A METHODOLOGY FOR OPTIMIZATION OF PRODUCTION STRATEGY FOR DEVELOPED OIL FIELDS

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Abstract. *Although developed oil fields have an established production strategy, changes of geological, economic or technological scenarios can demand changes of this strategy, requiring new optimization processes. These fields need the improvement of the existing drainage strategy in order to increase the potential production and to extend field life. The optimization of fields in production phase differs from the optimization of fields in the development phase due to (1) less flexibility and (2) the existence of a production history which allows improving reservoir characterization yielding more reliable reservoir forecast and making possible more detailed and less uncertain geological models. A more reliable geological model yields more accurate numerical model for reservoir simulation allowing more detailed optimization of the production strategy. The main objective of this work was to develop a methodology to automate optimization of drainage strategy for fields in production phase, using conventional simulation, streamline simulation and quality maps. The integration of these techniques provides a higher reliability and speedup of the optimization process, mainly in the water injection and production control and in the allocation of new wells. These techniques have been applied to an offshore field with water injection, and the presented results allow concluding that the use of the developed methodology improves the optimization process.*

Keywords. *Reservoir Simulation, Production Strategy, Streamline Simulation, Quality Map, Optimization*

1. Introduction

Drainage strategy optimization is a complex process that involves a lot of influent variables. A field development planning normally comprises a great amount of investments and important decisions are necessary. For fields in the beginning of production or in the beginning of the development planning, a few of information are available, and the degree of uncertainties is generally high. A lot of type of uncertainties is present, such as geological properties and structural characteristic of the reservoir, technological and economic scenario uncertainties, etc. In this stage, an approximate strategy is generally defined. The decisions are predominantly in a macro scale, as for example, definition of the production system, number and type of wells, use of or not use secondary recovery (Mezzomo, 2003), etc. Developed hydrocarbon field have a given drainage strategy already defined. However, the increasing of geological information, changes on economical or technological scenarios can impose the necessity of changes in the strategy. This signifies the initial strategy can be in continuous improvement or adaptation process.

Drainage strategy optimization of developed field differs significantly from strategy optimization of fields in development phase. Firstly, because there is less possibility of changes. For example, it is not possible to change the position of a well. Some possible changes are adding horizontal sidetracking to existing vertical well (Fabel, 1999) or placement of new wells, normally called infill drilling (Rushing, 2003). Second, along with the production, more information is available. A more detailed knowledge of the reservoir requires more analysis in the process. For instance, change a well completion, change operational conditions, etc.

As the quality and quantity of information increase, it is interesting the use of additional tools in order to refine and improve the knowledge of the reservoir. As more information are available, a greater refinement of the production strategy is justified. This motivates the use of additional techniques such as streamline simulation and quality map. These tools, described below, are support techniques that help more detailed analysis.

1.1 Streamline Simulation

The technique of streamline simulation decouples computation of saturation variation from the computation of pressure variation. The basic principle is a coordinate transformation from physical space (3D) to one dimension trajectory (streamline) along which displacement processes are computed. Saturation equation is solved along one dimension. Mathematical details can be found in Datta-Gupta (2001), Baker (2001) and Samier (2001).

Streamlines are one dimensional flow paths in the reservoir and have flow rates with a distinct origin and destination. Streamlines can represent drive mechanism to a producer or flux from an injector. When streamlines have the same origin and destination, they can be grouped or summed into bundles. Therefore, if origin and destination is a well pair, the relationship between the wells (injector/producer) is quantifying in terms of flow rate. These features of streamline simulation offer a powerful tool in applications such as waterflood management and strategy optimization (Grinestaff, 1999; Thiele, 2003; Guimarães, 2005). These features of streamlines simulation are used in the present work. Water injection is one of the most applied secondary recovery methods in the world. Therefore, an efficient water management is a key role in this scenario, and is a great challenge for petroleum industries. Streamline simulation is particularly interesting in this type of application.

