SELECTION OF ALTERNATIVES FOR OIL FIELD DEVELOPMENT BY GENETIC ALGORITHMS

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ABSTRACT

This paper presents a Genetic Algorithm application for selecting the best alternative for oil field development under certainty. The alternatives in this study are related to the arrangement of wells in a known and delimited oil reservoir and serve as a basis for calculating the net present value, which is used to assess the optimization process: the optimal alternative is the one that maximizes the Net Present Value of the field. The results obtained have revealed that the Genetic Algorithm model was able to find good alternatives for the oil field development, achieving good results for the Net Present Value

Key words: Oil Field Development, Genetic Algorithms, Reservoir Simulation

INTRODUCTION

The main task of reservoir engineers consists of developing a strategy for producing the greatest possible amount of hydrocarbon within the existing physical and economic limits. The level of production is determined by two issues: the exploration system to be installed *in situ* and the real geological reservoir.

Reservoir modeling involves many variables and parameters that are inserted as inputs into a simulation system which, in turn, provides a production forecast profile for the configuration that was given by the input variables and parameters [1].

The fact that it is possible to obtain different production profiles for different configurations suggests the development of an iterative method for finding a configuration that is capable of providing the best strategy, in other words, the optimal alternative from the economic point of view.

This problem involves an optimization process, which demands an *objective function* and a suitable optimization method. Therefore, this paper employs Genetic Algorithms [2] for the maximization of the *Net Present Value*, which is calculated according to the oil price and the oil production profile provided by a reservoir *simulator* [3].

An alternative in this optimization process is defined a the number and location of production and injector wells in a oil field. Thus, the optimization of an alternative consists c finding the number, location, and type of wells that are expecte to maximize the NPV.

Section 2 describes the whole optimization systen composed of a Genetic Algorithm, a reservoir simulator and module to calculate the NPV. Section 3 presents the result obtained with the proposed model and Section 4 contains th conclusions of this study.

OPTIMIZATION SYSTEM

The optimization system is made up of three main block the Genetic Algorithm, the IMEX Reservoir Simulator [4], an the Net Present Value Calculation Module. The Geneti Algorithm generates the set of variables and parameters th configure the alternative. The alternative is then submitted t the Reservoir Simulator, which supplies the Production Curv which in turn serves to calculate the Net Present Value (NPV In order to close the loop, the NPV that has been calculated i inserted into the Genetic Algorithm as the evaluation value c the alternative (chromosome). The framework of the propose optimization system is showed in Figure 1.

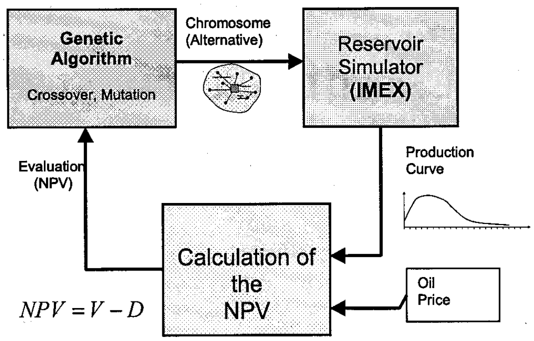

Fig. 1 - Optimization system framework.

CHROMOSOME REPRESENTATION

In this application of Genetic Algorithms (GAs), each chromosome in the population represents a development alternative to be evaluated.

The proposed chromosome representation is the following: one chromosome in the GA represents one complete alternative, i.e., a certain distribution of wells within the oil field.

A field is represented in the simulator by a grid with active positions and, in certain cases, inactive positions. The position of each gene on the chromosome is associated with the position $(i; j)$ in the active grid of the reservoir, where i is the horizontal, and j, the vertical axis, and the value $(i; j) = (1,1)$ represents the first active cluster in the upper left-hand corner. In other words, the chromosome is a mapping based on the field and wells that are represented in the simulator.

