



The impact of time-dependent matrix-fracture fluid transfer in upscaling match procedures

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ABSTRACT

Matrix-to-fracture transfer functions assume that fractures are instantaneously filled with water, leading to constant, time-independent shape factors. However, the water filling fracture regime, which can be observed for some conditions such as small injection rates, does not lead to constant shape-factors and is difficult to solve using commercial flow simulators. The purpose of this study is to (1) show the impact of rock wettability in reservoir simulation and upscaling procedures, and, (2) apply an upscaling matching procedure based on time-dependent matrix-fracture fluid transfer term. This work shows that the increase of rock preference for water can lead to upscaling limitations due to the partially immersed fractures behavior observed in cases with small fracture apertures and small injection rates, for water-wet rocks. A time-dependent matrix-fracture fluid transfer term was proposed for upscaling matching procedures. The developed method solves the limitation of time-independent shape factors and allows the dual porosity flow model to properly represent the dynamic behavior for different wettability scenarios. This work aims to contribute for understanding the impact of rock wettability in upscaling and reservoir simulation of fractured reservoirs and, provides solutions for flow simulation of dual porosity flow models under a water filling-fracture regime, which is common in water-wet rocks.

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1. Introduction

Reservoir simulation has been used for major reservoir development decisions for decades (Lemonnier and Bourbiaux, 2010). About half of the world's proven oil reserves are trapped in fractured carbonate reservoirs (Bourbiaux, 2010). Building a naturally fractured carbonate reservoir model keeping its heterogeneous behavior and in a reasonable simulation consumption time is a challenge.

The discrete fracture network (DFN) model cannot be included into field scale models because of the computational limitation to assign potentially billions of fractures in each cubic kilometer of reservoir rock (Dershowitz et al., 1998). For such simulations, fractured systems are usually modeled by dual-porosity formulations. The dual porosity idealization was first introduced by Barenblatt et al. (1960) and later by Warren and Root (1963). The model developed by Warren and Root (1963), also called sugar cube, is based on a regularly spaced parallelepiped block-type matrix model. The primary porosity is homogeneous and isotropic, and is contained within a systematic array of identical, rectangular

parallelepipeds. The secondary porosity is contained within an orthogonal system of continuous, uniform fractures that are oriented so that each fracture is parallel to one of the principal axes of permeability. Flow through the reservoir takes place only in the fracture network with the matrix blocks acting as sources. The interaction between them is modeled through a matrix-fracture transfer function that incorporates the so-called shape factor. The resulting transfer rate per unit bulk volume has the following form:

$$q = \sigma \frac{\rho k}{\mu} (p_m - p_f), \quad (1)$$

where σ is the shape factor, representing the characteristic of the fractured rock; p_m and p_f are matrix and fracture pressure, respectively; k is the matrix permeability and μ is the viscosity. Using a finite-difference formulation for the flow between the matrix and the fracture, Kazemi et al. (1976) introduced the application of the shape factor in numerical simulation:

$$\sigma = 4 \left(\frac{1}{L_x^2} + \frac{1}{L_y^2} + \frac{1}{L_z^2} \right), \quad (2)$$

where L is defined as a fracture spacing or matrix block size. The

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shape factor reflects the geometry of the matrix elements for pseudo-steady state conditions. However, there are discrepancies over the values reported for shape factor. Warren and Root (1963), Thomas et al. (1983), Ueda et al. (1989), Coats (1989), De Swaan (1990), Chang (1993), Lim and Aziz (1995) derived different shape factors for dual porosity approaches. These discrepancies indicate the need to better understand the matrix-fracture interaction. All the developed formulations were made assuming that all fractures are instantaneously saturated in water, under pseudo-steady-state conditions. This results in a constant, time-independent shape factor. However, partially immersed fractures do not lead to constant shape factors and this inadequacy of the pseudo-steady-state transfer assumptions explains the controversy developed around the definition of the shape factor (Bourbiaux, 2010; Rangel-German and Kavscek, 2006). Rangel-German and Kavscek (2006), observed the water filling fracture regime in imbibition experiments. In water-wet fractured reservoirs imbibition are an important recovery mechanism. For oil-wet systems, water will be rapidly displaced in the fracture leaving behind the oil from the matrix (Behbahani et al., 2005). So, it is acceptable assume that rock wettability could induce in different upscaling procedures given the presence of different mechanism of water displacement.

