# OPTIMIZATION OF A PRODUCTION SYSTEM FOR A PETROLEUM RESERVOIR

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***Abstract.*** *The main task of reservoir engineering is the development and management of petroleum reservoirs in order to produce the best amount of hydrocarbons considering physical and economic limits. The procedure of hydrocarbon recovery optimization, involves the maximization of an objective function, for instance, net present value, discount rate, or investment return coefficient. A more reliable evaluation of the objective-function can be performed using numerical reservoir simulation. Considering a geological model, a methodology was developed in this work for the optimization of a production system for a petroleum reservoir, in order to maximize an objective function. The first step was developed to obtain the ideal number of production wells and their location in the reservoir. The second step was developed for the study of economic and technical viability for the drilling of new wells in a field, including injection fluid system for supplementary recovery. Some examples were analyzed for the methodology validation and some results are presented. Parallel computing was applied to accelerate the process.*

***Keywords:*** *Reservoir Simulation, Optimization, Production System*

## 1. INTRODUCTION

The main task of reservoir engineers is the development and management of petroleum fields in order to produce as much hydrocarbon as possible, considering physical and economic limits. This problem has a very complex solution. It presents a great number of variables involved in the process: number of wells, their location, injection fluid systems for supplementary recovery, number of rigs, etc.

Arps et Alli [1967] took part in a study organized by the American Petroleum Institute. The main purpose of this work was to deduce equations to determine the recovery factor of reservoirs. The well spacing was one of the most studied parameters. After analyzing data of 312 reservoirs, they concluded that there were no mathematical relationship between recovery factor and well spacing.

Davis and Shepler [1969], observed that the well spacing initially used for the development of a field usually is not the optimum well spacing for this field. The optimum well spacing depends upon the characteristics of each reservoir.

The advances obtained in hardware and software in the last years, allowed numerical simulation of the reservoirs to be a valuable tool in forecast of production profiles and reservoir management.

The forecast of the reservoir behavior can be performed by constructing a physical-geological model. This model is formed by many parameters generated by reservoir characterization. The simulation model is the main tool to evaluate an objective function that mathematically represents the global objective of the project.

Using numerical simulation, Nystad [1985], Damsleth et Alli [1992], Beckner e Song [1995] among other authors developed methods to optimize problems related to exploitation of hydrocarbon fields. For all these works, the common aspects were: problem simplification and use of a low number of simulations and variables.

This work proposes a series of alternatives for the development of a reservoir showing several indicators for each possibility, facilitating the management decision. Although the simulation demands an additional effort, the importance of the decision to be made justifies the development of this kind of procedure. Parallel computing allows the project viability even for practical cases where the simulations require a long time. Due to the great number of simulations to evaluate the objective function, the use of external parallelization of the simulations is made using PVM (Parallel Virtual Machine), reducing the computing time.

## 2. METHODOLOGY

### 2.1 Methodology for the Optimization of the Producers Wells Number in a Reservoir

This Methodology was developed to obtain the ideal number of producers wells in a field, considering a initial regular well spacing. Several algorithms were tested but we are presenting the best option for the cases we tested. Only vertical well were tested in this work.

***Premises.*** This methodology was implemented to be applied in the initial phase of an oil field development where a geological model is built based on data obtained from seismic, geological studies and geostatistics techniques.

The option to start this work in this phase was due to the great necessity of data at this point and the importance of the decision to develop or abandon projects. Many decisions have to be made at this point: maximum production rate to design equipment, number of wells to be drilled, supplementary recovery system, compressors, pumps, etc.

***Algorithm.***

- The algorithm has as the main objective to maximize an objective-function (OF).
- The file with the original model is simulated using an initial well configuration with a small well spacing (to evaluate the potential of each region) .
- The OF of each well and of the whole field are calculated. A ranking with the classification of wells is obtained.
- An amount corresponding to approximately 20% of the initial number of producer wells is removed, with the constraint that adjacent wells cannot be removed at the same time. A new file is created.
- This new file is simulated and a new ranking is generated. The procedure is repeated until the OF decreases.

- A refining step can be executed at this point to remove wells one by one until the ideal number of wells is obtained (the number related to the highest OF for the field).
- Depending on the precision required and degree of uncertainty on the problem, other refinements can be used automatically or by hand to improve the solution..

Similar procedures can be used, with small differences, for example, to change the amount of wells to be removed in each step. There was no great advantage of these tests and the procedure presented here was, in average, the best one. The refinements produce better results but the number of simulations can increase significantly.

