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Flow Through Fractured Reservoirs Under Geological and Geomechancial Uncertainty

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Summary

The main aim of this work is the efficient preservation of fracture related geological and geomechanical uncertainties in naturally fractured reservoirs throughout the modelling, simulation and decision-making cycle of a field. For this purpose a workflow is designed that relies on multiple-point statistics (MPS) to represent the spatial complexity that comes with fracture network modelling with an emphasis on the uncertainties that are involved around fracture network distributions and the impact that could have on flow behaviour. This is tested on a synthetic field that is based upon a conceptual model for fracture distribution in folded carbonate rocks.

The results indicate that the suggested MPS-based workflow is capable of carrying fracture related uncertainties, in particular uncertainties around fracture network distributions, throughout the modelling cycle for naturally fractured reservoirs. The results also imply that not considering these uncertainties could eventually lead to water handling issues during production, if the facilities are not designed for all possible scenarios. This shows, how including more geological realism into the model building workflow for naturally fractured reservoirs can help assessing the overall risk of a project.

Introduction

The aim for this paper is to demonstrate a workflow for naturally fractured reservoirs that carries the geological and geomechanical uncertainties throughout the entire lifecycle of modelling. Due to a practitioner's general constraint on time, this should ideally be done with a manageable ensemble of reservoir models that robustly quantify a wide range of uncertainties and geological realistic scenarios for naturally fractured reservoirs (Arnold et al. 2016).

Static and dynamic data to describe fracture distributions and their behaviour in the subsurface are scarce and hard to obtain. Fractures are comparably small features and quasi-planar in dimension, making them difficult to detect with seismic and rendering it hard to predict their field wide distribution/density and their interconnectivity (Narr et al. 2006). Further complications arise from the interaction that occurs between the fluid and the solid, making fracture aperture – which dictates flow through fractures – a dynamic and highly anisotropic fracture property that needs to somehow be recognised when trying to understand the behaviour of fractured reservoirs (Min et al. 2004; Baghbanan & Bakhtar, 1985; Couples, 2014). Overall, this makes it impossible to get a full grasps on the workings of natural fracture systems in the subsurface and bears a huge source for uncertainties.

Another challenge arises from modelling naturally fractured reservoirs. First of all, computational limitations demand for discrete fractures to be upscaled to continuous media properties, which already introduces first order uncertainties (Elfeel et al. 2013). To model spatial complex geological features such as fracture networks as continuous media properties, multiple-point statistics (MPS) can be of great use and were first applied by Jung et al. (2013) to model the uncertainty that is involved around fracture distributions in reservoirs (Mariethoz and Caers, 2014). After creating geological realistic Discrete Fracture Networks (DFN), the DFNs are subsequently upscaled and a decision needs to be made on whether a cell should be described as a dual medium (matrix and fractures modelled separately) or a single medium system (assuming that matrix and fractures can be lumped together into one cell, without significant loss of information). The emerging binary patterns are then used as training images for MPS to populate the reservoir model with fracture distributions. The underlying assumption here is that fracture sets have a somewhat repetitive nature to them that can be captured and distributed over a larger area by the training image.

To achieve the defined aims and take up the stated challenges the paper proceeds as follows: First, a workflow is established that allows for covering a wide range of fracture related uncertainties with a feasible number of training images. Afterwards, the workflow is tested on a synthetic case study, which is then followed by concluding remarks.

Workflow

The selection of an adequate training image is crucial and represents one of the major challenges when it comes to successfully applying MPS. Here it is of importance that the training image captures as much fracture related uncertainty (prior range of fracture properties) as possible in an efficient manner. The procedure can briefly be summarised in four steps:

- As training images are required to be stationary, the first task is to figure out, if fracture trends or different fracture sets occur in different zones of the reservoir. Does fracture intensity, orientation, length etc. change in space and how many training images will it require to represent these variations? What are the prior distributions for fracture properties?
- For each identified zone, the prior range of fracture properties must be assessed. By randomly sampling from these prior ranges, a large set of geological realistic DFNs is created and subsequently upscaled (Figure 1).

