

"A hybrid workflow that calibrates the Well Index using explicit near-well DFN geometry while preserving conventional simulation time."

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Workflow for WI Calibration Using DFN Modeling in the Near-Well Region of Fractured Reservoir

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Introduction

Brazilian pre-salt fields, present significant challenges for reservoir simulation due to strong multiscale heterogeneity. Fractures or high-permeability layers control fluid flow, particularly in the near-well region. Oda-based dual-permeability (DK) models often overestimate fracture connectivity in well blocks, inflating the Well Index (WI) and leading to optimistic production forecasts. More approaches such as local grid refinement improve accuracy but increase computational cost. This work proposes a computationally efficient workflow that calibrates WI using explicit DFN modeling restricted to the near-well region while preserving simulation time.

Methodology

The proposed Hybrid Dual-Permeability (DKH) workflow consists of four steps: (1) conventional upscaling in the inter-well region; (2) filter fractures within a defined radius around each well; (3) compute WI from an explicit DFN model executed only in the first timestep; and (4) transfer the calibrated WI to the conventional DK model.

We compare two approaches: the conventional Oda-based dual-permeability model (DK), applied to the entire field, and a hybrid approach that combines Oda in the inter-well region with explicit DFN modeling near well. An intermediate DFN model (DKDFN) is used to compute a realistic WI, later incorporated into the hybrid dual-permeability model (DKH). DKDFN computes WI using explicit fracture aperture and permeability (Figure 1). The resulting WI replaces DK values, forming the DKH model (Figure 2).

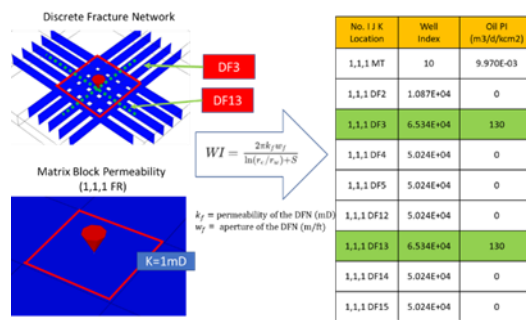


Figure 1: WI calculation for DKDFN based on the explicit DFN in the near-well region.

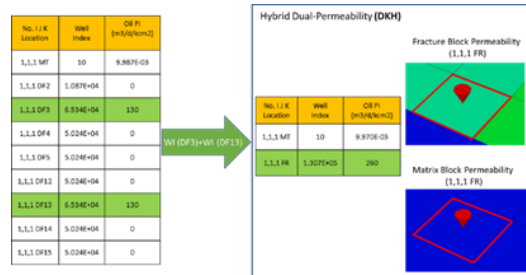


Figure 2: The WI from the DKDFN replace those in the DK, resulting in the DKH solution.

The workflow is validated using a synthetic DFN scenario and then applied to a real field under uncertainty. Since both DK and DKH are evaluated as ensembles of paired models differing only in WI, an adapted NQDS metric is used to quantify bias between them. Instead of comparing simulations to observed data, NQDS directly

measures deviations between DK and DKH responses for each model pair.

Application

To evaluate the advantages and limitations of DK and DKH, two synthetic scenarios were constructed: Scenario A, where fractures do not intersect the wells, and Scenario B, where fractures are well connected. The reference solution is a high-resolution 2D single-porosity model (Figure 3).

The methodology was then applied to a naturally fractured Brazilian pre-salt reservoir. A stochastic DFN realization is illustrated in Figure 4, with four producers and one injector. An ensemble of 100 models was generated by combining fracture and matrix uncertainties.

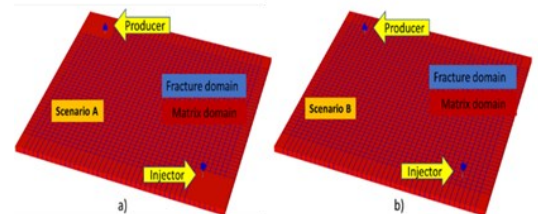


Figure 3: Reference solution (rock-type property) for (a) scenario A and (b) scenario B.

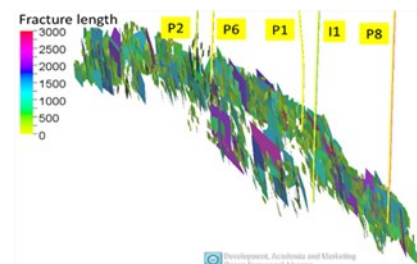


Figure 4: DFN example for one stochastic realization and field production strategy.

In the validation case, Figure 5 shows that in Scenario A the DK model overestimates liquid production, while DKH matches the reference solution with no production. The DFN intersects the well block but it does not intersect the wellbore. As Oda method ignores connectivity, DK overestimates the WI. In Scenario B, where fractures are well connected to the well, DK, DKH, and the reference show similar responses (Figure 6).

In the real-field application, NQDS results highlight significant differences between DK and DKH. As shown in Figure 7, model 6 presents minimal bias (NQDS ≈ 3), while model 17 exhibits large deviations (NQDS ≈ 350), mainly due to fracture connectivity near the aquifer. In model 17, DK has more fractured blocks, increasing water production. The WI representation near well P1 is illustrated in Figure 8, where DK assigns WI > 0 to multiple blocks, while DKH only consider the fractures intersecting the wellbore. Consequently, water coning is more pronounced in DK, as confirmed by the saturation maps in Figure 9. Ensemble results in Figure 10 show that wells with higher fracture density, such as P8, present larger NQDS dispersion, while dynamic interference from fractured wells can lead to elevated NQDS values in non-fractured wells.