## 2.2 Methodology to Study Economic and Technical Viability to Drill New Wells in a Developed Field

The purpose of this methodology was to determine the most adequate type (producer or injector) and the best location for new wells to be drilled in a developed field. This option is important because this problem occurs frequently, specially when economic conditions or the geological model change.

The great advantage of such a procedure is that it can be automatic, integrating reservoir performance and economic analysis.

***Premises.*** For this methodology, a file with the field history match is used as an initial model to the production forecast.

***Algorithm.***

- New positions are chosen for a new producer well or a new injector well, considering the residual oil saturation map after five years of production with the original wells (several strategies can be used).
- New files are generated, each one containing a new well in one of the chosen positions.
- After the simulation of each one of these files, the post processor is used to calculate the objective-function (OF).
  - With these values, the most adequate type and the best location for the new well to be drilled is determined.
  - The same procedure is used to evaluate the economic and technical viability of the drilling of more wells, combining the best options. The procedure is repeated increasing the number of wells until the OF increases.

# 3. APPLICATIONS

## 3.1 Application 1

For the first application, it was chosen a simple model, with a Cartesian grid of 1323 cells, composed by three layers: one of water and two of oil (Figure 1). The aquifer located beneath the layer of water, contributes to the pressure maintenance and to increase the final recovery factor. A three-phase (oil, gas and water) system is used in this model.. The main characteristics of the model are shown in Table 1.

The initial well spacing used was 400 m and the position of each well will be shown in Figure 2.

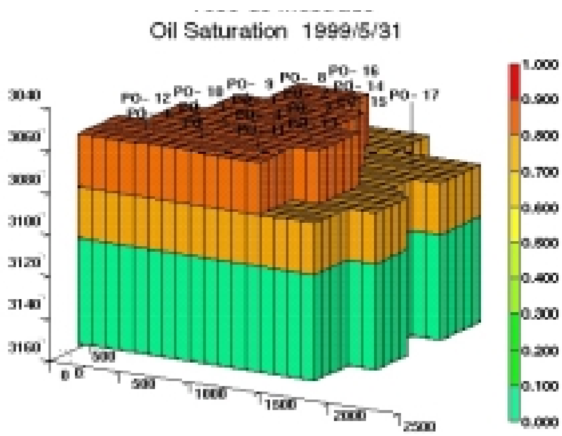


Figure 1: Grid Simulation of Model-2

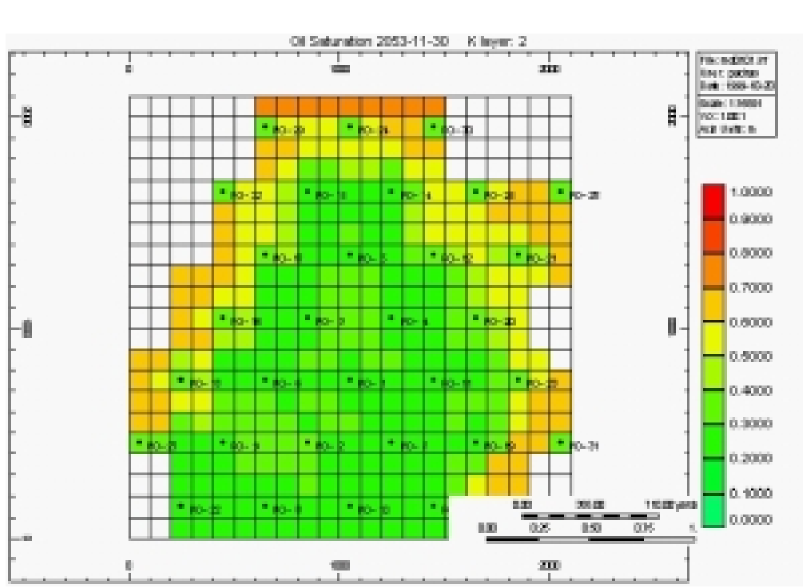

Figure 2: Well location

Table1.Main features of Model –2

| Parameters | Value | Unit |
|---|---|---|
| Total number of blocks | 1323 | |
| Active Blocks/ Nulls Blocks | 858/465 | |
| Grid | 21 x 21 x 3 | |
| Dimensions i and j | Di = 100 e Dj = 100 | m |
| Dimensions k | Dk1=50; Dk2=25 e Dk3=25 | m |
| Permeab. Horizontal (Kh) | Kh = 200 | mD |
| Permeab. Vertical (Kv) | Kv = 10 | mD |
| Porosity (ϕ) | 25 | % |
| Medium depth | 3125 | m |
| Oil density | 0,866 | - |
| Gas density | 0,745 | - |

| | | |
|---|---|---|
| Bubble Point | 210,03 | $Kg/cm^2$ |
| Swi | 18 | % |
| Sor | 22 | % |
| Drilling Costs/well | 5.300.000,00 | US$ |
| Anual discount rate | 15 | % |
| Drilling time/well | 4 | months |
| Number of rigs | 1 | |
| Production Costs | 8 | US$/bbl |
| Oil Price | 18 | US$/bbl |
| Gas Price | 90 | US$/1000 $m^3$ |
| Water depth | 60 | m |

