SELECTION OF PARAMETERS FOR HISTORY MATCHING OF PETROLEUM FIELDS USING STREAMLINE SIMULATION

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Abstract. *Streamline reservoir simulation has made significant advances in the last ten years and it represents an interesting tool in several areas. One of the promising applications of this technique is in the production history matching of petroleum fields. The objective of the history matching process it to build reservoir models consistent with production data as well as geological constraints. History matching is a very time-consuming step of a simulation study, but is an essential phase once even with modern reservoir characterization techniques the quantity and quality of information obtained is still not sufficient to perfectly represent and reproduce reservoirs. In the petroleum industry, a usual procedure is to perform history matching manually, requiring many cycles; it is based on the judgment and experience of the professionals involved. The choice of parameters to be modified is not an easy task. This paper shows the use of streamline simulation as a support technique on history matching process. Once streamlines can delineate drainage areas of the reservoir, the technique is applied to allow a better understanding of fluid flow behavior on the reservoir, mapping heterogeneities location and then choosing adequate geological parameters, such as permeability and porosity, according to the identified flow patterns. The potential of streamline simulation is specially used to determine wells influence zones. Once parameters have been chosen, an automated methodology is used in the history match process, applying traditional simulator and external parallel computing. For validation purposes, the procedure is first applied to a simple synthetic field and then to a real field, with more structural complexity.*

Keywords*. Reservoir Simulation, History Matching, Streamline Simulation*

1. Introduction

Even with advances of the reservoir characterization techniques, such as modern seismic data acquisition facilities, seismic inversion, well logs, seismic 4D, as wells as powerful geostatistical software, the information collected is still not sufficient to construct models that satisfactorily match real reservoirs. Therefore, production information is often necessary to calibrate the initial model. The incorporation and integration of production information into simulation models is called history matching.

1.1. History maching

History matching is a tool used to obtain more reliable reservoir models that can be utilized for production forecasting and predictions of future reservoir performance. The objective is to build consistent reservoir models, taking into account available data such as geological knowledge as well as production data: water rate, oil rate, gas rate, pressure, etc. History matching process, which is basically an optimization problem, consists on modification of reservoir properties such as porosity, permeability, relative permeability, among others, to match production data. An important step of the process is the definition of an objective-function to quantify the difference between measured data and simulated results. The subsequent step is the modification of model properties in order to minimize the objective-function.

There are several optimization methods that can be applied in the history matching process. Gradient methods involve the computation of derivatives of the objective-function with respect to the unknown parameters. A serious limitation of these methods is that for large number of parameters, gradient calculation can be prohibitive, in terms of CPU time, and for highly nonlinear problems, convergence is very difficult to be reached (Ravalec-Dupin, 2002). Gradual deformation methods are used by Roggero (1998) for constraining 3-D stochastic reservoir models to historical production data. This procedure is a combination of gradient method and a geostatistical parameterization technique. Another method used for history matching follows the idea of evaluating sensitivity coefficient of the objective-function for each grid block and the application of simulated annealing to minimize the error between simulated and observed data (Wang, 2002).

Another category of history matching procedures is based on direct search methods. In general, methods that use derivatives are not very efficient for problems with very irregular functions. To circumvent these drawbacks, Schiozer and Souza (1997), Leitão and Schiozer (1998), Schiozer (1999), Leitão and Schiozer (1999) developed a methodology for history matching improved by distributed computing (based on PVM - *Parallel Virtual Machine*) to accelerate the process. The algorithm used in this methodology is a direct search method where parameters assume only discrete values. The main characteristic of this method is that it is more robust and it works for complex and irregular objective-functions, once convergence is always obtained. Other advantage is that it is not necessary to choose a tolerance for the objective-function, which normally implies some difficulties; a tolerance for the parameters is required, which is normally easier to determine in practical cases. One of the disadvantages inherent to direct search methods is the difficulty of finding a global minimum, principally for very irregular functions. However, in this methodology, this difficulty can be minimized by starting the process of search in several points.

