Representation of Reservoirs Generated by Object-Based Stochastic Simulation in Numeric Flow Modeling
A. Pumptis/Petrobras, D. J. Schiozer/Unicamp

Abstract
The interest for the reservoir characterization through the use of object-based stochastic simulation has increased recently in the petroleum industry, mainly because it is a promising technique for the evaluation of new fields. The objective of this work was to study the representation of object-based stochastic reservoirs in numerical flow simulation and the influence of such a process in the petroleum production forecast. Using data of object-based stochastic simulations of a real petroleum field containing sand rich turbidities reservoirs poorly connected, it was studied the interaction of four different reservoir characterization tools: (1) object-based stochastic simulation, (2) calculation methods of petrophysical properties, (3) upscaling and (4) numeric flow simulations.

Aiming the representation of the real model with the smallest acceptable computational effort, it is shown how the choice of the calculation method of petrophysical data and the upscaling process affect the flow simulation results. It was possible to test the importance of each part of the process, especially the influence of the model heterogeneity and of use of different grids in the flow simulations. Concerning volumes in situ and oil and gas production the effect of the object-based stochastic simulation and of different methods of properties calculation were more important in the final results. Water production was most influenced by the upscaling process.

It is shown the importance of each part of field production prediction process from the reservoir characterization through the flow simulation. The influence of heterogeneity and details about the upscaling process are discussed.

Introduction
The main objective of this work is to present a procedure to integrate representative data obtained from object-based stochastic simulation, upscaling and reservoir flow numerical simulation.

This work also was conducted to obtain the impact of the upscaling procedure in the numerical flow simulation, showing how the variation of grid size in the oil, water and gas production of the wells, especially in the cases tested here which is a poorly connected reservoir.

The main attributes investigated in the process were: reservoir limits, porosity and absolute permeability. Porosity and permeability are important variables to be considered in the reservoir behavior during production and for some types of reservoirs, the method used to calculate these attributes have significant effects in the field production. For this reason, it is also investigated the influence of the calculation methods (kriging and stochastic simulation) in the final results.

The use of different realizations of the geological model and the consideration of different techniques to represent the reservoir in the modeling of the reservoir performance allows the uncertainty assessment related to volumes in place, production and economic evaluation, yielding an adequate reservoir management during exploration and development phases.

During these phases, it is important to have reliable procedures in the modeling processes. On the other hand, it is important to have fast responses, which are obtained through fast simulations. For this reason, it is necessary to evaluate the influence of each step of the process in the final results.

In this work, object-based stochastic images are associated to the other reservoir characterization data in a fine scale, which should be used to represent adequately the heterogeneity. However, as in most of the practical cases, such scale yield too many grid blocks to be used in the flow modeling process. Therefore, upscaling techniques are used to transfer data from the geostatistical model (fine scale) to the flow model (coarse scale) in order to have reliable models to quantify the impact of uncertainties, in the prediction of reservoir performance, in history matching procedures or in the optimization of production strategy.
Case History and Definitions
The data used in this work is from a real petroleum field composed by turbidity sediments deposited in proximal areas of depositional system, generating a compound of discreet channels with low connectivity index. (Palhares, 1991 and Moraes et al, 2000). The reservoirs have between 70 and 80 million years. The main production mechanism is solution gas drive and there is also the influence of a small aquifer.

The data were originally studied by Santos (1998) that has performed the geological modeling, obtainment of parameters and geometric modeling of the reservoirs and the object-based stochastic simulation based on turbidity channels. The final models considered by Santos (1998) as the most significant were used here to represent the reservoir in the numerical flow simulation. Several images of the reservoir were generated yielding a wide variation of reservoir volume.

One of the parameters that were analyzed was the petrophysical data that was generated on the geostatistical scale. Four different models were tested. Initially, it was used a constant porosity model using the average porosity of the reservoir (22%). This model is referred here as phi_c. The second model is called phi_krig and it was generated from kriging based on well logs. The third model was based on the second one but it was used a 12% cut off porosity value (phi_krig/2). In the last model (phi_sim), one selected image generated by stochastic Gaussian simulation was used to represent the reservoir.

The absolute permeability was calculated based on the porosity model, using on correlations generated by a similar known field.

Porosity and permeability upscaling was also tested for different coarse grids in the flow simulation model. Porosity upscaling was performed using an arithmetical average (Renard & Marsily, 1997). In the permeability upscaling process, it was used a numerical model based on finite difference calculation. As suggested by Renard & Marsily (1997) the analytical methods have good approximation when the reservoir is stratified or isotropic with lognormal permeability distribution and uniform flow. Ligero et al. have tested several cases and concluded that numerical method can be used in a mode general case and usually present better results.