1.2 Quality Map

Quality map is a bi-dimensional representation of several three-dimensional properties of a reservoir. The idea is to try to encapsulate a set of properties in a unique property, or a quality index. Besides the frequent use of quality map in drained strategy optimization, quality concept may be also applied in other areas as for example, to compare reservoirs, to rank stochastic realizations and to incorporate reservoir characterization uncertainty into decision making, such as choosing well locations, with fewer full field simulation runs. In a drainage optimization process, a lot of reservoir properties should be analyzed, such as porosity map, permeability map, net-to-gross and net-pay, fluids saturation, etc. Moreover, these properties vary between the several layers of the reservoir. Quality map make the analysis more efficient.

Nakajima (2003) propose the use of quality maps to guide reservoir managers in horizontal wells placement. The maps represent the regions with production potential in a reservoir, providing the best place to locate a well. There are several methods of generating a quality map (Cruz, 1999; Nakajima, 2003). In the present work, however, only numerical method is used.

2. Methodology

The methodology presented in this paper consists of the integration of three tools: finite difference reservoir simulation, streamline reservoir simulation and quality map. In Fig. 1 is presented the general methodology flowchart.

1) Evaluation of the base case to assess the main characteristics of the field and well production, such as for example oil rate, water rate, water cut, gas oil rate, well bottom hole pressure and average reservoir pressure. Economical indexes are also evaluated, such as net present value of the well and the field. It is assumed that the base case is history matched;

2) Streamline simulation is run in order to generate quantitative flux relationship between producer wells and injector wells and the relationship between the water volumes injected and oil volumes produced. These information are used to compute injector efficiency and the influence of a given injector associated to a given producer;

3) Quality map is generated in order to classify producer wells and to define regions for new wells perforation;

4) Based on the previous analysis and on the classification map, a set of changing is defined. Changes are tested and, if it improves the results, are implemented. Otherwise, the set of changes is checked for remaining changes. The set of changes showed in Fig. 1 (bounded by dashed line) is related to a given producer well. However, the injector well associated to the tested producer well is also tested. For example, if the producer well is shut, then the injector associated is also shut;

5) If a given change is implemented, new quality map and new streamline simulation related to the model resulted, are generated;

6) The process goes on until a stop criterion is reached. The stop criterion depends on the case. However, some basic criteria can be observed. For example, the process can be stop when all wells are analyzed, or when a certain number of consecutives changes (after 3 changes, for example) do not increase the analyzed index, in this case NPV.

To guide the strategy refinement, the classification map, showed in Fig. 2 is used. Four main regions are defined based on two main indexes: NPV and Np. Red region, for example, it is characterize by NPV low or mean, and Np low or mean. Each major region is divided in smaller regions based on others indexes. For example, Region 1 have oil rate (Qo) low and water production index (W) high. The index Mq that appears in the classification is related to quality map index. Based on this classification, orders of priority are established. Numbers inside white ellipse represent a sequence of priority. In the classification map showed in Fig. 2, others indexes can be added. As consequence, the number of regions increases.

Some general aspects related to the methodology are: (1) Finite difference simulation is used as the main tool in the process. All quantities necessary to the process, such as, field and well production phases (oil, gas, water), field and well fluids injected are generated through this technique; (2) the economical and technical indexes are calculated using the end of history period as reference, in other words, is considered the increment from end of history. Other aspect is that the proposed methodology is not completely automated. Instead, it provides forms to automate part of the process, through indexes that facilitates the analysis.