In traditional history matching procedures, reservoir properties values are perturbed and a fluid flow simulation is run to compute the impact on the objective-function, which is a sensitivity analysis to select those parameters of greater impact. Then, most influents are selected in order to find a combination that provides greater reduction of objective-function. Recent methodologies, based on streamline simulation, are being proposed in the literature; in such cases, reservoir properties are modified along streamlines to match production data (Ravalec-Dupin, 2002).

In this work, a methodology based on streamline simulation is proposed. The resources of a commercial streamline simulator are used to support the history matching process.

1.2. Streamline simulation

Streamline-based flow simulation has made significant advances in the last ten years. Commercial simulators already are fully 3D, account for gravity, fluid mobility change effects as well as moderated complex well controls. Most recent advances also allow for compressible flow and compositional displacements. Several recent publications demonstrate how streamline-based simulation can be applied to situations where traditional simulation, based on finite difference, have some limitations such as for very large models (Maschio and Schiozer, 2002; Maschio and Schiozer, 2003). The technique 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 et al. (2001).

One of the most interesting aspects of streamline simulation is the quantification of connectivity between areas of reservoir, a well and its surrounding areas (an aquifer, for example) and between injector and producer. The connectivity between injectors and producers are computed by:

$$WAF_{PI} = \left[\sum_{j=1}^{Np} \sum_{k=1}^{Nsl} \frac{q_{JPI}^{k}}{q_P} \right]$$

where WAF_{PI} is the contribution of well I to well P, q_{JPI}^{k} is the phase J flux associated with streamline k between wells I and P, q_P is total flow rate of well P, Nsl is the number of streamlines between wells P and I and Np is number of phases.

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 optimization (Grinestaff, 1999) and for history matching, which is the application of the present work.

2. Applications

This work shows how the application of a streamline simulator can help in the history matching process. The aspect of streamline simulation used is the relationship between injectors and producers. Two cases are used in the applications: a synthetic case and a real field. First, the use of visual aspect of streamlines is demonstrated using the synthetic model. In real cases, it is very difficult to analyze streamlines visually, due to highly heterogeneous distributions and consequent difficulty to identify streamline patterns. Therefore, for real field, the quantitative aspect of well connectivity is applied.

Two initial simulation models are built: one for streamline run and another for conventional simulator runs. After streamline run, the procedure consists of choose regions identifying by streamlines, in which permeability values will be changed for history matching. Once regions are selected, an automated methodology is applied to find the better combination of permeability values in horizontal and vertical directions. The methodology includes the use of parallel computing to accelerate the process. The optimization method is based on a direct search algorithm.

2.1. Field A

A synthetic field model was built. The model is represented by a grid of 21x21x3 blocks, in x, y and z directions, respectively. The reservoir is divided in four distinct regions, with different values of permeability. Horizontal permeability was considered equal in x and y directions (k_x=k_y=k_h). Four producers and one injector were used. Figure (1) shows distributions of permeability values and well configuration for the case. The heterogeneous model was used to generate a history of production. Then, heterogeneous permeability distribution (k_h and k_z) was replaced by homogeneous values (k_h=440 mD, k_v=45 mD). This new model became the base model to be matched.

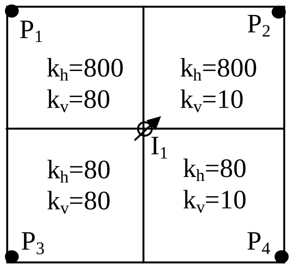


Figure 1. Schematic model for synthetic field A

2.2. Field B

Field B is an offshore field of Campos Basin, Brazil. The reservoir is formed by sandstone turbidites confined by faults with good porosity and permeability. The STOIP of the field is approximately 100 million m^3 and the main production mechanism is solution gas drive. It is a developed field, with more than 20 years of production. The drainage is accomplished through 33 oil production wells and 13 water injector wells. The available data before production started counting with nine seismic lines, 8 perforated wells, 4 oil analyses (PVT), formation test analysis, interpreted electric logs and data cores of 3 wells. The data cores comprise porosity and permeability sample, 7 analyses of relative permeability, 10 capillary pressures and rock compressibility. This is a field with a considerable level of structural complexity. In this case, quantitative relationship between injector and producers was used. After run streamline simulator, rates from injectors to a given producer is plotted in order to see those injectors with more influence over the analyzed producer.