The results obtained were analyzed comparing the output from the numerical flow simulation considering seven different objective-functions: oil, water and gas volumes in place (OOGP, OWIP and OGIP); oil, water and gas cumulative production (Np, Wp and Gp); and cumulative water injection (Wi). The results were carefully analyzed in order to measure how sensitive there were with respect to the variation of the object-based stochastic model, porosity model and upscaling.

Process Description and Application
The complete process is detailed in this section and it can be represented in Fig. 1.

Maping of genetic units and object-based stochastic simulation

Choose of thick grids and upscaling.

Statistical analysis for choice the images

Numeric flow simulations

Analysis of reservoir behavior and future forecasts

Estimate of petrophysical data

Figure 1 – Proposed methodology.

The first step of the methodology was performed by Santos (1998) who worked on the geological characterization of the reservoirs geometry. Santos (1998) obtained representative equations of the turbidity bodies geometry used in this work. The next step was to generate several images of the turbidity channels based on an object-based simulator. In this work, 47 images were used and one example is illustrated in Fig. 2.

Figure 2 - Image generated by the stochastic object-based simulator. Measures in meters.

Using the 47 images, a statistical treatment allowed the selection of 3 images that represent the uncertainty of the problem. Based on the reservoir volume, the selected images were: a pessimistic (P10), an intermediate (P50) and an optimistic (P90). The names P10, P50 and P90 indicate that 10% of the images have a volume below 114 MMm$^3$, 50% below 119 MMm$^3$ and 90% below 127MMm$^3$, respectively.

The images used in this work were chosen following the criteria proposed by Galli et al. (1996) that are:

- Grid which is consistent with the upscaling problems related to very small blocks;
- The number of blocks must allow to test a great variety of parameters for each simulation method;
- The characteristics of the flow simulators yield restrictions to the grid regarding the permeability upscaling (execution time and memory, for instance).
Therefore, the fine grid model was build based on a 50x100x100 grid (X, Y and Z directions respectively). Each block has approximately 35m horizontally and 2.5m vertically. Most of the images show a bigger reservoir with more than 70% of the total volume connected and less than 30% in smaller reservoirs separated hydraulically. The work was than concentrated in the main reservoir where most of the producers were located. The final fine grid model was then composed by a 50x100x47 grid model.

Porosity and permeability values were generated using the four different procedures described in the previous section.

The coarse grid models used after upscaling were regular Cartesian grids. Two models were grouped only on the horizontal direction (25x50x47 and 10x20x47), two were grouped only on the vertical directions (50x100x23 and 50x100x8) and two with horizontal and vertical upsampling (25x50x8 and 25x50x10). The last model was created with vertical and horizontal upsampling and an irregular grid refined in the central region of the reservoir.

After the construction of all possible situations concerning (1) object-based stochastic simulation, (2) porosity model, and (3) upsampling, numerical flow simulation were realized using a Black-Oil formulation of commercial simulator.

The results were compared with observed data but the most important objective was to compare the several realizations to measure the impact of each step in the final results.

The operational conditions of the 22 producers and 6 injectors were kept constant in all cases and during the entire simulation runs. Those conditions were obtained from the observed data of the field.

**Application and Results**

Table 1 shows a summary of all variables analyzed during this work.

<table>
<thead>
<tr>
<th>Table 1 – Analyzed variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Images</td>
</tr>
<tr>
<td>Upscaling</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Methods for porosity determination</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Objective functions</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

**Volumes in pace analysis**

Comparison with observed data

The first set of parameters analyzed were the volumes in place. Unfortunately, the results have shown that the volumes generated by the object-based stochastic simulation were not representative of the observed data, as shown in Table 2. Therefore, it was recommended to get back to the characterization process to study the reasons of the discrepancies.

Even with these results, the study was continued because the objective of the work was to measure the impact of each phase of the modeling process in the final results. However, it was not possible to compare the results with the observed data.

<table>
<thead>
<tr>
<th>Table 2 – Oil volumes in place obtained from flow simulation of the fine grid case (50x100x47)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated</td>
</tr>
<tr>
<td>Phi_krig.2</td>
</tr>
<tr>
<td>Phi_sim</td>
</tr>
<tr>
<td>Phi_krig</td>
</tr>
<tr>
<td>Phi_cte</td>
</tr>
</tbody>
</table>

The big difference between the results and real data can be attributed to some factors. First, wells are generally located in places where expected oil volume and productivity are high. Therefore, data collected from such wells are optimistic. However, in the conditioned stochastic simulation process this information was not taken into consideration yielding possibly an optimistic volume of oil in place.

The second possible factor was that Santos (1998) mapped several turbidity bodies in the study area, including those with unfavorable porosity and permeability conditions which yield low productivity and continuity. Therefore, some of the turbidity bodies generated and that were conditioned by the 54 wells of the field could have lower volumes than those obtained by the simulation.