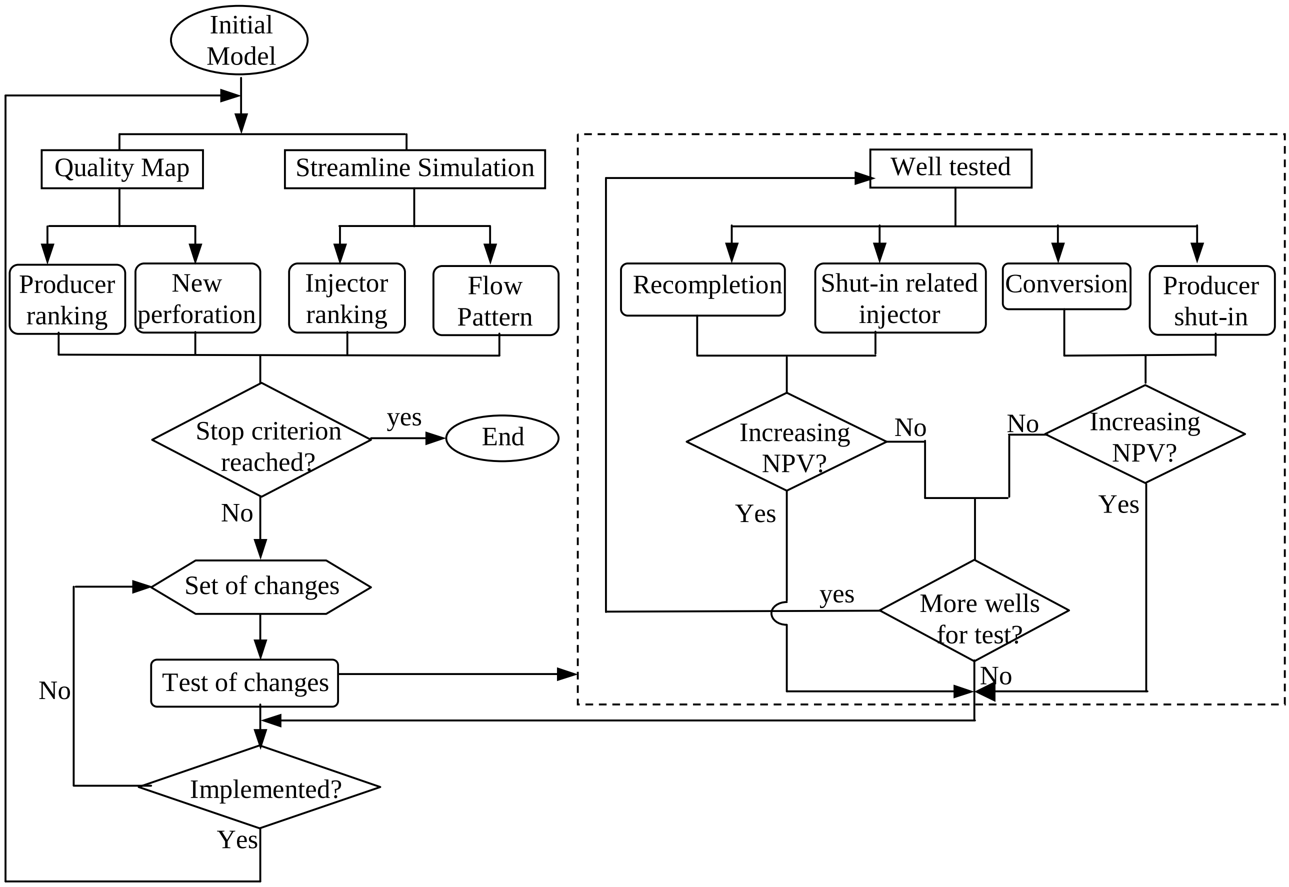


Figure 1. Methodology general flowchart

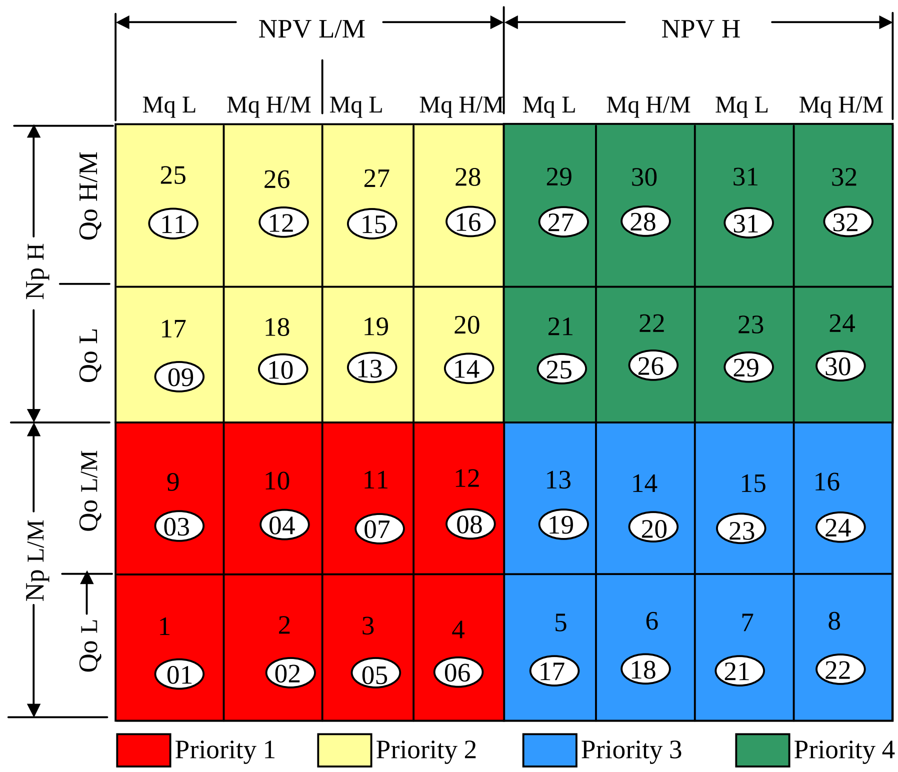


Figure 2. Classification map

2.1 Index classification for producer wells

The index classification for producer wells is presented in Tab. 1. The indexes marked with an asterisk were defined by Schiozer *et al.* (2002). Other indexes, not utilized in the presented work, can also be found in the work of Schiozer.

Table 1. Producer index classification

Index	Classification (Denoted by letter "C")
NPV*	$\overline{NPV} = \frac{\sum_{i=1}^{n_p} NPV_i}{n_p}$,such that $\begin{cases} NPV_i \geq \overline{NPV} \Rightarrow C_{NPV} high \\ 1/2\,\overline{NPV} < NPV_i < \overline{NPV} \Rightarrow CNPVmean \\ NPV_i \leq 1/2\overline{NPV} \Rightarrow C_{NPV} low \end{cases}$
Np*	$\overline{Np} = \frac{\sum_{i=1}^{n_p} Np_i}{n_p}$,such that $\begin{cases} Np_i \geq \overline{Np} \Rightarrow C_{Np} high \\ 1/2\,\overline{Np} < Np_i < \overline{Np} \Rightarrow C_{Np} mean \\ Np_i \leq 1/2\overline{Np} \Rightarrow C_{Np} low \end{cases}$