**3.2 Application 2**

For this application was chosen an offshore field. This model is made up of a grid of 19x36x5 and is composed by five layers: one of water and four of oil. The values for the properties of this field used for this model were provided by Petrobras. Well location is a function of residual oil saturation (for example as in Figure 3). Injection wells were tested in the aquifer and in the oil region to accelerate oil production.

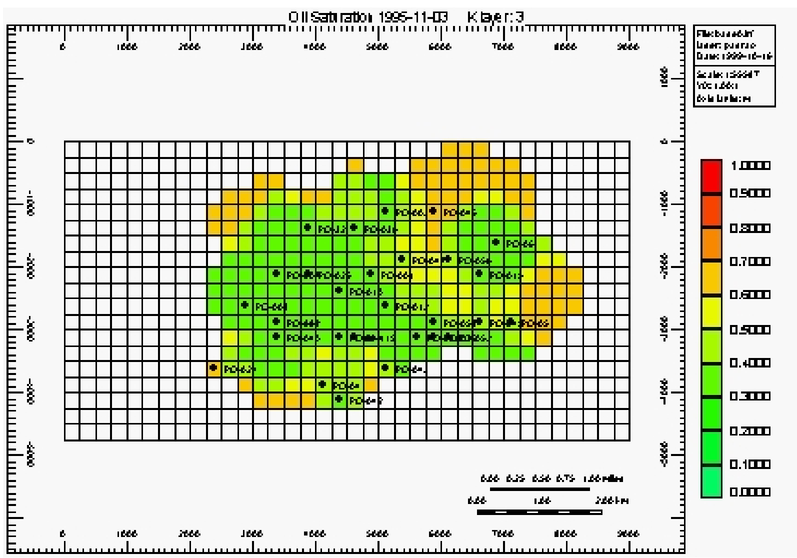


Figure 3: Residual Oil Saturation - Layer 3:

**4. RESULTS**

This section presents the results of simulations for the objective function NPV for the two proposed applications. The values for NPV does not include governmental taxes. Therefore, the NPV values are very high.

For the first application it is presented the ideal number of wells, and for the second application it is shown the best position for the wells to be drilled in each case

4.1 **Results – Application 1**

Figure 4 presents the results using two procedures for the removal of wells. It can be observed that the curves can be different but the optimum number of wells is between 6 and 8 wells. The best solution was obtained for 7 wells (US$ 106.265.329). Using only the best procedure 9 simulations were executed.

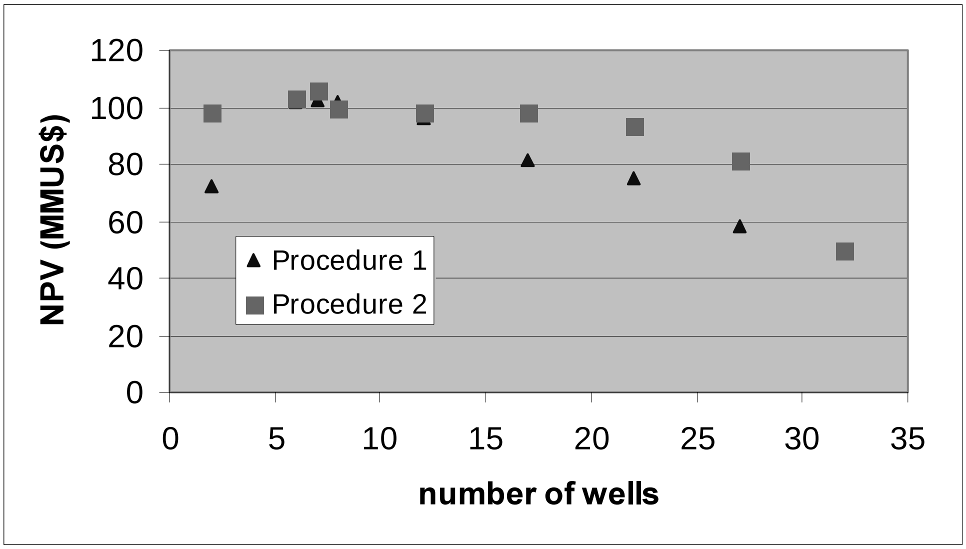


Figure 4: NPV as function of number of wells – initial well spacing of 400 m

## 4.2 Results – Application 2

Tables 2, 3, 4 and 5 show the results for the solutions for the Application 2. The best injector well is in the position: I26, J11 (K:5) causing a increase in NPV of 4,0% when compared to the original case. The best producer well is located in the position: I21, J7 (K:1,2,3) increasing the NPV by 5,2%.