- The next step is to decide on whether to model a cell as single or dual porosity. Shape factor and fracture porosity were the effective fracture properties that drove this decision. If a certain threshold value for each of these properties was exceeded, the cell was modelled as dual porosity (Figure 1). Instead of picking a set value for this threshold, a range was selected.
- Going through the combinations for fracture properties as explored in step one and two, having a representative number of realisations for each parameter combination and applying various cut-offs per training image results in an unmanageable amount of training images. It is therefore necessary to apply some sort of clustering method to the resulting training images that allows for picking a reasonable number of representative training images, whilst still describing the overall uncertainty of the system. Here, the k-means clustering algorithm is applied, which allows for the separation of all training images into n clusters that are each represented by a cluster centre. The training image closest to each cluster centre is then selected as being representative for the entire cluster. To determine the appropriate number of clusters for each dataset, the elbow method is applied, trying to keep the trade-off between total sum of squares within each cluster and the number of clusters in balance.

Figure 1 Conceptual DFN model (left) is upscaled (Oda Gold method) to continuous media properties (porosity pictured in middle) and subsequently a threshold is applied to determine whether a cell is modelled as single or dual porosity. The resulting pattern corresponds to the training image used for MPS.

With the training images configured, a set of synthetic models that represents all possible combinations of different training images for each zone is build. At present, the only purpose of those training images is to determine the impact that different fracture network patterns have on fluid flow and whether it is necessary to model fractures and matrix as single or dual- porosity media. Therefore, the fracture permeability in dual porosity cells is set constant in all directions (knowing that permeability in fractures is highly anisotropic).

Case Study

The case study used in this paper is based upon a conceptual model for fold-related fracture distributions in a low quality carbonate rock shown in Figure 2. There are three distinctive zones with different fracture patterns. In the folds crest fractures are orientated parallel to the fold axis, are rather short, have a high intensity and a low order of dispersion. The flank is characterised by longer fractures that show a higher degree of disorder and are lower in intensity. In terms of fracture properties, the intermediate area represents a transition from fractures observed in the flanks to the crest.
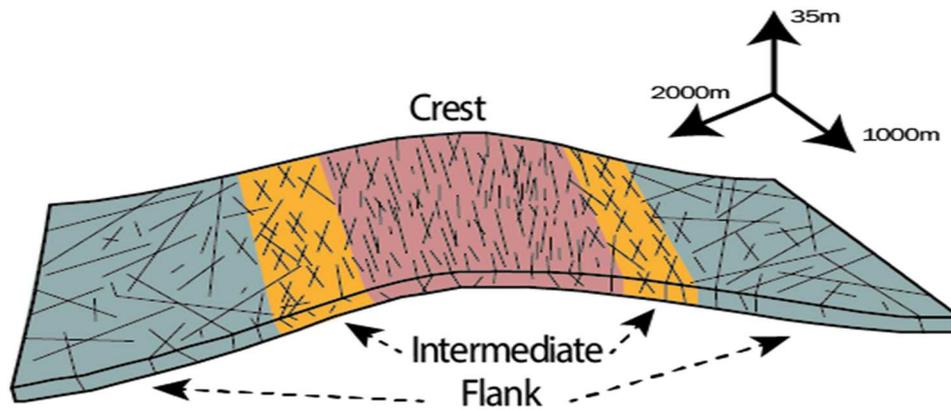
Figure 2 Conceptual fold model, showing the different types of fracturing along the flank, the crest and the intermediate zone.

The three distinctive zones require for the use of a different training image per zone. As explained in the methodology section, the full range of uncertainty around the fracture distributions is efficiently explored by picking a representative subset of training images for each zone. All possible combinations for training images lead to 125 synthetic models. For simplicity, the flow simulations were run under a dead-oil configuration, with a producer pair on the folds crest and an injector sitting on each flank.

