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"Traditional coarse-scale simulation models tend to present optimistic oil production results for miscible gas injection."

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A New Upscaling Technique for Compositional Reservoir Simulations of Miscible Gas Injection

Victor de Souza Rios

Introduction

The use of compositional reservoir simulation is necessary to better represent the physical phenomena associated with enhanced oil recovery methods, particularly with miscible or near-miscible gas injection processes. Due to its high computational costs, it may be very time consuming to perform compositional simulations in fine-scale geological models. Therefore, upscaling of fine-scale models is required and the use of coarser grids is necessary to reduce computational time. Some upscaling techniques that are robust for waterflooding, however, can degenerate results due to loss of resolution of small-scale phenomena, averaging of sub-grid heterogeneity and numerical dispersion, especially in oil fields where miscible gas is injected.

This text presents the main contributions of a paper published in the Journal of Petroleum Science and Engineering by Rios et al. (2018), which aims at presenting a new technique for a robust upscaling of compositional displacements allowing a better representation of the small-scale results when miscible gas injection is considered, as in cases in which the produced gas is partially or totally reinjected in the reservoir. It can be applied in any compositional simulator with no need to adapt any transport coefficient, thus providing a flexible and computationally efficient approach.

The proposed technique is based on employing an alternative fluid model with a pseudo minimum miscibility pressure (PMMP) above experimental values, in order to ensure an immiscible displacement. This solution does not violate the phase behavior and ensures formation of two hydrocarbon phases in the reservoir. Therefore, the gas relative permeability plays a role on the simulation results and can be used for an improved fit of the fine model production curves. The technique is applied in two steps, first an alternative fluid model is generated and then pseudo relative permeability curves are used to better fit the production curves.

The Problem and Methodology

In order to study the phenomenon associated with miscible gas injection, a single layer representing part of a carbonate reservoir stratigraphic subzone was considered. Figure 1 shows the permeability maps for the fine and coarse-scale models. Each model presents a pair of wells (the injection well is positioned in the lower left corner and producer in the upper right corner) and first contact miscible gas injection was performed.

Evaluating the injection of CO_2-rich gas, it is possible to visualize the importance of a robust upscaling technique for compositional reservoir simulation of miscible process. Figure 2 shows saturation maps for the reference model in two different scales. The left figure is the representation in the rigorous fine-scale and the right image is the fine-grid gas saturation averaged over the corresponding desired coarse grid.

As it can be observed in Figure 2, gas saturation map in fine-scale model presents only values 0 or 1, due to the first contact miscible displacement. However, when this map is averaged to the coarse-scale, gas saturation values varies between 0 and 1. Thus, the resulting gas saturation map is more likely to represent an immiscible displacement than a first contact miscible process in the coarse-scale. Therefore, for an effective upscaling process, coarse-scale simulation runs need to reproduce this gas saturation variation. For this reason, standard static upscaling alone cannot be considered when compositional simulations need to be performed. It is necessary to work on dynamic compositional upscaling techniques to better represent the coarse-scale model results.

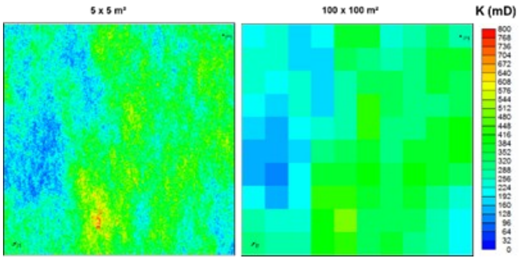

Figure 1: *Absolute permeability map for fine and coarse-scale models. Rios et al. (2017).*

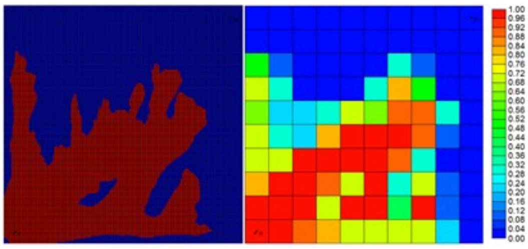

Figure 2: *Behavior of the miscible gas front in the fine-scale and its equivalent, averaged over the coarse-scale.*

One important step to establish a robust compositional upscaling procedure for miscible gas injection is to reproduce the average immiscible behavior of the gas saturation front. For this purpose, to overcome and compensate the limitations of coarser models, we propose a two-steps technique that allows the improvement of the coarse-scale simulation results, working on an alternative fluid model and on pseudo-relative permeability curves. The two steps are described below:

1) Use of an alternative fluid model with a Pseudo Minimum Miscibility Pressure (PMMP) - Pseudo because it is not an experimentally obtained pressure, but based on a numerical approach - above the experimental values in order to guarantee an immiscible displacement.
2) Generation of pseudo relative permeability curves (gas-oil in this case) as a history matching task.

The first step of the proposed methodology is an important novelty of this work. When creating an alternative fluid model with immiscible behavior, not only the physical representation of the averaged gas saturation map is improved, but also it allows the gas-liquid relative permeability curves to become effective and the generation of pseudo relative permeability plays an important role to better represent the reference fine scale results using a coarse model. It is also important to highlight that while the first step is unique for a reservoir fluid, the second one can vary depending on the upscaling ratio considered in the simulation model.