Table 2 – 1 injector

| | Methodology | | |
|---|---|---|---|
| Model | NP (MSCF) | GP (MMSCF) | NPV (US$) |
| B1 | 34683 | 3834,9 | 655680143 |
| B2 | 34566 | 3818,7 | 654535433 |
| **B3** | **34695** | **3835,9** | **655789469** |
| B4 | 34577 | 3820,9 | 654797135 |
| B5 | 34588 | 3824,5 | 654841885 |
| B6 | 34627 | 3829,0 | 655233133 |
| B7 | 34238 | 3780,6 | 650890503 |
| B8 | 34378 | 3780,3 | 652633142 |
| B9 | 34558 | 3816,5 | 654428600 |
| B10 | 34523 | 3818,9 | 654299505 |

Table 3 – 1 producer

| | Methodology | | |
|---|---|---|---|
| Model | NP (MSCF) | GP (MMSCF) | NPV (US$) |
| A1 | 33130 | 4049,6 | 649708254 |
| A2 | 32896 | 3856,9 | 644770446 |
| **A3** | **31044** | **4793,0** | **663463952** |
| A4 | 33311 | 4166,3 | 653026461 |
| A5 | 32872 | 3686,1 | 637825943 |
| A6 | 32976 | 3793,5 | 641919557 |

| | | | |
|---|---|---|---|
| A7 | 33522 | 4074,8 | 652873724 |
| A8 | 33368 | 4172,4 | 652962361 |
| A9 | 33196 | 3931,3 | 648100819 |
| A10 | 33547 | 4389,3 | 657754014 |

According to Tables 4 and 5, the best set of 2 injectors was obtained for wells in the positions: I24, J9 (K:5) and I12, J13 (K:4,5) causing a increase in NPV of 4,2%. Considering 1 injector and 1 producer, the best option was: for the injector I24, J9 (K:1,2) and for the producer I16,J18 (K:5) increasing the NPV by 4,9%.

Table 4 – 2 injectors

| | Methodology | | |
|---|---|---|---|
| Model | NP (MSCF) | GP (MMSCF) | NPV (US$) |
| C1 | 34565 | 3958,3 | 655680143 |
| C2 | 35613 | 3977,5 | 657012052 |
| C3 | 35479 | 3959,3 | 655712695 |
| C4 | 35521 | 3963,4 | 656101662 |
| C5 | 35101 | 3918,2 | 651591522 |
| C6 | 35106 | 3919,6 | 651705394 |
| **C7** | **35621** | **3979,8** | **657049819** |
| C8 | 35120 | 3922,0 | 651778350 |
| C9 | 35143 | 3923,4 | 651975617 |
| C10 | 35520 | 3960,6 | 651778350 |

Table 5 – 1 producer and 1 injector

| | Methodology | | |
|---|---|---|---|
| Model | NP (MSCF) | GP (MMSCF) | NPV (US$) |
| D1 | 35114 | 3888,6 | 655871189 |
| D2 | 34939 | 3860,0 | 652417079 |
| D3 | 35465 | 3901,6 | 659096959 |
| D4 | 35710 | 3969,1 | 661193212 |
| **D5** | **35767** | **4101,3** | **663380311** |
| D6 | 35135 | 3869,3 | 655881367 |
| D7 | 35606 | 4047,3 | 661974042 |
| D8 | 34607 | 3826,2 | 645629151 |
| D9 | 35338 | 3902,6 | 657502977 |
| D10 | 34997 | 3861,1 | 653662716 |

## 5. CONCLUSIONS

Considering the results obtained with the application of the methodology to obtain the ideal number of producers wells the following conclusions can be achieved:

- Automatic procedures to support reservoir management decisions using reservoir simulation was proposed. The use of such procedures can save time and lead to interesting results.
- Several procedures are possible and they can lead to different results for the same model. This is due to the difference between the number of well removed in each step using each procedure and also due to respecting or not the constraint of neighborhood of the wells. However, all procedures lead to similar solutions.
- The best procedure was in general obtained with the procedure presented in this work.
- This constraint of not removing at the same time adjacent wells is important because the removal of a well affects the production rate of its neighbors.

- Parallel computing allowed a great reduction in the simulation time and it accelerated the process allowing to analyze a greater amount of options.

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