When comparing the results for all models (Figure 3), it becomes clear that there is only a slight difference in total oil production (Δ 20%). The profiles all look very similar, showing a steady increase until up to 3 – 4 years of production, which then gradually levels out. The timing for the initial water breakthrough on the other hand behaves very different throughout the ensemble of models (Figure 3). All profiles have a similar sigmoidal shape that eventually leads to a water cut of 80 – 90% at the end of the simulation, but first water breakthrough varies between 0 to 3.5 years after simulation start. For that reason, although the total oil production for all models is comparable, the total water production for each model strongly varies (Δ 70%).
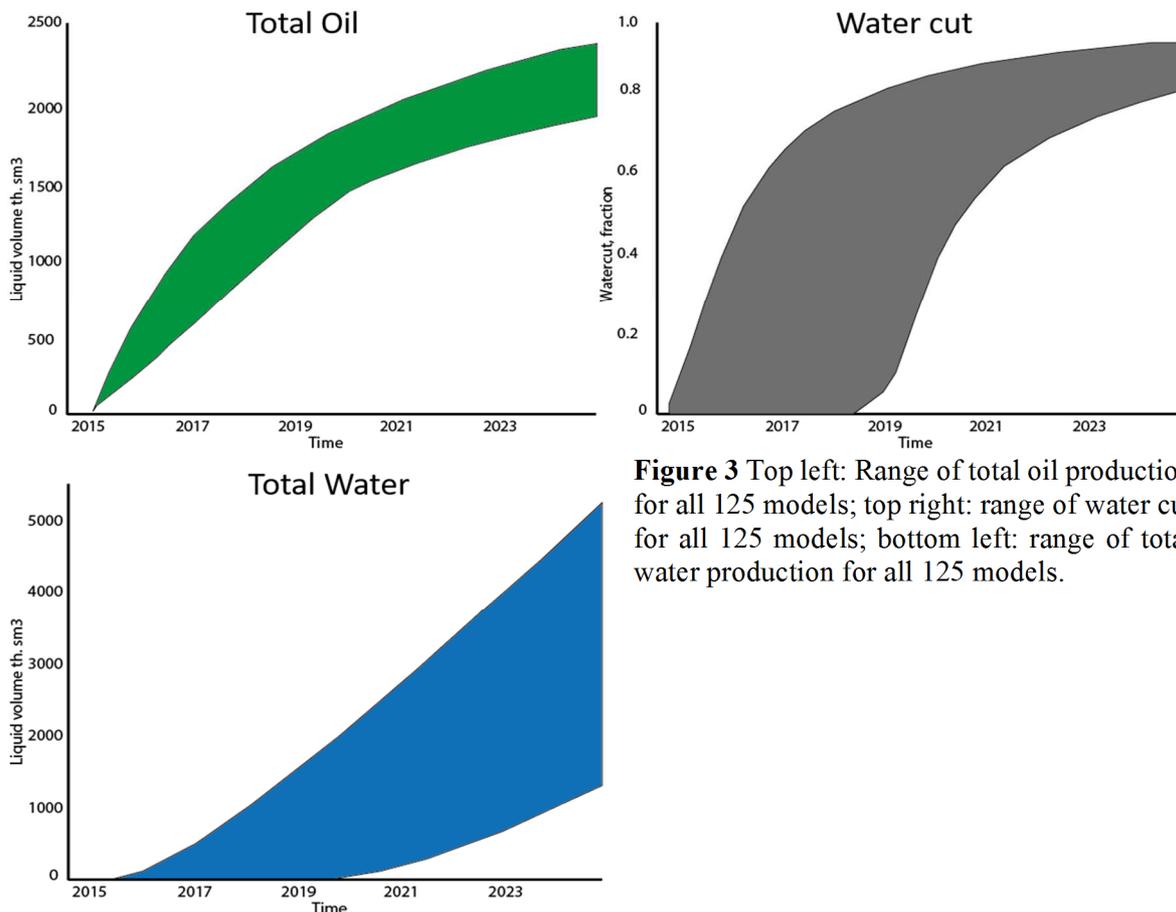
Figure 3 Top left: Range of total oil production for all 125 models; top right: range of water cut for all 125 models; bottom left: range of total water production for all 125 models.

Conclusion

The idea behind this study was to evaluate the impact of geological and geomechanical uncertainties when it comes to the characterisation of naturally fractured reservoirs. The synthetic case study has shown that not considering these uncertainties (although still very simplified) could eventually lead to water handling issues during production, if, the water treatment facilities at the surface are not designed for all possible scenarios. This shows, how including more geological realism into the model building workflow for fractured reservoirs can help with better assessing the overall risk of a project.

Acknowledgements

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