The value of each gene represents what is contained in the corresponding cluster. The wells are represented by a symbolic alphabet of discrete values {0; 1; 2; 3; 4; 5; 6}, which mean:

0: There is no well.
1: There is a vertical production well.
2: There is a vertical injector well.
3: There is a horizontal production well.
4: There is a horizontal injector well.
5: There is a directional production well.
6: There is a directional injector well.

The evaluation is performed in the following manner: the alternative is submitted to the simulator; the simulator provides a production profile of the field, which depends on the number of wells that are in place and on the period simulated in years. Based on the profile thus obtained, the Net Present Value of the reservoir is calculated in the manner described in the section below.

CALCULATION OF THE NET PRESENT VALUE

Basically, the Net Present Value is calculated as the difference between the present value and the development cost, as is described in the following expression:

$$NPV = PV - D \qquad (1)$$

where PV is the present value and D is the development cost.

The Development Cost D, which considers the investments that were made so that it would be possible for the reservoir to begin to produce, is calculated as:

$$D = (a + r)n_p + b + \sum_{j=1}^{n_p} |p_j - P_{PL}|.c \qquad (2)$$

where

- a Average drilling cost for each well plus cost of the "Christmas Tree"[1]
- r Cost of the riser, which corresponds to the waterline cost multiplied by the cost of line per kilometer.
- b Transfer cost plus platform and plant cost.
- p_j Position of the well j.
- P_{PL} Position of the platform.
- c Cost of line per kilometer.
- n_p Number of wells.

Normally, for each alternative, these values are known a priori and remain fixed.

The present value (PV) represents a value that is assigned today for future objects or events. In order to measure the time distance between the "today" and the day on which the event that is to occur will be priced, an exponential discount factor is used.

For the reservoir problem, the present value is formed by the difference between the costs and revenues that will occur during the specified production period: the present value of revenue PV_R minus the present value of the operation cost PV_{Cop} to which a tax rate I of about 34% is applied:

$$PV = (PV_R - PV_{Cop})(1\text{-}I) \qquad (3)$$

The Value of Revenue depends on the production $Q(t)$, and on oil prices $P_{oil}(t)$ In this case, because market conditions are certain, the price of oil may be expressed as a deterministic $P_{oil}(t)$ function. Hence, for each time t, the value of revenue is obtained as:

$$R(t) = Q(t) \,.\, P_{oil}(t) \qquad (4)$$

and the present value of revenue is:

$$PV_R = \sum_{i=1}^{T} R(t).e^{-\rho.t_i} \qquad (5)$$

where ρ is the discount factor fixed at 0.1, T is the reservoir's maximum time of profitable activity (i.e., the highest t in which the value of revenue is higher than the operating cost), and the t_i value is the i-th time step in the oil or gas production value. It should be noticed that the t_i does not advance in fixed time steps.

The Value of the Operating Cost is given, for each time t, by the following expression:

$$C_{OP}(t) = m.np + C_y(t) + R_y Q(t) P_{oil}(t) + C_F \qquad (6)$$

[1]A Christmas Tree is a set of valves that is located on the wellhead and serves to control the oil flow. In this case (offshore production) wet Christmas Trees are used and should be pointed out on account of their high cost (from one to 2.5 million US$ per unit).

where
m   Maintenance cost of a well (same for all the wells).
n_p Number of wells.
C_V Time-variable production-dependent costs.
C_F Fixed costs.
R_y Royalties rate.
$Q(t)$ Oil production in time t
$P_{oil}(t)$ Oil price in time t

and the present value is,

$$PV_{Cop} = \sum_{i=1} C_{OP}(t).e^{-\rho t_i} \tag{7}$$

With the PV_R and PV_{COP} values, the present value PV (Eq.3), and, subsequently, the net present value NPV (Eq. 2), are obtained.

RESULTS OBTAINED

The tests were performed with a simple reservoir configuration in the form of a 30 x 30 x 1 parallelepiped. This reservoir presents constant porosity parameters along the entire field.

