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Construction of single-porosity and single-permeability models as low-fidelity alternative to represent fractured carbonate reservoirs subject to WAG-CO₂ injection under uncertainty

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Introduction

Fractured carbonate reservoirs are typically modeled in a system of dual-porosity and dual-permeability (DP/DP), where fractures, vugs, karsts and rock matrix are represented in different domains. The DP/DP modeling allows for a more accurate reservoir description but implies a higher computational cost than the single-porosity and single-permeability (SP/SP) approach. The time may be a limitation for cases that require many simulations, such as production optimization under uncertainty. This computational cost is more challenging when we couple DP/DP models with compositional fluid models, such as in the case of fractured light-oil reservoirs where the production strategy accounts for water-alternating-gas (WAG) injection. In this context, low fidelity models (LFM) can be an interesting alternative for initial studies.

This text presents the main highlights of the paper published by Menezes et al. (2022) and shows the potential of compositional single-porosity and single-permeability models based on pseudo-properties (SP/SP-P) as LFM applied to the benchmark UNISIM-II-D-CO subject to WAG-CO_2 injection and gas recycle.

Methodology

Two workflows are proposed to assist the construction of SP/SP-P models for studies based on (i) nominal approach and (ii) probabilistic approach of reservoir properties. Both workflows begin with a parametrization step, in which different parametrization methods are subjected to an optimization process so that corresponding SP/SP-P models based on pseudo-properties are obtained. The pseudo-properties are optimized for a base case in order to minimize the mismatch between forecasts of the SP/SP-P and DP/DP models. Table 1 summarizes the parametrization methods used in the work. The letters C and L in the nomenclature stand for Corey's correlations and van Lingen model, respectively, which were used for the construction of the pseudo relative permeability curves.

***Table 1**: Number of parameters of each parametrization method used to determine the pseudo-properties by optimization.*

Nomenclature	C9	C12	C17	L8	L12
Rel. perm. pseudo curves	7	7	14	6	6
Rock type distribution	2	2	3	2	2
Permeability multiplier	-	3	-	-	3

The objective of this preliminary step is to evaluate the performance of different parametrization methods and chose the one with the best performance to be used in the next steps of workflows I and II. The reader is suggested to check the workflows in the mentioned paper for more details.

Workflow I: This workflow is a cross nominal study in which two SP/SP-P models are constructed based on the same parametrization method but with different WAG-CO_2 injection strategies. This allows the user to evaluate the chosen parametrization method and the response of the SP/SP-P models when subjected to different production strategies.

Workflow II: The second workflow proposes a methodology to construct an SP/SP-P ensemble under uncertainty, considering geostatistical realizations and different availability of the platform facilities. In this case, the pseudo-properties are adjusted by robust optimizations based on representative models from the DP/DP ensemble.

Application

The workflows were applied in the benchmark carbonate reservoir model UNISIM-II-D-CO. The same strategy (S1) was applied to optimize the pseudo-properties in the nominal and probabilistic approaches, but both workflows have steps designed to assess the robustness of the SP/SP-P ensemble to varying production strategies. Thus, a different strategy (S2) was considered for this purpose, differing from S1 in the number and placement of the wells. The production strategies account for WAG-CO_2 injection as EOR method and the produced gas is fully reinjected into the reservoir. The probabilistic approach (workflow II) accounts for an ensemble of 197 scenarios, combining different reservoir uncertainties (geostatistical realizations of petrophysical properties, relative permeability, rock compressibility and technical attributes related to well index multiplier and availability of platform, manifolds, producers and injectors wells. The consistency and reliability of the DP/DP and SP/SP-P ensembles were verified by comparing the production, injection and economic forecasts with those obtained for the reference model UNISIM-II-R, which represents the true response and is not part of the ensemble.

Results

Parametrization: The SP/SP-P models resulted in a substantial reduction in the simulation runtime, varying from 66 to 78% faster than the DP/DP model (Figure 1a). The good response of the SP/SP-P models is also noted in Figure 1b, which shows the relative differences of NPV (in percentage) to the DP/DP model.

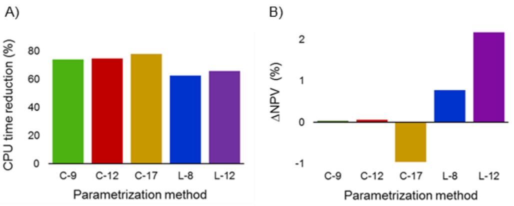

***Figure 1**: Performance of the parametrization methods in terms of: (a) computational gain, and (b) the relative difference of NPV between the five proposed SP/SP-P parametrizations and the DP/DP model.*