“By correcting Oda-based connectivity bias, the Hybrid dual-permeability approach delivers more reliable production forecasts in naturally fractured carbonate reservoirs.”

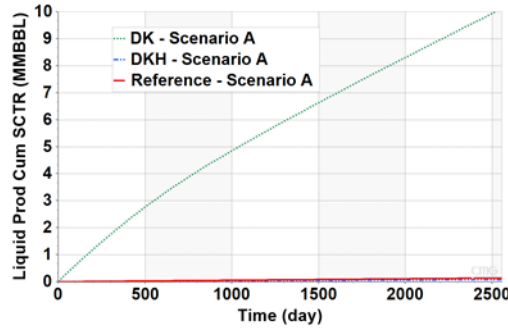


Figure 5: Cumulative liquid production for the DK, DKH, and reference solution in Scenario A.

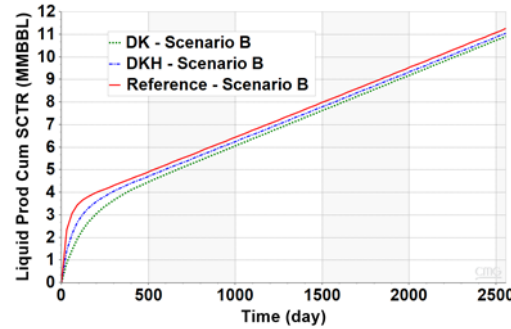


Figure 6: Cumulative liquid production for the DK, DKH, and reference solution in Scenario B.

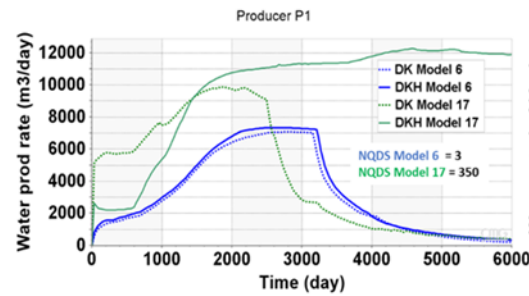


Figure 7: Q_w for producer P1. A significant bias can be observed for model 17 ($NQDS=350$), whereas for model 6 ($NQDS=3$) the Q_w are quite similar between DK and DKH. $NQDS$ directly quantifies deviations between DK and DKH.

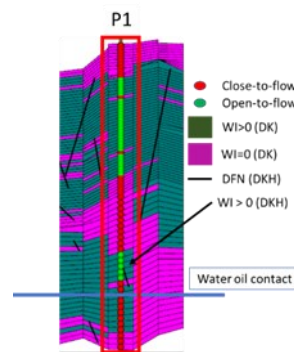


Figure 8: Schematic representation of WI near well P1 for Model 17, comparing DK and DKH. Green blocks indicate active fracture cells ($WI > 0$) in DK. Only one DFN fracture intersects the well, resulting in a single active WI block in DKH.

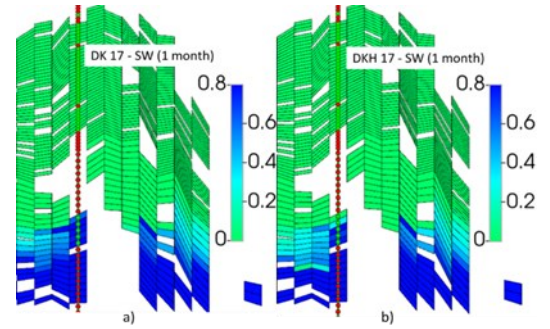


Figure 9: Water saturation 1 month after the production starts for the (a) DK and (b) DKH. A more pronounced water coning effect is observed in the DK, owing to the larger number of fractured blocks with $WI > 0$.

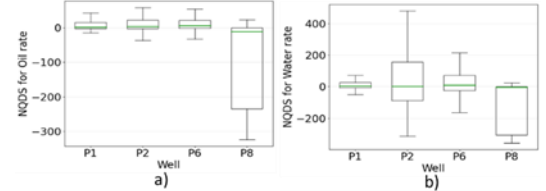


Figure 10: $NQDS$ for (a) Q_o , and (b) Q_w . The green line is the median for the ensemble.

Conclusions

This work presents an automated workflow to calibrate the Well Index (WI) using explicit DFN modeling in the near-well region without increasing computational cost. The method filters near-well fractures, computes WI from a DFN model executed only in the first timestep, and transfers the calibrated WI to a hybrid dual-permeability model (DKH). Validation with a synthetic case and a Brazilian pre-salt field shows that DKH corrects permeability overestimation while preserving simulation efficiency in fractured reservoir studies.

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Reference

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Manuel Gomes Correia holds a PhD in Petroleum Engineering from UNICAMP. He has been a researcher at UNISIM/CEPETRO/UNICAMP since 2014, leading and contributing to R&D projects focused on reservoir modeling and energy transition applications.

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