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Integration of multiscale carbonate reservoir heterogeneities in reservoir simulation

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ABSTRACT

The construction of robust reservoir models considering geological carbonate heterogeneities, such as fractures and vugs, upscaling and numerical flow simulation remains a challenge. This work performs a methodology aiming a suitable representation of flow simulation and upscaling techniques according to small and large scale carbonate reservoir heterogeneities. The methodology is applied to one specific flow unit type considering diffuse fractures, sub-seismic fractures and isolated vugs.

The methodology follows four elementary steps: division of reservoir into flow units, geostatistical modeling, upscaling procedures and flow simulation modeling of carbonate reservoirs. Given the presence of multiscale geological features and computational limitations, the upscaling procedure is separated as a function of heterogeneities scale.

The process is shown for one flow unit of a specific case where flow progress in matrix and fracture occur at different time steps which make the single porosity approach difficult. For regions of fractures not fully connected, the flow takes place in the matrix. A dual permeability flow model is the best approach since it can take into account both flow progresses in connected fracture networks and in matrix medium.

The methodology has shown several advantages: sequential control over static properties and pseudo-functions integrated with upscaling procedure; definition of the accurate simulation flow model; and improvement of the integration of multiscale heterogeneities in reservoir simulation.

This work presents a new methodology and analysis that can be useful for multidisciplinary areas.

1. Introduction

Carbonate oil reservoirs hold significant quantities of the world oil and gas reserves. About half of the world proven oil reserves are trapped in fractured carbonate reservoirs. The high number of uncertainty involved in the development of carbonate reservoirs leads to the need of understanding the flow behavior in all scales (Ahr, 2008).

For flow simulation purposes, the development of a naturally fractured carbonate reservoir keeping its heterogeneous behavior and in a reasonable simulation consumption time, can be a challenge. Fracture scales could range from small scale diffuse fractures, intermediate scale sub-seismic faults to large scale seismic faults.

The discrete fracture network (DFN) model cannot be included into field scale models because of the computational limitation to fix possibly billions of fractures in each cubic kilometer of reservoir rock. Upscaling is therefore a pre-requisite for flow simulation (Dershowitz et al., 1998).

The translation of DFN models and/or implicit fracture models into an equivalent medium is set by upscaling procedures. Either analytical or numerical methods can be used to upscale fracture permeability. Oda (1985) proposed an analytical equation to calculate fracture-permeability tensor and Lough et al. (1997) presented an approach using the boundary-element method. Oda's solution is faster since it is an analytical solution. The equation can be described as:

$$K_f = \frac{1}{V_{cell}} \sum_{s=1}^{NBsets} \sum_{f=1}^{NBFracs} V_{f,s} \frac{C_{f,s}}{12 e_{f,s}} \overline{N_{f,s}}$$

where in V_{cell} is respect to block volume, $C_{f,s}$ and $e_{f,s}$ are related to fracture conductivity and fracture aperture, respectively. *NBsets* is the number of fracture sets, *NBFracs* is the number of fracture per set, $V_{f,s}$ is the fracture volume, $N_{f,s}$ is respective to matrix projection relatively to pressure block gradient in fracture plan. However, this method is only valid for well-connected and high density DFN. The second method, numerical solution, consists in

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solving a steady-state flow problem, under boundary conditions, on the discrete fractured network with application of Poiseuille's formula for fracture flows. This method takes into account the full geometry of the system but requires a larger CPU simulation time. Because of the high computational effort, this method is normally applied only to small density of fractures.

Another issue in upscaling procedures is related to the multi-scale fractures length relative to simulation grid block size. Lee et al. (2001) demonstrated that long fractures, whose scale is much larger than grid block, have more influence in flow than short or medium scale fractures. Any homogenization method will under-estimate the real effect of these geological features. Small scale fractures can be modeled as part of an equivalent medium using dual porosity simulators or implicitly in matrix component. Some works, for instance Li and Lee (2006), consider a numerical method to upscale medium discrete fractures and an analytical method to upscale small scale fractures. In addition to fracture length scale, flow properties of fractures and interaction with matrix medium can be important to determine a representative model (Single Porosity system (SP), Dual Porosity system (DP), Dual Permeability (DK) or explicit fault modeling).

