Effect of Grid Size in Risk Assessment of Petroleum Fields
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Abstract
It was shown recently that it is important to evaluate risk through probabilistic methodologies that involve a high number of simulation models because of the number of uncertain attributes. Geological modeling yields reservoir models that are represented through fine grids with millions of blocks. A probabilistic risk evaluation based on such grids would require a very high computational effort. Therefore, an upscaling procedure is necessary to reduce the grid size but it is difficult to select a grid size that could represent an adequate balance between precision of risk assessment and computational effort.

The methodology applied to quantify risk involves a sensitivity analysis in order to reduce the number of critical attributes and the simulation of reservoir models obtained through all possible combinations of these attributes. After the simulation of the models, a statistical treatment is used to evaluate the risk involved in the process. Several procedures can be used to speed up the process; however, the number of simulation runs may be very high. Upscaling of the simulation models can decrease significantly the computational effort and global time of the risk analysis process but it can also yield an inadequate risk assessment.

In this paper the effect of the grid size on the process is evaluated. It was developed a methodology (1) to select an adequate grid size and (2) to speed up the risk analysis process. The choice of geological representative models from coarse grid risk evaluation can to be useful to represent the risk on fine model, avoiding the simulation of all fine models, yielding a significant speedup of the process.

Practical applications of upscaling in a probabilistic risk assessment, that use the concept of representative models selected to characterize geological uncertainties, are shown through calculations performed in a petroleum field represented by a fine grid simulation model with geological uncertainties.
Some of these approaches rely on fast simulation models that can be response surface models, proxy models, coarser grids or simple modeling approaches. The use of these techniques may be a good solution for some cases but it may yield poor results in other situations. Most of the time, it is not easy to identify how sophisticated the model must be.

The objective of this paper is (1) to investigate the effect of the grid size in the risk analysis process in order to define an adequate grid size and (2) to identify a methodology to verify if the selected model is adequate.

In the examples of this work, the absolute permeability of a fine grid is upscaled to coarse grids with different dimensions. The applicability of each coarse grid in the risk assessment is evaluated in order to select an adequate grid size that gives the same information as the fine one.

**Risk Quantification**

The risk assessment methodology used in this work was proposed by Loschiavo et al. (2000) and implemented by Steagall and Schiozer (2001) and Schiozer et al. (2004). The methodology is based on the numerical flow simulation of several possible scenarios of the reservoir, combining the uncertain attributes.

The simulation models are built through the derivative tree technique. Each final branch of the tree corresponds to a complete simulation model that is built automatically. The probability of each resulting model is equivalent to the product of the probability of attributes that compose it.

According to this methodology, the number of reservoir simulation models increases exponentially as the number of uncertain attributes increases. To avoid an elevate number of simulation models, a sensitivity analysis is proposed to reduce the number of uncertain attributes and select only the critical ones. In this step, the effect of each attribute is evaluated using objective functions such as Net Present Value (NPV) and Cumulative Oil Production (Np).

Critical attributes are used to build automatically the derivative tree technique. After the simulation of all models of the tree, the results are submitted to a statistical treatment and production forecast with uncertainty and risk it is obtained. Usually the risk is expressed in terms of three percentile values: P10 (Optimistic), P50 (Probable) and P90 (Pessimistic). The risk of the process is represented as the NPV difference between P10 and P90.

As discussed previously, the simplifications that were proposed by various authors to reach viability of the process are considered in this work.

**Upscaling**

Upscaling techniques are commonly used to adapt the fine grid properties to coarser grids with an adequate number of cells in order to be used in reservoir simulation. The employment of coarse grids requires a smaller amount of time and computational effort and also requires a smaller memory capacity. This is an important characteristic that can be explored in risk quantifying, since an elevate number of reservoir models are submitted to simulation.

The property usually submitted to upscaling is the absolute permeability. Although various upscaling techniques are available for absolute permeability, in practice, it is difficult to select the most adequate.

In this work, equivalent permeabilities of coarse grids are obtained through the technique developed by Maschio and Schiozer (2003). This technique is based on Dykstra-Parsons coefficients that represent a measurement of the heterogeneity of a permeability data set and it is as efficient as and faster than numerical methods.

**Application**

**Model.** The model studied in this paper is based on Model 2 of the SPE 10th Comparative Solution (Christie and Blunt, 2001), which is described by a regular Cartesian grid with 60x220x85 cells. However, the use of this model with a high number of cells may not be feasible for conventional commercial simulators. Therefore, a coarser model was obtained through upscaling from the original Model 2. This coarse model is denominated as Fine Grid in this work.