3. Results and discussion

3.1. Case A

Streamline simulator was run using base model. Streamlines from injector to producers, for case A, are shown in Figure (2). As expected, four regions are defined by streamlines. Streamlines distribution appears quite homogeneous for each region. Each producer well is supported in the same way by injector, that is, rate form injector is equally distributed for producers. In a simple case such this, it is possible mapping regions visually through streamlines.

For each region, history matching was realized in three different ways: in Solution 1 (S1), it was used field water rate as objective-function; in Solution 2 (S2), it was used wells water rate as objective-function, for example, for region 1, water rate for well 1, for region 2, water rate for well 2, and so on; Solution 3 (S3), combining average reservoir pressure and field water rate. Table (1) shows values of permeability (k_h and k_z) for each form of matching. Parameters (k_h and k_z) were modified according multipliers between 0.05 and 2.0 for k_h and between 0.1 and 2.0 for k_z, both with 15 intervals.

In Figure (3) are present curves for water cut (which is a relation between water rate and water rate plus oil rate) for 4 producer wells, before and after matching. In Figure (4) are shown history for field parameters: water cut (a) and average reservoir pressure (b). As expected, Solution 1 provided worst history matching, because objective-function had little influence under the changing of parameters. Solution 2, provided intermediate results, with greater error related to well P2 and average reservoir pressure. Better history matching was achieved through Solution 3. Combination of average reservoir pressure and water rate in a unique objective-function favor, in this case, the field average pressure matching. For the three cases, the values of permeability are not very close to the true values, mainly in region 2 and 4. This reflects in the results for wells 2 and 4, which still present some mismatch related to the history.

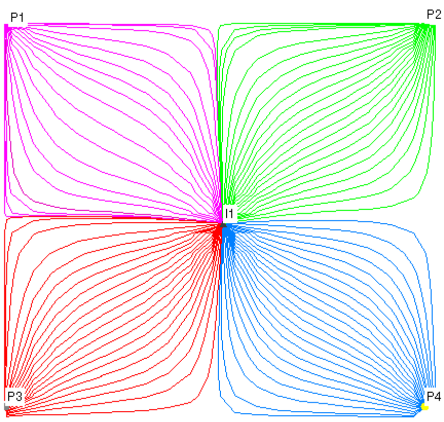


Figure 2. Streamlines distribution for case A

Table 1. Permeability values (mD) after matching for case A

		Regions			
		1	2	3	4
True	K_h	800	800	80	80
	K_z	80	10	80	10
S1	K_h	880	22	76	160
	K_z	10	4.5	90	20
S2	K_h	880	250	79	880
	K_z	33	16	38.7	4.5
S3	K_h	880	650	79	88
	K_z	90	17	90	99