Also, the consideration of an average porosity of 22% may have leaded an overestimation of the volume because this number was obtained from data of the producer wells. The fact of having several discontinuous turbidity bodies with lower porosity values may have been properly taken into account.

Some attempts to correct the volume in place were made with no success. Due to the big volume difference, it was decided that the process should return to its initial phase and the studies here followed with other objectives.

Another interesting fact observed later was that the rates and pressure obtained from the flow simulations did not resulted in a difference as big as the differences in the volumes in place. This fact may also yield an explanation for the difference between the observed and obtained volume data; the generated data may be more continuous and with a higher connected effective porosity than the real field.
It is important to register the high discrepancies obtained in this example. In this case, observed data was available to point problems in the process but in some other cases, this type of study may be used as a predictive tool and may yield wrong reserves and production estimation. The object-based simulation process must be studied carefully in such cases.

Analysis of the results obtained from flow simulation

Oil, gas and water volumes in place are naturally not significantly affected by upscaling (Fig. 3). However, these volumes present variations from 11 to 17% for the different images generated by the object-based stochastic simulator (Fig. 4). The variation obtained from the porosity-permeability model yield variation from 17 to 21% (Fig. 5).

The criteria used to select the representative images was based on the total volume of the reservoir and, therefore, in some cases, a image with higher total volume can present smaller oil volume because of the number of objects generated in the water zone. It can also change with phi calculation method.

Oil and Gas cumulative production

The optimistic image (P90) yields variations of Np and Gp with respect to the other images that can be negative or positive, depending on the grid and porosity model. This happens because the OOIP is not always more optimistic for this image, as explained in the previous section. The image P10 always has a pessimistic oil production. The same occurs with the gas production. See Fig. 6.

The porosity-permeability model affects significantly the recovery factor (between 14 and 17% for the P50 model). The higher recovery factor was obtained for the method phi_sim. Even with smaller oil volume in place, the cumulative production is higher for this method as observed in Fig. 7.
The influence of upscaling in the cumulative oil production is much higher than the influence in the oil volume in place. However such influence is smaller than the effect of the porosity-permeability model.

The influence of upscaling in the gas production is much higher than the influence of the porosity-permeability model. The possible explanation for that is the upscaling in the pressure distribution that affects the gas production.

It is important to notice that the vertical upscaling causes a decreasing in the oil and gas cumulative production. Also, it can be observed from all cases tested that for more homogeneous models, the influence of the upscaling is smaller (Fig. 8).

In general, the grid 10x20x47 presents the worst results comparing all coarse grids with the fine grid. Analyzing several results from this model (pressure behavior, oil flow rate, Gas-Oil ratio, Water Cut, and Injection flow rates), it can be observed that this grid is not representative of the reservoir (fine grid). This result is repeated for all images and all porosity models.

For instance, it can be observed in Fig. 9 the difference of the pressure behavior between the 10x20x47 grid and the fine grid. The results of another coarse grid were also included in the graph to compare the difference. Due to the upscaling and size of the blocks, the production of the first wells was very low and the pressure of the field was almost not affected.

In Fig. 10, it can be observed that the water gets in the producer several years before in the fine grid than in the coarse grid. However, the 25x50x8 grid presents a much better match after the beginning of the water production, what can not be observed for the 10x20x47 grid.

Analyzing several simulations, it can be observed that for more homogeneous distribution of petrophysical data (phi_c te and phi_krigl2) the interference of the upscaling is smaller.
This is observed in the results of image P50, but not so clear in other cases. See Fig. 8.

**Water production and injection**

It can be observed a big variation in the water production in all cases analyzed. The most important influence among all porosity calculation methods was from the phi_sim method what yields big impact, not only in the water production (Fig. 11) but also in the water injection (Fig. 12). These figures were obtained for P50 but the P10 and P90 images presented the same behavior.

The porosity-permeability model caused a variation between 34 and 61% in the cumulative water production. The impact of the different images varied from 29 to 72%. The upscaling process caused a variation of 67 to 99%.

The differences in the Wp and Wi behavior for the analyzed images can be better visualized in the Fig. 13. This behavior differs for the porosity calculation methods used. In general, the image P50 shows larger values of Wp for most of the grids, decreasing to the thickest grids vertically. Already the images P10 and P90 also show reduction in the accumulated production of water for thick grids horizontally.

![Figure 11 – Water cumulative production – P50 – different coarse grids](image)

Some of the problems related to water injection can be minimized by a short history match that could be used to discard several images and some coarse grids and to correct the productivity and injectivity changing the characteristics of the well zones.

However, due to the high heterogeneity of the model the influence of the upscaling was very strong yielding different results, mostly due to the difficulties of the coarse grid to reproduce the “fingering” observed in the fine grid model.