The Fine Grid is described on a regular Cartesian grid with 20x100x14 cells and was adapted in order to have uncertainty in the structural model. A fixed production strategy was adopted. The probable structural model has 12 vertical producer wells and 6 vertical injector wells. The optimistic structural model has 15 producer wells and 8 injector wells. The wells were opened gradually, one every thirty days. The injection fluid was water.

**Geological Uncertain Attributes.** Uncertain attributes are structural model, water-oil contact, porosity, rock compressibility, horizontal permeability, vertical permeability and relative permeability. These uncertain and their respective values and occurrence probability are shown on Table 1. All attributes have three uncertain levels except structural model that has only two levels.

**Results**

**Upscaling.** Initially the Fine Grid with 20x100x14 cells (28,000 blocks) was upscaled in 6 distinct coarse grids with the following dimensions: 20x50x14 (14,000 blocks), 20x25x14 (7,000 blocks), 10x25x14 (3,500 blocks), 20x50x7 (7,000 blocks), 20x25x7 (3,500 blocks) and 10x25x7 (1,750 blocks). The property submitted to upscaling was the absolute permeability and the technique used was that developed by Maschio and Schiozer (2003).

Before risk quantifying, it was analyzed the effect of the grid size in the base model that is composed by the combination of all the most probable uncertain attributes. The comparison between fine and coarse grid simulation results was carried out by two objective functions: Cumulative Oil Production (Fig. 1) and Cumulative Water Production (Fig. 2).

It is possible to observe that the curves referring to 20x50x14, 20x25x14 and 10x25x14 grids are almost coincident to the curves for the Fine Grid. These three coarse grids that were not upscaled in the z direction, are equivalent to the base model of the Fine Grid. As a result, the risk quantifying can be executed using one of these three coarse grids with the same precision if the Fine Grid was used and without any modification in coarse models. The unique difference is related to the reduction of risk analysis time as the grid is coarser.
Otherwise, the 20x50x7, 20x25x7 and 10x25x7 coarse grids were upscaled from the Fine Grid, considering coarsening at the z direction. The coarse grid Cumulative Oil and Water Production were not coincident with those of the Fine Grid. It is important to observe that the coarse grids with 20x50x7, 20x25x7 and 10x25x7 cells Cumulative Production are practically coincident. Therefore, if one has to choose a coarse grid with upsampling in the z direction it is preferable to use the 10x25x7 coarse grid that has only 1,750 blocks and will produce faster risk quantifying.

In this work it is proposed to use the smallest coarse grid in the risk analysis process. However, an approach should be used to approximate the fine and coarse grid simulation results of the base models. It is proposed to match the oil and water rates for the coarse grid to that ones of the fine model.

**Matching Oil and Water Rates.** The comparison between oil and water rate of the base models constituted by the Fine and 10x25x7 Coarse Grids are shown at Figs. 3 and 4. It is possible to observe that the curves representing the rates are not coincident. This was an expected behavior.

An important property to capable to approximate coarse grid results to those of a fine grid is the relative permeability. The oil and water rates of the coarse grid were approximated to the fine grid, through matching of the relative permeability, as shown at Figs. 3 and 4. Therefore, the probable relative permeability was changed to that one obtained in the matching. The optimistic and pessimistic relative permeabilities were corrected to be consistent to the matched probable relative permeability.

Taking into account the time reduction for risk analysis when a coarse grid is used, the global process to obtain the risk curve for the Fine Grid (20x100x14) and the 10x25x7 Coarse Grid are compared.

**Sensitivity Analysis.** The main goal of the sensitivity analysis is to reduce the number of uncertain attributes and to choose the critical ones. It is the first step in a risk analysis process and consists of changing the attributes one by one in the base model.

The simulation time chosen for the sensitivity analysis is 20 years and the objective functions analyzed is Net Present Value (NPV) and Cumulative Oil Production (Np) for both grids.

In Figs. 5 and 6 are presented the results for the Fine Grid (20x100x14) and for the matched Coarse Grid (10x25x7), respectively. It is possible to observe that the more critical attributes, that is water oil-contact, porosity, structural model and relative permeability, are the same for both simulation methods.

In order to define the critical attributes to be included in the derivative tree, the gradual addition of attributes was considered, as proposed by Costa and Schiozer (2003). According to this procedure, the number of critical attributes to be included in the tree must stabilize the Net Present Values Percentiles for the Percentiles P10, P50 e P90. Fig. 7 shows the same number of critical attributes stabilizes the percentiles for Fine Grid and Coarse Grid.