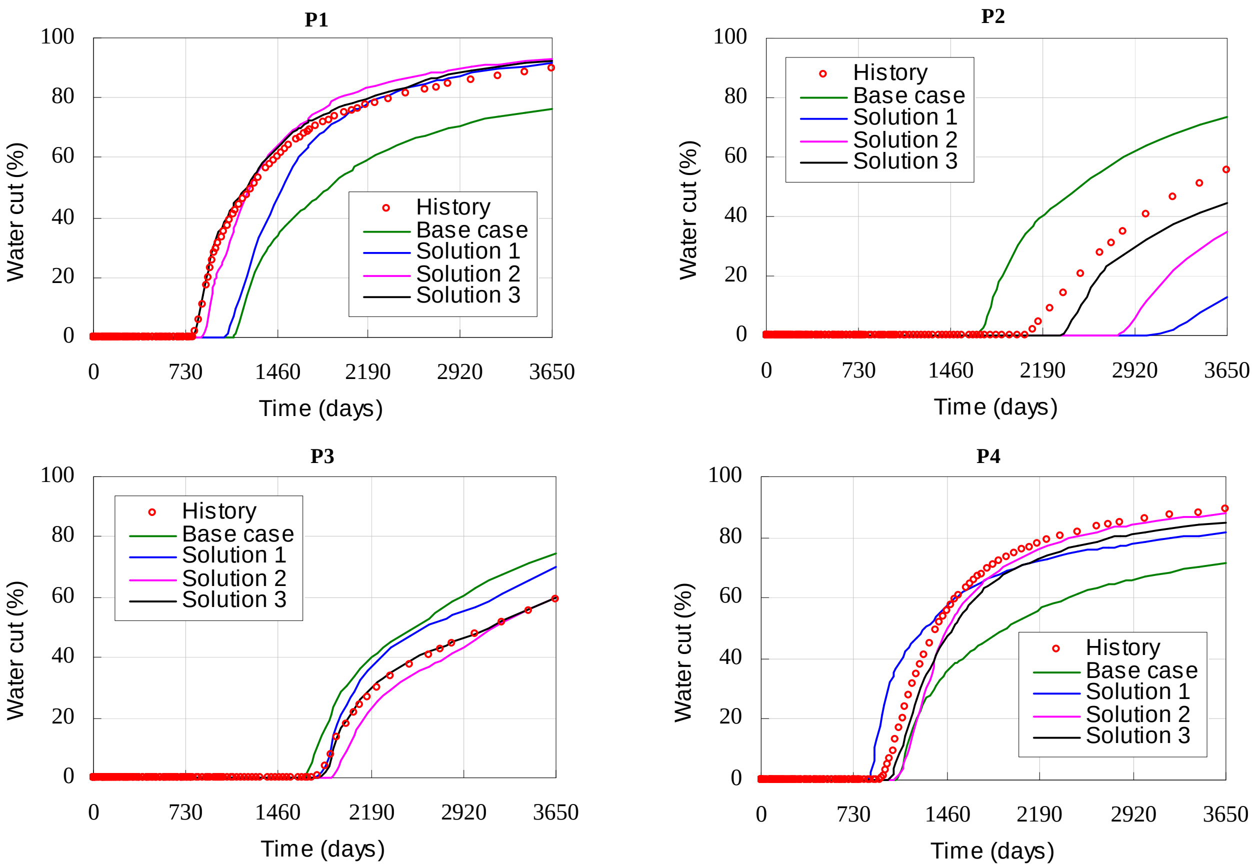
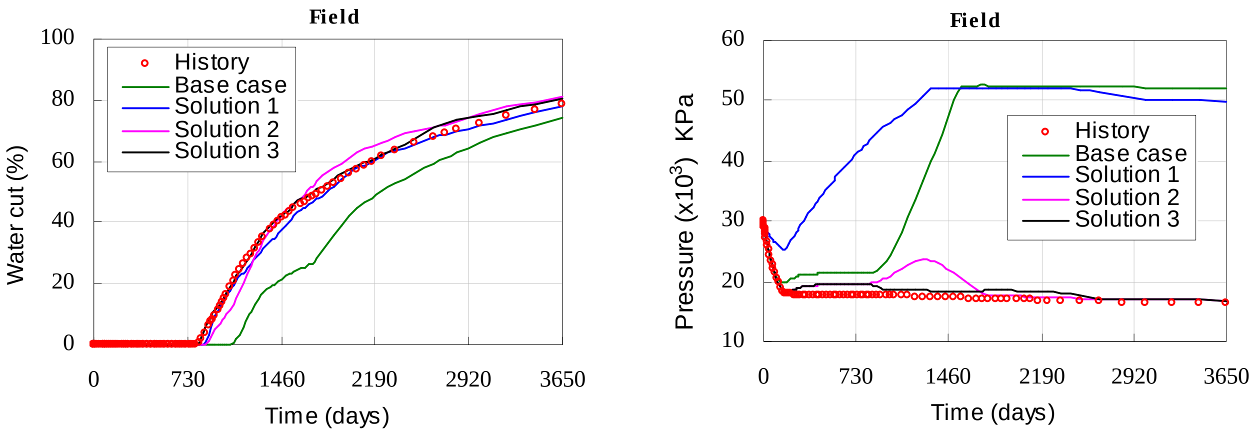


Figure 3. Wells history matching for field A



(a) (b)