Setting up the flow model for a naturally fractured reservoir is still a challenge. Bourbiaux (2010) developed a methodology to define guidelines for selecting the proper flow modeling approach of a fractured reservoir. This methodology identifies three drive criteria for the selection of a proper flow simulation model: the fracture scale compared to simulator grid cells; the connectivity of the fracture network and continuity of matrix medium; and the

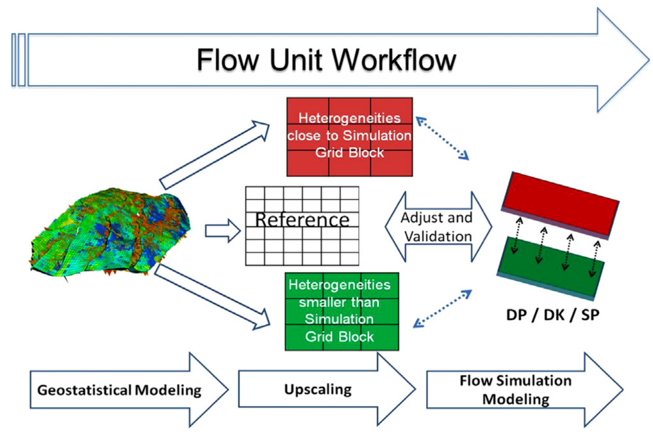

Fig. 2. Main drives of methodology.

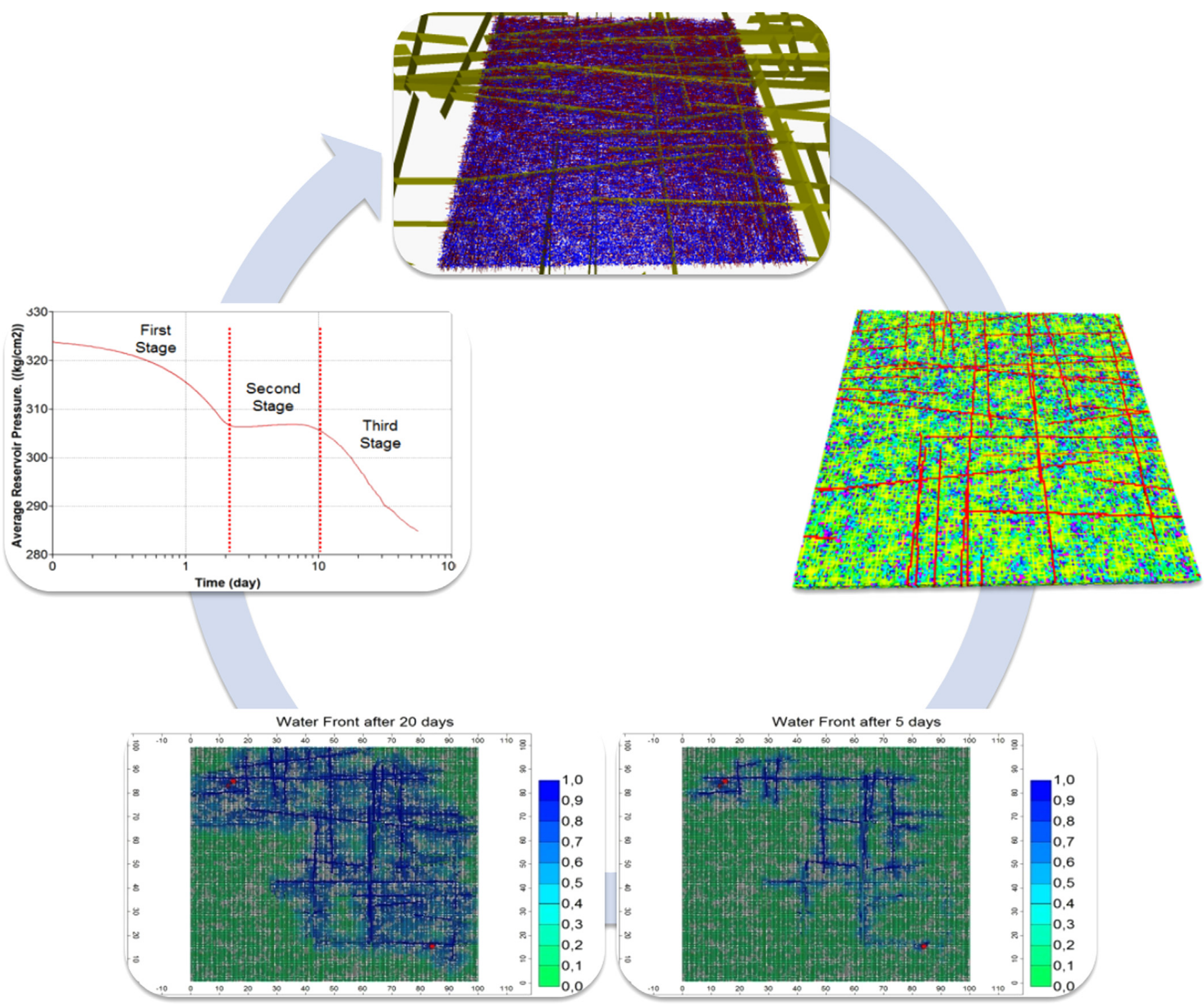

Fig. 1. Overview of challenges in fractured carbonate reservoirs.