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A HYBRID UPSCALING PROCEDURE FOR MODELING OF FLUID FLOW IN FRACTURED SUBSURFACE FORMATIONS

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This paper is dedicated to the memory of Dr. Magne S. Espedal

Abstract. Natural fractures reside in various subsurface formations and are at various length scales with different intensities. Fluid flow in fractures, in matrix and between matrix and fractures are following different flow physics. It is thus a great challenge for efficiently modeling and simulation of fluid flow in fractured media due to the multi-scale and multi-physics nature of the flow processes.

Traditional dual-porosity and dual-permeability approach represents fractures and matrix as different continuum. The transfer functions or shape factors are derived to couple the fluid flow in matrix and fractures. The dual-porosity and dual-permeability model can be viewed as a multi-scale method and the transfer functions are used to propagate fine-scale information to the coarse-scale reservoir simulation. In this paper, we perform a detailed study to better understand the optimal way to propagate the fracture information to the coarse-scale model based on the detailed fracture characterization at fine-scale.

The Discrete Fracture Modeling (DFM) approach is used to represent each fracture individually and explicitly. The multiple sub-region (MSR) method is previously used for upscaling calculations based on fine-scale flow solution by finite volume method on the DFM. The MSR method is the most appropriate upscaling procedure for connected fracture network but not for disconnected fractures. In this paper, we propose an adaptive hybrid multi-scale approach that combines MSR and DFM adaptively for upscaling calculation for complex fractured subsurface formations that usually involve both connected fracture network and disconnected fractures. The numerical results suggest that adaptive hybrid multi-scale approach can provide accurate upscaling results for flow in a complicated geological system.

Key words. fractures, porous media flow, multi-scale, upscaling

1. Introduction

Natural fractures reside in various subsurface formations and are at various length scales with different intensities. The accurate modeling of flow through such systems is important for many types of problems, including the management of energy resources (oil, gas, geothermal) and geologically sequestered CO_2, as the fractures often provide the primary conduits for flow.

Fluid flow in fractures, in matrix and between matrix and fractures are following different flow physics. Moreover, fracture distribution in subsurface formation usually displays significant variation in connectivity and size over the formation. Large and strongly connected fractures are typically located near bedding planes and fault zones, while small and disconnected fractures are usually located away from those regions. In addition, as discussed in [16], the dimensions and spatial frequency of fractures are impacted by the thickness of the confining stratigraphy. The variation in fracture properties, especially fracture connectivity, requires to model different fracture zones using different numerical treatments to achieve accurate upscaling results as discussed in [4, 14, 18].

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The dual-porosity and dual-permeability model starts from the assumption that fractured porous media can be considered as the overlapping of a matrix continuum and a fracture continuum, which are locally connected to each other. The basic assumption in the dual-porosity and dual-permeability approach is that the global flow occurs only through the fractures and the matrix is only locally connected to the fracture networks and serves as the storage space for fluids [19]. The dual-porosity and dual-permeability model can be viewed as a multi-scale method, in which flow between matrix and fractures occurs on the fine-scale and flow through fractures on the coarse-scale. Since fracture permeability is extremely higher in comparison with matrix permeability, an additional assumption in [19] is that the fine-scale flow in matrix blocks reaches pseudo-steady state instantly after the global flow starts, at which the time rate of change of pressure is a constant [19]. The transfer functions or shape factors can thus be derived to couple the fluid flow in matrix and fractures based on the fracture characterization and are used to propagate the fine-scale information to the coarse-scale reservoir simulation. The analytical form of the transfer functions can be derived based on approximated fracture model [1, 2, 13, 15, 19, 20, 21]. Numerical upscaling procedure needs to be applied to accurately compute transfer functions based on realistic fracture characterization.

In previous work, we have performed global flow simulations using discrete fracture modeling (DFM) for fine-scale reference solutions and multiple subregion method (MSR) for upscaling treatment [6, 7]. DFM represents each fracture individually and explicitly, which requires unstructured gridding of fracture-matrix system using 3D (Delaunay) triangulations and transmissibility evaluation between each pair of adjacent elements [11]. MSR is a generalized dual-porosity and dual-permeability approach that numerically calculates the mass transfer between fractures and matrix based on discrete fracture information and multiple subregions are used to characterize the global flow regime at pseudo-steady state [6, 12].

The assumption of instant pseduo-steady state is not valid if the transient period is too long, which can happen if the formation contains disconnected or locally connected fracture network, or if the coarse blocks contain wells. Therefore, the MSR is an appropriate upscaling procedure when all of the fractures are globally connected so matrix and fractures exchange fluid locally while large-scale flow only occurs through the fracture network [12]. The global use of MSR loses accuracy if reservoir contains large portion of disconnected fractures, or the disconnected fractures are in key regions such as near-wells. In this paper, we present some preliminary numerical results using an adaptive hybrid multi-scale approach, which combines MSR and DFM based on fracture characterization. The numerical results suggest that adaptive hybrid multi-scale approach can provide accurate upscaling results for flow in a complicated geological system.

This paper proceeds as follows. First, we briefly review dual-porosity model and, the DFM and the MSR method for upscaling procedure. Second, the hybrid methodology is described and the computations for the internal and inter-block connections are explained for the multi-scale approach that integrates DFM and MSR. Next the hybrid approach is applied to several cases (2D and 3D) for two-phase, three-phase and compositional flow examples. These results demonstrate the improvement in accuracy attainable from the hybrid procedure. We also discuss computational demands for this approach, which are important to consider because the hybrid method is more expensive than the global MSR procedure.