Figure 4. Field history matching for model A

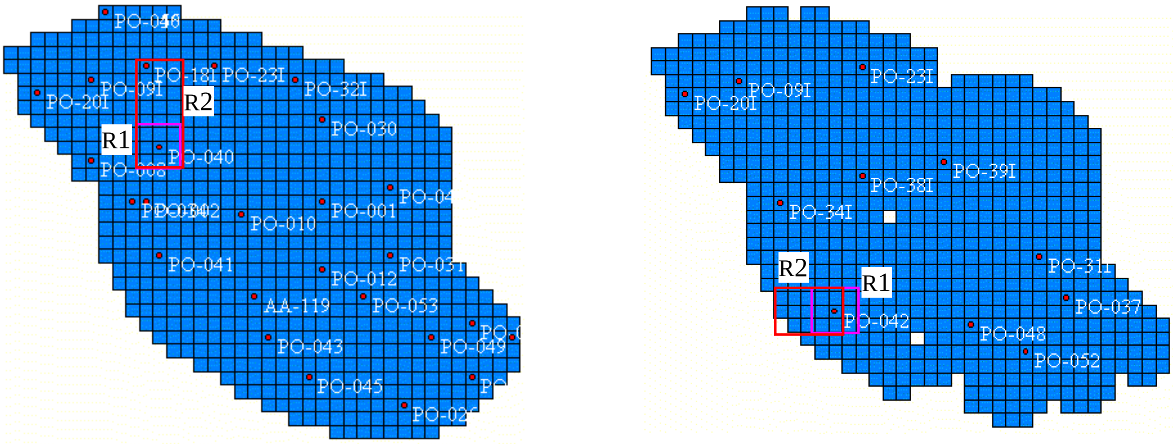
3.2. Case B - Real Field

For field B, firstly the base case (initial model) was run using a conventional simulator and through a ranking of the most problematic wells, two of them were selected to be matched. The methodology was then applied for these two producer wells. The production parameter to be matched was water rate. Well positions are shown in Figure (5-a) for Layer 3 of the reservoir model; among them, appears the producer PO-040. Normally, matching of wells is called fine matching and, in this step, a region around well is chosen for properties variation. Following this procedure, initially region R1, drawn on the Figure (5-a) was selected and horizontal and vertical permeability was changed. For changing in this first region, the results were Solution 1, in Figure (6-a), which is not a satisfactory matching.

After this first trial, the same model was run using the streamline simulator. In Figure (7-a) is shown water rate from injectors to producer PO-040 as function of simulation time. One can see that PO-040 is supported by 3 injectors (PO-18I, PO-09I and PO-20I) and the injector PO-18I exerts the greatest influence in water production of this producer.

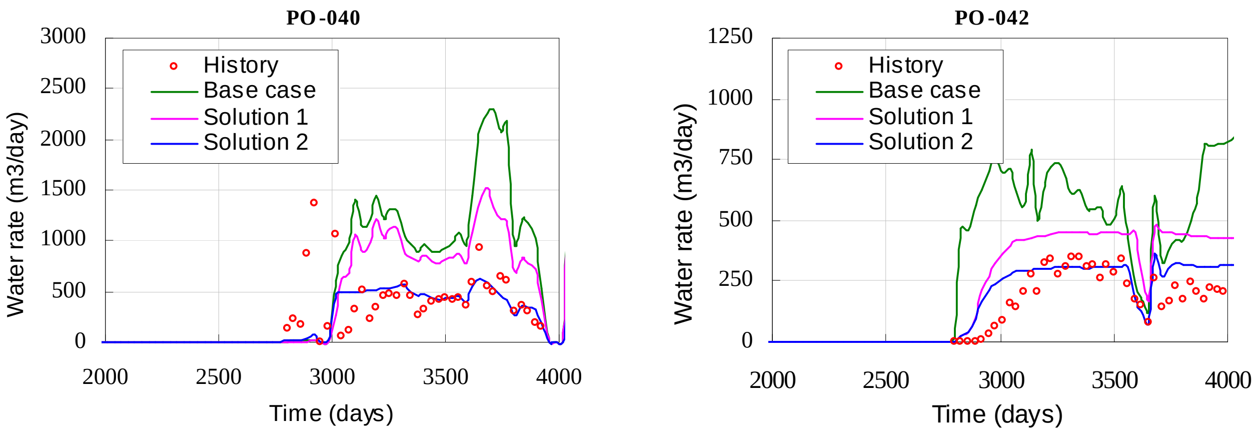
After this analysis, a new region (R2) was selected and the same parameters used in the previous matching (Solution 1) were changed. This resulted in a much more satisfactory matching (Solution 2 in Figure 6-a).