Qo_a*	$\overline{Qo\_a} = \frac{\sum_{i=1}^{n_p} Qo\_a_i}{n_p}$, such that $\begin{cases} Qo\_a_i \geq \overline{Qo\_a} \Rightarrow C_{Qo\_a} high \\ 1/2\,\overline{Qo\_a} < Qo\_a_i < \overline{Qo\_a} \Rightarrow C_{Qo\_a} mean \\ Qo\_a_i \leq 1/2\overline{Qo\_a} \Rightarrow C_{Qo\_a} low \end{cases}$
Mq*	$0 \leq Mq \leq 1$ $\begin{cases} Mq > 2/3 \Rightarrow C_{Mq} high \\ 1/3 < Mq < 2/3 \Rightarrow C_{Mq} mean \\ 0 \leq Mq \leq 1/3 \Rightarrow C_{Mq} low \end{cases}$
W	$\overline{W} = \frac{\sum_{i=1}^{n_p} W_i}{n_p}$ $\begin{cases} W_i \geq 3/2\,\overline{W} \Rightarrow C_W high \\ \overline{W} < W_i < 3/2\,\overline{W} \Rightarrow C_W mean \\ W_i \leq \overline{W} \Rightarrow C_W low \end{cases}$

2.2 Index classification for injector wells

In Tab. 2 is described the injector efficiency (IE) which is derived from streamline simulation and is suitable to analyze injector wells. This index is obtained through the ratio between the volume injected by a given injector and the volume of oil produced as result of the injection.