**Risk Curves.** Once all models of the derivative tree are simulated, a statistical treatment is done to obtain the risk curve for Net Present Value (Fig. 8). According to Figs. 1 and 2, the risk curve mismatched Coarse Grid was not an adequate representation of the Fine Grid curve. However, as result of the relative permeability matching (Figs. 3 and 4), the risk curve for matched Coarse Grid is a good representation of the risk curve of Fine Grid. This result validates the proposed procedure of matching the base model of the Coarse Grid with the base model of the Fine Grid.

**Representative Models.** In the risk methodology, an elevated number of models can be necessary and, in certain circumstances, it is not viable to use all the models. In such cases, some models, denominated geological representative models, are capable of representing the geological uncertainty of a reservoir. In this work, the representative models were selected based on the matched Coarse Grid (10x25x7) and considering the plots NPV against Oil Recovery Factor, Cumulative Oil Production and Cumulative Water Production (Fig. 9). The representative models are different models (in terms of Np, Wp e RF) that are closer to optimistic, probable and pessimistic percentiles. It is important to notice that there are eleven representative models, four for percentiles P10 and P90 and three for percentiles P50.

The choice of representative models from matched Coarse Grid can be useful to represent the risk on Fine Grid, avoiding the simulation of all fine models and yielding a significant speedup up of the risk process. In this case the Fine Grid is simulated only twelve times, one for the base model and eleven for the representative models.

The position of representative models related to risk curves is illustrated on Fig. 10. It is possible to notice that the representative models are coincident to the risk curves in Fine and Coarse Grids. However, when the representative models are simulated admitting fine model, they are not totally coincident with the risk curves. A reason for this behavior can be seen in Fig. 11, which shows the NPV dispersion for the Fine Model against matched Coarse Model. It was observed that the models that present the worst match are the models that considered a pessimistic relative permeability.

For each particular case, considering the results as in Fig. 11, the user of this methodology can decide: if the results (differences between fine and coarse representative models) are acceptable, the risk curve constructed with the coarse model is considered as the final curve. If not, an additional matching must be performed for the representative models and a new risk curve is calculated using the new coarse model.

In the case of the example presented in this work, this matching could be performed in the pessimistic relative permeability but the results were considered acceptable and therefore, this step was not performed.

**Process Time.** The risk process time for the Fine Grid and the for Coarse Grids: 20x50x14, 20x25x14, 10x25x14, 20x50x7, 20x25x7 and 10x25x7 (matched) are showed at Fig. 12. It is possible to observe the great reduction of time with the decrease of the model dimension.
Conclusions

The use of fine grids requires a greater simulation time and consequently a greater time for the global risk analysis process. A methodology was proposed to speed up the process, maintaining the desirable precision. The base fine model was coarsened in a smaller grid and both models were simulated. The coarse model simulation result was matched to the base fine model guaranteeing an adequate risk curve compared to that one obtained through fine models. An additional step can be the selection of representative models from coarse grid risk evaluation that can be useful to represent the risk on fine model, avoiding the simulation of all fine models, yielding a significant speedup up of the process.

Nomenclature

area Structural model

cpor Rock compressibility
dwoc Water-oil contact

RF Oil Recovery factor

kx Absolute permeability in x direction

ky Absolute permeability in y direction

kz Absolute permeability in z direction

kr Relative permeability

Np Cumulative oil production

NPV Net Present Value

por Porosity

Wp Cumulative water production

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References


Figure 1. Comparison between Cumulative Oil Production for Fine and Coarse Grids.

Figure 2. Comparison between Cumulative Water Production for Fine and Coarse Grids.

Figure 3. Oil Rate for Fine and Coarse Grid (10x25x7) – Before and After the matching of relative permeability.

Figure 4. Water Rate for Fine and 10x25x7 Coarse Grid – Before and After the matching of relative permeability.

Table 1: Uncertain Attributes for the Studied Case

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<td></td>
<td>dwoc2</td>
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Figure 5. Sensitivity analysis – Fine Grid (20x100x14)  
(a) Net Present Value and (b) Cumulative Oil Production.

Figure 6. Sensitivity analysis – Coarse Grid (10x25x7)  
(a) Net Present Value and (b) Cumulative Oil Production.

Figure 7. Percentile variation for gradual addition of attributes in Net Present Value for Fine Grid (20x100x14) and for matched Coarse Grid (10x25x7).

Figure 8. Net Present Value risk curve for Fine Grid and for Coarse Grid 10x25x7 (Before and After the matching of relative permeability).
Figure 9. Geological representative models for matched Coarse Grid (10x25x7)

Figure 10. Position of Geological Representative Models related to the risk curves

Figure 11. Net Present Value dispersion

Figure 12. Process risk analysis time