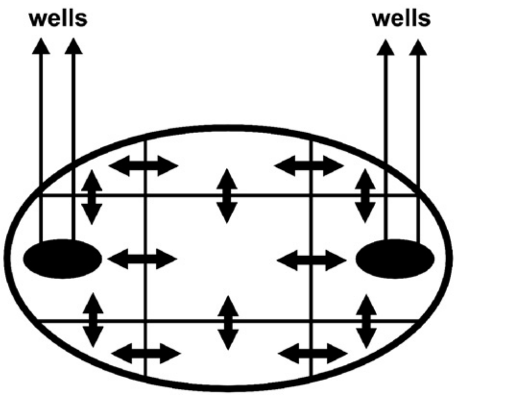

Fig. 1. The conceptual model of reservoir containing 9 zones, 2 of them acceptable for wells placement.

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