Table 2 - Injector efficiency classification

Index	Classification
IE	$\overline{IE} = \frac{\sum_{i=1}^{n_p} IE_i}{n_p}$ $\begin{cases} IE_i \geq 3/2\,\overline{IE} \Rightarrow C_{IE} high \\ \overline{IE} < IE_i < 3/2\,\overline{IE} \Rightarrow C_{IE} mean \\ IE_i \leq \overline{IE} \Rightarrow C_{IE} low \end{cases}$

3. Field Application

The study presented in this paper was applied to a modified offshore field. The STOIP of the field is approximately 100 MMm3. It is a developed field, with 1800 days of production history. This field has useful life of 2922 days (keeping the production strategy applied during the history period). The field is drained by 11 oil producer wells and 9 water injector wells, all horizontal. In 1800 days, all the producer and injector wells are already in operation. The water injection began after 180 days of primary production. The simulation model is composed of a grid of 60 blocks in the x direction, 35 blocks in the y direction and 7 layers (14700 simulation cells), discretized into a Cartesian grid. Datum depth is located at 3000 m, water oil contact is located at 3100 m and gas oil contact is located at 2900 m. In Fig. 3 is presented a three-dimensional horizontal permeability map of the reservoir.

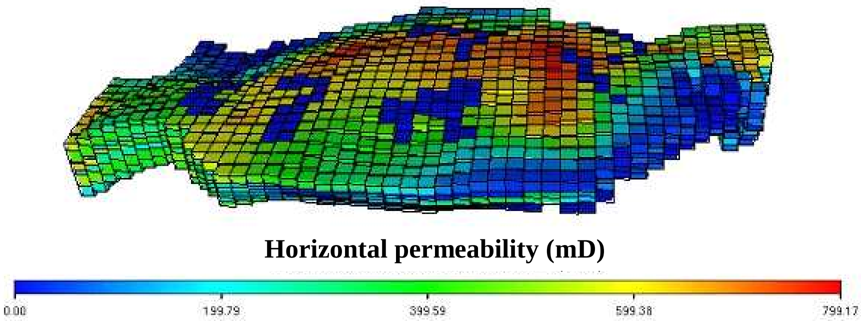
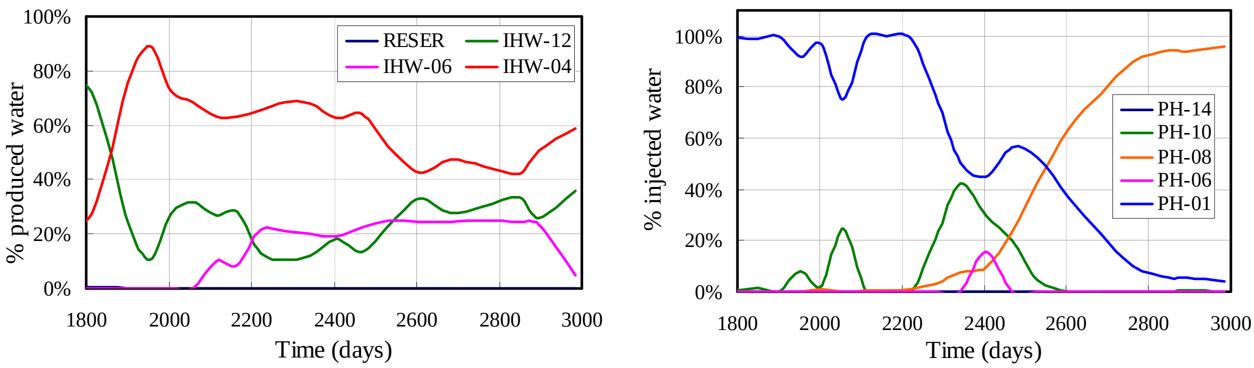


Figure 3. Three-dimensional permeability map of the reservoir studied

4. Results and Discussion

The following results correspond to a forecasting period of 2922 days after history period (1800 days). Two examples of the application of streamline simulation are presented in Fig. 4. In part “a” of the figure is showed the relationship between a given producer (PH-02) well three injector wells. The injector IHW-04 predominates in the total water flux to producer. In Fig. 4-b, is the contribution of injector IHW-07 for 5 producers. The overall relationship between all wells is presented in Tab. 3 and 4. Table 3 is the distribution of the flux of each injector (row) to producers (column) and Table 4 is the destination for each producer (column) of the injected water (row). Figure 5 shows an example of oil volume produced as result of water injected.