Workflow I: The parametrization method C-9 was select for the following steps of workflow I. The models named SP/SP-P 1 and SP/SP-P 2 were constructed by optimizations of pseudo-properties using production strategies S1 and S2, respectively. Then, a cross-simulation was performed by applying S1 to SP/SP-P 2 and S2 to SP/SP-P 1. Figure 2 shows the substantial computational gain obtained by the SP/SP-P models, with a simulation runtime reduction varying from 74 to 77%. The relative differences in the NPV at the end of the production period are lower than 1.3% in relation to the DP/DP models. In the case studied in this work, the parametrization C-9 showed to be efficient to construct SP/SP-P models, and both models SP/SP-P 1

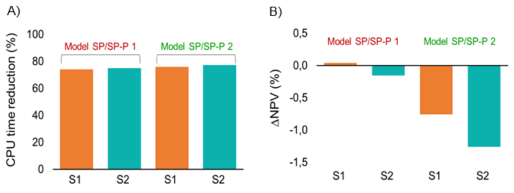

***Figure 2**: Performance of the parametrization method C-9 used in the Workflow I: (a) computational gain, and (b) the relative difference of NPV between the SP/SP-P models 1 and 2 (based on strategy 1 and 2) and the DP/DP model.*

> *"Simulation runtime reduction of single-por / single-perm models based on pseudo-properties was 81%, on average, compared to dual-por / dual-perm models."*

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and SP/SP-P 2 showed good approximation to the DP/DP model. Nevertheless, the model SP/SP-P 1 showed the best response in terms of NPV.

Workflow II: In this workflow, we selected parametrization C-12 and used production strategy S1 to optimize the pseudo-properties. Strategy S2 was used to assess the robustness of the SP/SP-P approach when applying the models with a different strategy, working as a control strategy. Figure 3 points out the potential of the SP/SP-P system to substantially reduce the simulation runtime. On average, the simulation runtime reduction was 79 and 83% for strategies 1 and 2, respectively.

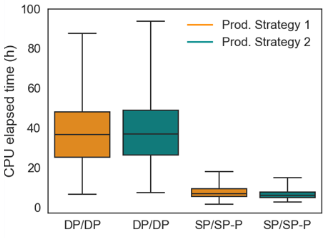

***Figure 3**: Boxplots indicating the simulation runtime of the DP/DP and SP/SP-P ensembles considering the entire production period of the field.*

The visual inspection of Figure 4 reveals a good match between the SP/SP-P and DP/DP ensembles for the NPV and oil recovery factor (ORF) risk curves of both production strategies. This indicates that the parametrization used is convenient for studies subjected to different production strategies. All risk curves encompass the true response of UNISIM-II-R, indicated by vertical dashed lines.

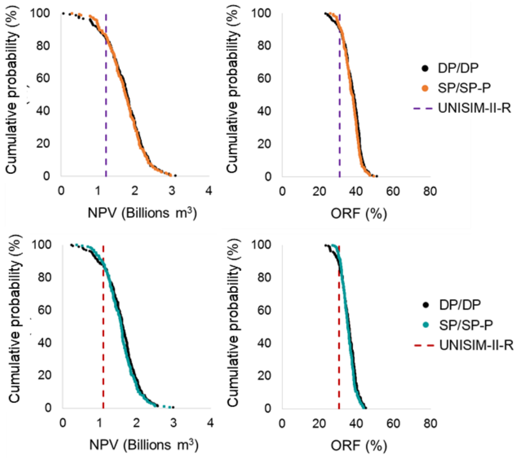

***Figure 4**: Risk curves for field indicators at the end of the production period of the SP/SP-P and DP/DP ensembles. The orange circles correspond to simulations of the SP/SP-P model applied with the same strategy as the one used in the optimization of the pseudo-properties (S1). The cyan circles correspond to simulations of the SP/SP-P model applied with a different strategy (S2).*

Concluding Remarks

- This work indicates the potential of compositional SP/SP-P models as LFM for initial studies based on single or multiple scenarios under uncertainty, reducing computational cost while maintaining a good response compared to DP/DP models. Within the scope of studies related to low-fidelity models, the work presents and successfully applies new parametrizations in the construction of SP/SP-P models based on pseudo-properties. The proposed parameterizations resulted in SP/SP-P models with good performance in both innovative workflows presented in the paper, even when applied with different production strategies.
- Workflow I is related to nominal studies where the pseudo-properties are tuned by optimizations based on a single reservoir scenario. The cross study proposed in this case allows evaluating the efficiency of a parametrization method when different production strategies are considered. Moreover, it allows the user to choose the SP/SP-P model that presents the lowest strategy dependency. Workflow II, in turn, proposes the construction of an SP/SP-P ensemble under uncertainty by performing robust optimizations to determine the pseudo-properties. For the example applied, the computational time reduction was 81% on average. Once the SP/SP-P ensemble is available, it may be used by several studies, which makes uncountable the computational advantage of applying workflow II.
- The proposed workflows are expected to assist the construction of SP/SP-P models to be applied in forecast studies, risk analysis and intermediate stages of decision analysis. However, the user is recommended to verify the final solution in a medium or high-fidelity model.

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> *"The SP/SP-P models may be applied in initial steps of forecast studies, risk analysis and intermediate stages of decision analysis."*

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