The same procedure was applied to producer PO-042. The Region R1 (Figure 5-b), with the producer in the center, was chosen as first trial to match the well, changing horizontal and vertical permeability within the region. The resulting match (Solution 1) is shown in Figure 6-b. Then, model resulting of previous step (match of the well PO-040) was run with streamline simulator and relationship between the producer PO-042 and supporting injectors are plotted in Figure (7-b). In this case, water rate originating of these injectors is very low. Therefore, this suggests that the water produced in this well is originating from aquifer, located at periphery of the Layer 5. This motivated the choice of a new region (R2) including aquifer blocks near well PO-042. The curve of produced water for changing in this new region is plotted in Figure (6-b) and show that Solution 2 is more satisfactory than Solution 1.



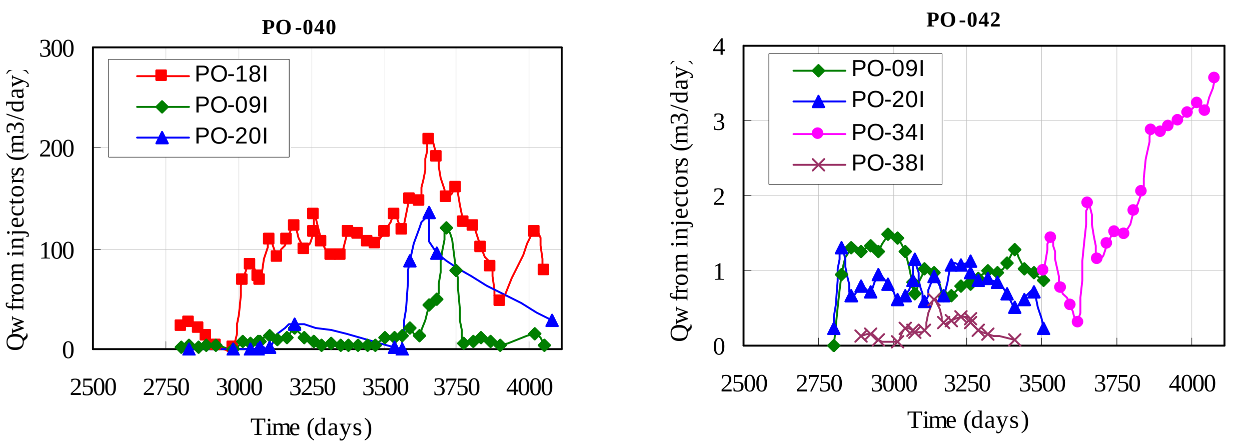
(a) (b)

Figure 5. Wells positions: (a) Layer 3, (b) Layer 5



(a) (b)

Figure 6. History matching for well PO-040 (a) and for well PO-042 (b)



(a) (b)

Figure 7. Water rate from injectors to producer PO-040 (a) and PO-042 (b)

4. Conclusions

For real cases, especially with structural and flow complexity, history matching is a difficult task. A better understanding of flow patterns and fluids distribution in the reservoir can facilitate the process. This work shows that streamline simulation is an interesting tool to support history matching process, once this technique provides insights of flow behavior and fluid distribution. A powerful feature of this simulation method is the quantification of relationship between injectors and producers and, even with some approximations, it permits an overall characterization of flow. This resource was used with success in a real case where two producer wells with high disagreement between observed and simulated water rate were successfully matched after mapping the origin of water.

Streamline simulation does not substitute traditional simulation but it can be used as complimentary tool for several reservoir engineering tasks.

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