(a) (b)

Figure 4. Flow distribution between producer and injector during production time

Table 3. Percentage flow distribution from injectors to producers

Prod/Inje	PH-01	PH-02	PH-06	PH-07	PH-08	PH-09	PH-10	PH-11	PH-12	PH-13	PH-14
IHW-01	-	-	-	0.03%	-	7.89%	-	91.63%	-	-	0.45%
IHW-02	-	-	86.97%	-	-	-	12.65%	-	0.15%	0.24%	-
IHW-03	0.97%	-	-	0.00%	0.00%	4.50%	-	0.45%	-	-	94.07%
IHW-04	-	61.15%	6.14%	-	0.94%	1.20%	27.35%	0.08%	3.14%	-	-
IHW-05	-	-		13.14%	-	-	-	-	-	86.86%	-
IHW-06	-	8.42%	1.59%	0.00%	-	-	0.00%	0.00%	89.99%	-	-
IHW-07	17.11%	-	0.31%	-	80.29%	-	2.29%	-	-	0.00%	-
IHW-10	-	-	0.61%	-	0.05%	-	99.35%	-	-	0.00%	-
IHW-12	0.00%	79.41%	-	0.01%	0.54%	14.08%		5.97%	-	-	-

Table 4. Percentage flow distribution from producers associated to injectors

Inje/Prod	RES	IHW-01	IHW-02	IHW-03	IHW-04	IHW-05	IHW-06	IHW-07	IHW-10	IHW-12
PH-01	4.29%	-	-	58.36%	-	-	-	37.35%	-	-
PH-02	0.07%	-	-	-	55.85%	-	18.14%	-	-	25.94%
PH-06	-	-	90.47%	-	5.32%	-	3.25%	0.01%	0.94%	-
PH-07	13.73%	0.87%	-	0.04%	-	85.20%	0.01%	-	-	0.17%
PH-08	1.36%	-	-	0.03%	20.26%	-	-	72.28%	1.86%	4.21%
PH-09	0.05%	29.11%	-	32.10%	7.48%	-	-	-	-	31.26%
PH-10	0.08%	-	6.86%	-	12.37%	-	-	0.04%	80.64%	-
PH-11	0.10%	95.13%	-	0.91%	0.13%	-	-	-	-	3.73%
PH-12	0.40%	-	0.08%	-	1.45%	-	98.06%	-	-	-
PH-13	1.15%	-	2.23%	-	-	96.62%	-	-	0.01%	-
PH-14	1.19%	0.25%	-	98.56%	-	-	-	-	-	-

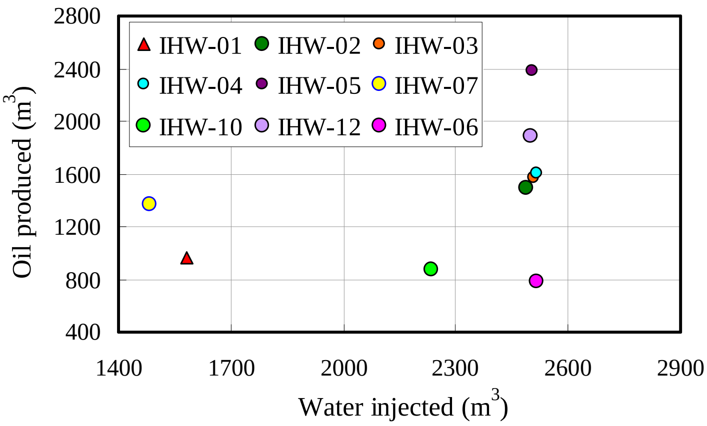


Figure 5. Oil production as result of water injection

Figure 6 presents two examples of quality map used to test injector (a) and producer placement (b).