In order to initialize the population into GA. the following items were considered:

• The solutions that were generated contained only vertical wells, both for production and for injection.

• The probability rate for well placement that was employed varied between zero and a different maximum value for each chromosome. In this manner, when a population is generated, chromosomes with different quantities of wells are generated.

• The genetic operators that were employed were uniform crossover and mutation [2], and two new genetic operators for mutation that are described below.

WELL-ADDING OPERATOR

For the selected chromosome with probability p_{aw}, a production or injector well is inserted in a randomly chosen position.

WELL-ELIMINATING OPERATOR

For the selected chromosome with probability p_{pw}, a well is eliminated from the chromosome.

The following rates and parameters were applied when the genetic algorithm was executed:

Crossover rate	pc = 0:65;
Mutation rate	pm = 0:1;
Well addition rate	paw = 0:1;
Well elimination rate	ppw = 0:1;
Population Size	100 individuals;
Number of generations	20
Number of cycles	4

For calculating the net present value, the following parameter values were considered (costs expressed in US dollars):

Drilling cost	20,000,000
Lines/Km cost (CL)	2,000,000
Riser cost (water line=1000m)	1000 x CL
Plant and Platform cost	400,000,000
b*	4,000

The following results were obtained for these values:

NPV:	(US$)	1,650,448,202.4
Investment:	(US$)	1,109,463,679.05
Reserve:	(m3)	58,245,500

Figure 3 below shows the well configuration that corresponds to the best alternative found by the algorithm.

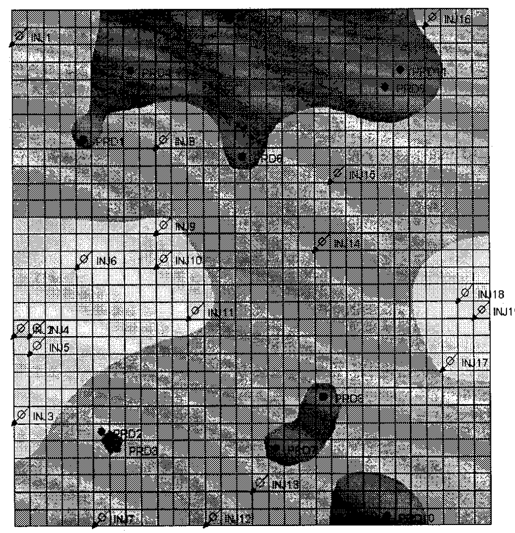

Fig. 3 - Distribution of wells found by the genetic algorithm.

In Figure 3, it may be observed that the genetic algorithm placed the production and injector wells, denoted as PRDxx e INJxx, respectively, in two groups of production wells with the injector wells arrayed around them, totaling 11 production wells and 19 injector wells.

The time it takes for the algorithm to evolve a solution is a critical aspect in the context of this paper. The results obtained required 36 hours of computation time on an Intel PIII-800 computer. Another point that should be considered is that the population is quite small in proportion to the large search space that is required for finding solutions in this problem.

CONCLUSIONS

This paper has presented an optimization system for alternatives related to investment in oil fields under certainty and has made use of Genetic Algorithms as the optimization method. The net present value was used as the objective function, which considered the variations in the number, types and positions of the wells. The internal parameters of each well were regarded as constant.

Though they are still preliminary, the results presented here have been encouraging.

The next stage of this research project involves attempts to obtain a better performance from the system by means of 3 nain initiatives: parallel processing, a new genetic algorithm nodel and a hybrid neuro-fuzzy system. When evolution is arried out in a parallel manner, several computers execute eservoir simulators at the same time and are capable of valuating several alternatives (chromosomes) simultaneously. The new genetic algorithm model involves chromosomes of ariable sizes for automatic identification of the ideal number of wells, where genes contain the real values of the *i* and *j* coordinates of each well in order to simplify the search process. Lastly, a neuro-fuzzy system is to be trained with a reservoir simulator behavior, so as to reduce the number of simulator executions during evolution.

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