The developments for time-dependent shape-factors are a current challenge. Rangel-German and Kavscek (2006), proposed the following formulation for shape factor:

$$\sigma_s(t) = \frac{A(t)}{Vl(t)}, \quad (3)$$

where $A(t)$ is the area of the matrix block in contact with water, V is the bulk volume of the rock matrix block and l is the distance between the saturation at the fracture and the matrix average saturation. Ferno et al. (2011) measured the wettability effects on the matrix-fracture fluid transfer. They showed that fluid transfer between the fracture and the matrix may occur even when fracture is not completed saturated. Other authors (Kazemi and Gilman, 1993; Chang, 1993; Lim and Aziz, 1995; Sarma and Aziz, 2003; Rangel-German et al., 2010; Golghanddashti, 2011; Saboorian-Jooybari et al., 2012; Paiva and Schiozer, 2012) developed new formulations for time-dependent shape-factors.

The classical shape-factors has remained a controversial concept giving is missing interpretation among certain matrix-fracture transfer mechanisms (Lemonnier and Bourbiaux, 2010). Besides, the rock wettability could result in different upscaling procedures given the presence of imbibition forces in water-wet rocks. Time-dependent shape-factors are not yet implemented in commercial flow simulators but static properties, fault transmissibility and the matrix-fracture fluid transfer term (*transmf*) can be changed over simulation time steps (Saboorian-Jooybari et al., 2012). *Transmf* has a direct impact on time required for a fluid transfer between matrix and fracture system and, consequently, the time required for water front advance in a fracture system. Therefore, the time-dependent *transmf* can be a good solution to mask the absence of a time-dependent shape-factor in commercial flow simulators. The IMEX, is the black-oil simulator used in this work. The *transmf* multiplier keyword in IMEX is TRANSMF. So, TRANSMF keyword is a multiplier applied to the equation three, previously described. However, it is not the same keyword for other flow simulators. For ECLIPSE, the multiplier for flow between fractures and matrix in a dual porosity run is MULTMF.

The purpose of this study is to (1) show the impact of rock wettability in reservoir simulation and upscaling procedures and, (2) propose an upscaling matching procedure based on a time-dependent matrix-fracture fluid transfer term (*transmf*). The matching procedure is used between the reference model and the coarse grid. The reference model is single porosity model based on

a refined grid. The base case is a model with intermediate values of fracture density, fracture aperture and injection rate.

The methodology is used for more six scenarios by applying small changes to crucial parameters (fracture density, fracture aperture and injection rate) in the base case. So, the base case is a model with intermediate values of fracture intensity, fracture aperture and injection rate which is the starting point to generate the six scenarios. Each scenario, inclusively the base case, has a coarse dual porosity flow model and a correspondent reference model to use for match procedures. The purpose of applying our methodology to different scenarios is to (1) validate the methodology to distinct simulated flow patterns, (2) compare different wettability scenarios, and (3) show that for same particular cases filling fracture regime is more expressive. The selected attributes are based on some studies (Rangel-German and Kavscek, 2006; Qasem et al., 2008; Ferno et al., 2011) that reveal these attributes and rock wettability as critical on matrix-fracture fluid transfer for fractured reservoirs. The reference model is a refined single porosity synthetic case that follows the Warren and Root (1963) assumptions for dual porosity models. The conventional upscaling procedure for discrete fracture networks is an analytical upscaling approach based on Oda method (Oda, 1985). Oda method is the most common upscaling approach for discrete fracture networks. However, this method is only valid for well-connected and uniform fractures. Thus, this approach is suitable if we consider Warren and Root (1963) geometric assumptions. It avoids upscaling issues related to geometric properties, which is not the focus of this work. Considering a constant matrix-fracture fluid transfer term, this upscaling method is used to compare the influence of wettability in upscaled matches. The methodology is presented in two sections for a further link in application and results section for the two procedures.

2. Methodology

The development of this work follows two procedures: (1) apply a conventional upscaling workflow procedure, without matching procedures, in order to show the impact of rock wettability in reservoir simulation and upscaling procedures, and, (2) apply an upscaling matching procedure based on a time-dependent multiplier for matrix-fracture fluid transfer term (*transmf*).

2.1. Impact of rock wettability in reservoir simulation and upscaling procedures

The first procedure (Fig. 1) is divided in three steps: (1) define a fine grid model to use as reference model for reservoir flow response, (2) apply a conventional upscaling procedure (Oda, 1985) to discrete fracture networks in order to obtain the effective block fracture permeability for the coarse dual porosity model, (3) dual porosity model is then used to compare the reservoir flow response with reference model based on a refined grid that follows Warren and Root's assumptions (orthogonal system of continuous and uniform fractures and constant matrix porosity and permeability). The output effective permeability by Oda method (1985) is then applied in the fracture system for the dual porosity model. Matrix permeability for the dual porosity model is assumed as the same defined in the reference model.

The key for the first procedure is to avoid geometric issues in the upscaling procedure in order to do a proper comparison through dynamic response between the reference model and the dual porosity flow model. These comparisons help to (1) expand laboratorial studies (Rangel-German and Kavscek, 2006; Ferno et al., 2011) to reservoir simulation, and (2) addresses the rock

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