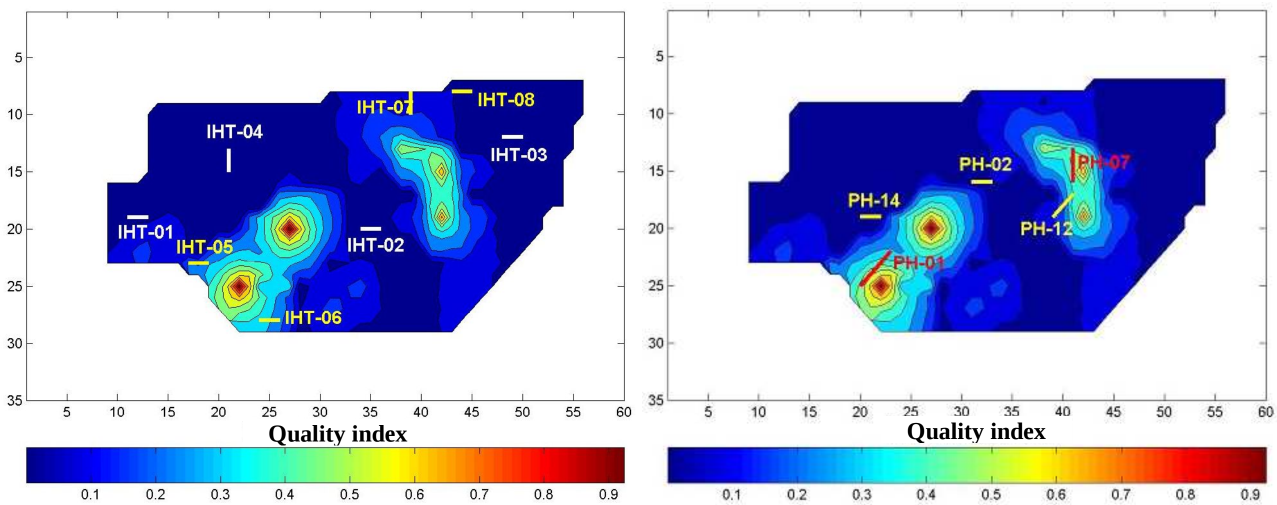


Figure 6. Quality map examples with injectors (a) and producers allocation

Regarding the optimization process specifically, since is not feasible to show the entire process, in the following is the description of some steps in order to show the context of the methodology application and the support tools employed. Firstly, an optimization process without the use of the streamline simulation and quality map was carried out

(Process 1). Other optimization process (named here Process 2) was done using the support tools. A comparison of these processes is presented in Fig. 7. Some runs and respective changes for Process 2 will be discussed. For example, run 2 and run the main changes were shut-in two injector wells (IHW-06 and IHW-10) with low injection efficiency, as can bee seen in Fig. 5. In run 30 was opened a new producer well in a region with high quality map index and in run 31 was opened a new injector well in a region neighboring to a region with a high quality map index.

The analysis of the Fig. 7-a allows observing the evolution of NPV for the two processes. It is possible to note that there is a higher increase in the NPV. On the other hand, less optimization run was done in the Process 2. In Fig. 7-b, 7-c and 7-d is the cumulative oil production (Np), cumulative water production (Wp) and cumulative water injection (Wi), respectively. A significant increasing in NPV for Process 2 is observed after run 21 approximately, that is followed by an increase in Np and decrease in Wp. Between optimization runs 1 and 21, production and injection water related to Process 2 is much lower than Process 2. This explains the increase in NPV, even with a lower Np. The significant increase in NPV after run21 for Process 2 is resulted of the increase of injection efficiency. Even increasing water injection, water production was not increased and oil production was improved.