Results and Discussions

The results are presented in two parts, showing each step of the proposed technique.

Once the alternative immiscible fluid model is obtained, it is possible to replace the original fluid model to observe the

impact and conclude the first step of the technique, as shown in Figure 3 where the oil recovery factor curves are compared for: (i) the coarse models with miscible fluid model (yellow curve), (ii) the coarse model with immiscible fluid model (dashed black curve), and (iii) the fine-scale reference model with miscible fluid model (red curve).
Thus, the alteration of the fluid model has already allowed a significant approximation between the recoveries of the coarse and refined models. It is observed, however, that there is still a difference subject to improvement. Considering that the coarse case now presents two-phase flow in the reservoir, by adjusting the gas-oil relative permeability curve, it is possible to reproduce satisfactorily the recovery behavior observed in the refined reference model. This is the second step of the proposed technique and the final results are highlighted in Figure 4.

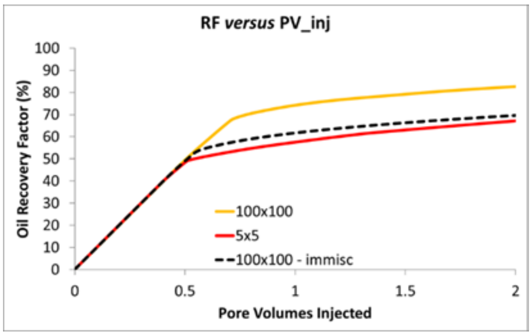

Figure 3: *Oil recovery factor versus injected pore volume of gas with coarse model (miscible and immiscible) and refined model.*

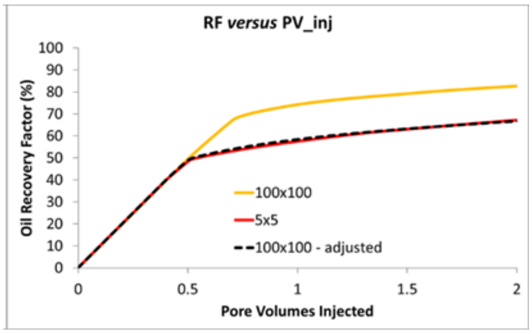

Figure 4: *Oil recovery factor versus injected pore volume of gas with coarse model (miscible and final adjusted immiscible) and refined model.*

As previously mentioned, besides the significative improvement on the oil recovery factor curve, the technique also allowed coarse models to better represent the averaged fine-scale gas saturation map, indicating a closer agreement with the reference results also qualitatively. Figure 5 shows this effect considering the gas breakthrough moment of the reference fine model. Figure 5.a shows the saturation map of the fine-scale model, while Figure 5.b represents the same map averaged to the coarse-scale. This is the reference map to be compared with the coarse-scale runs. Figure 5.c shows, for the same time, the gas saturation simulated with regular static upscaling and original miscible fluid model. The last figure, Figure 5.d, highlights the final gas saturation map after applying the two steps of the proposed technique. It is possible to observe that the overall behavior is much better represented in Figure 5.d, which complement the best fit of the production curves and emphasize the effectiveness of this upscaling technique for compositional simulations of miscible gas injection.

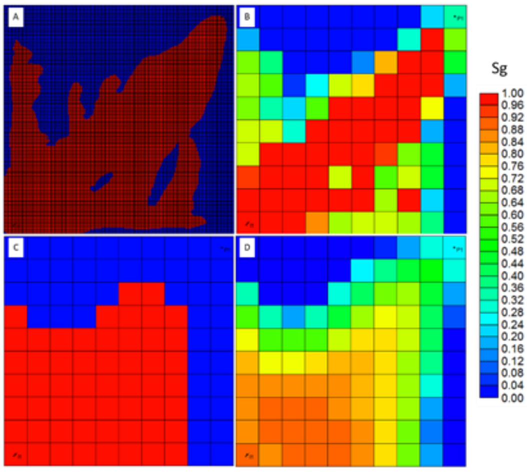

Figure 5: *Behavior of the miscible gas front in the fine-scale (A), its equivalent averaged over the coarse-scale (B), coarse-scale with static upscaling and original fluid model (C) and final coarse-scale result after the technique.*

Conclusions

The problems arising from the grid upscaling process from the geological to flow simulation models considering miscible gas injection were evaluated in this work. It was verified that the coarser scale simulations tend to present optimistic oil production results, for miscible gas injection, in comparison to the simulations in a more refined scale.
The main reason relates to the difficulty in representing unstable flow and channeling on a coarse-scale. The involved phenomena tend to disappear with the smoothing of the forward fronts, represented by the numerical dispersion derived from the truncation error.
The proposed technique presents two important contributions for a robust and effective upscaling procedure in compositional simulation of miscible gas injection cases: it makes the gas saturation behavior more representative of the fine-scale averaged gas saturation map and modifies the pseudo-relative permeability curves in order to better reproduce production curves using coarse-scale simulation models.

References

Rios, V. S., Santos, L. O. S., Quadros, F. B., Lykawka, R., & Schiozer, D. J. 2017. Methodology to Improve Miscible Gas Injection Forecast Based on a Field Scale Simulation Model. In OTC Brasil. Offshore Technology Conference.

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