The target water injection rate was the same for all cases and the variation were observed only in the cases where the simulator could not reproduce the same rate. This behavior was observed mainly in the most heterogeneous models (phi_sim) and most coarse grids.

![Figure 12 – Cumulative water injection – P50 – coarse grid model](image)

It can be observed in Fig. 9 that the 10x20x47 grid was again not representative of the problem.

**Results and Discussion**

The objective of this work was to show the process of representation of reservoirs in numeric flow simulation based on the object-based stochastic simulation.

A great number of images can be generated and the selection of representative images can be based on volumes in place. If great uncertainty is present in the process, optimistic and pessimistic images can be selected. If observed data is available it can be used in the selection process.

The first variable to match in the process is the reservoir volume. If the results are not compatible with observed data, the process should be reviewed, as recommended in this work for the case studied. At least, a sensitivity analysis of the geometric parameters that were used to generate the objects must be performed.

It was also observed that the object-based stochastic simulation must be used carefully to avoid significant errors. One important aspect to be avoided is the use of information that can overestimate volumes.
The second important parameter to be observed is the continuity of the reservoir and selection of production zones. The difficulties are greater and a detailed characterization process is important. History data is also very useful in such a case.

The integration of object-based stochastic simulation, upscaling and flow simulation is very useful in the characterization, reserve assessment, and prediction of reservoir performance. These techniques can be used jointly to predict uncertainty and history match can be used to select the best alternatives.

The analysis of the volumes in place show greater influence of the object-based stochastic simulation and porosity model.

For the porosity model, kriging was efficient and fast. In order to perform other stochastic simulation, it is recommended to follow the steps suggested by Chilès & Delfiner (1999).

Oil, gas and water production was affected by the entire characterization process but the most relevant step was the upscaling. Coarse grid can reduce significantly the flow simulation time but there is a limit of acceptable results that can vary from problem to problem. The reduction of time for coarse grids is significant not only in the flow simulation but in the entire characterization process.

When the level information is low and uncertainty is high, coarser grids can be used and several flow simulation runs can be used to measure impact of uncertainty in the production. Without the observed data to match history production, it is difficult to select images and size of the grid.

When the level of information is higher, finer grids and history matching are recommended. Fine grids are also necessary to represent better reservoirs with greater heterogeneities.

The most affected parameter in the example studied was water production. Different realizations and different grids have influenced significantly water movement in the reservoir. Therefore, depending on the recovery mechanism, finer grids are also recommended.

Conclusions

The main objective of this work was to study the application of object-based stochastic simulation in the representation of reservoir in the prediction of production performance. The integration of this technique with porosity and permeability models, upscaling and flow simulation was applied to a field composed by small turbidity reservoir with low connectivity.

The first step of this integration must be the comparison of volumes in place with observed data. We have observed that some characteristics of the object determination can overestimate reservoir volume. This step must be further investigated. If discrepancies occur in this step, the process must be reviewed.

For the porosity distribution determination, kriging was fast and efficient. The permeability distribution must be determined more carefully because of the influence in the recovery, especially for coarser grids. For strong heterogeneous reservoirs or images, relative flow modeling in the reservoir is strongly affected by upscaling, permeability model and image generation and selection.

Depending on the stage of reservoir development, grid size and tools for representation of geology may be selected differently.

Nomenclature

\[ \text{Cte} \quad = \quad \text{Constant} \]
\[ \text{Gp} \quad = \quad \text{Cumulative Gas Production} \]
\[ \text{NPV} \quad = \quad \text{Net Present Value} \]
\[ \text{Np} \quad = \quad \text{Cumulative Oil Production} \]
\[ \text{Krig} \quad = \quad \text{Kriging} \]
\[ \text{Krig12} \quad = \quad \text{Kriging without } \phi \text{<12\%} \]
\[ \text{OGIP} \quad = \quad \text{Gas Originally in Place} \]
\[ \text{OOIP} \quad = \quad \text{Oil Originally in Place} \]
\[ \text{OWIP} \quad = \quad \text{Water Originally in Place} \]
\[ \text{Phi} \quad = \quad \text{Porosity} \]
\[ \text{Sim} \quad = \quad \text{Stochastic Gaussian Simulation} \]
\[ \text{Wcut} \quad = \quad \text{Water Cut} \]
\[ \text{Wi} \quad = \quad \text{Cumulative Water Injection} \]
\[ \text{Wp} \quad = \quad \text{Cumulative Water Production} \]

Acknowledgments

The authors wish to thank UNISIM team and PETROBRAS for allowing the use of the data set in this study.

References


MORAES, M. A. S., BLASKOVSKI, P. R., ALMEIDA, M. S., Parametrização de sistemas turbidíticos análogos, internal report, Petrobras, 2000.