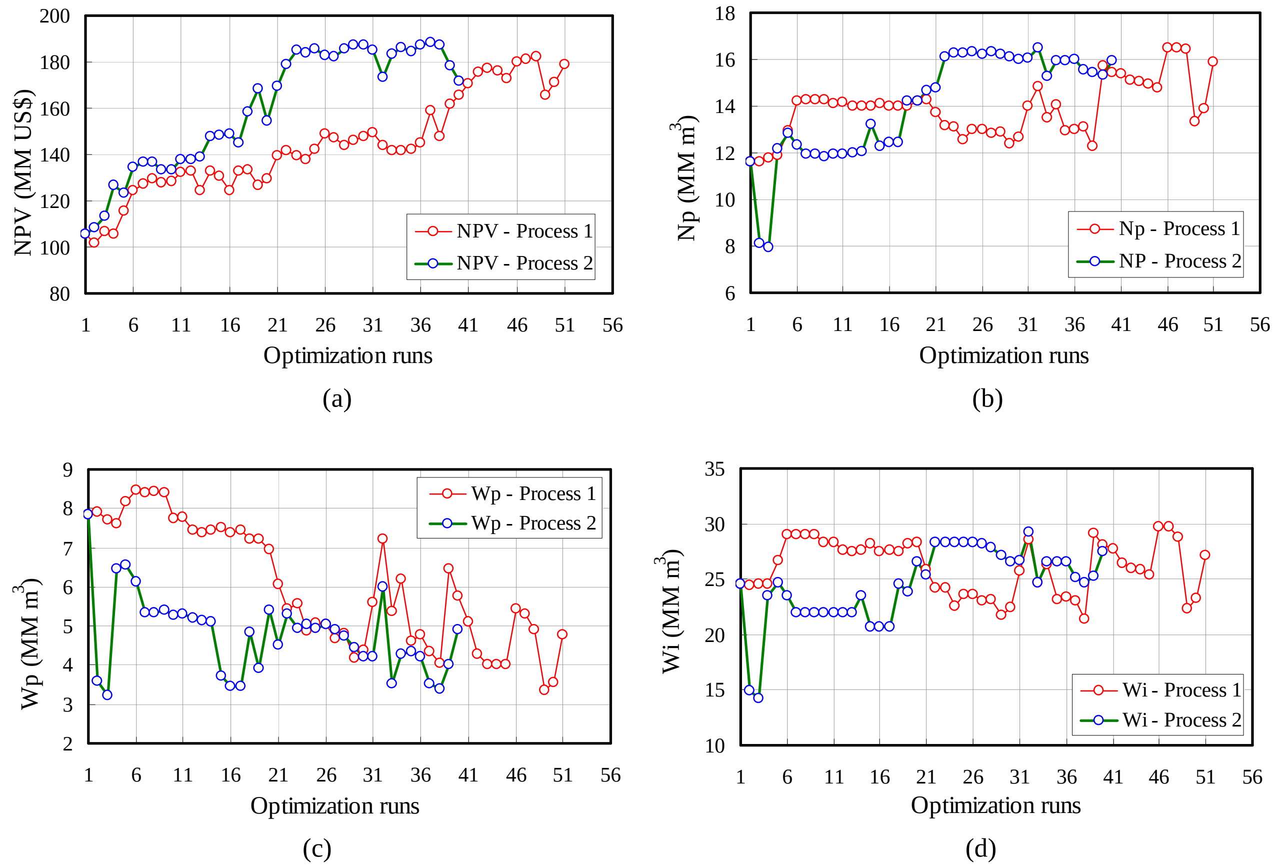


Figure 7. Comparison of two optimization process: Process 1 without using support tools and Process 2 using support tools; NPV (a), Np (b), Wp (c) and Wi (d)

5. Conclusions

The drainage optimization process is complex due to high number of control variables involved. Using the integration of three important tools, exploring their potential, this paper presented a methodology that can contribute for the process. Although it can also be use used for initial production fields, the methodology was tested in a developed oil field and it was possible to show the advantages of the streamline simulation and quality map as support tools. Finite difference simulation must be used as main tools. The use of economic and production index permitted the purpose of automated procedures to improve drainage optimization processes.

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