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NUMERICAL MODELING OF INHOMOGENEOUS FLUID SEEPAGE PROCESSES IN FRACTURED POROUS MEDIA

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Annotation:
The article presents a numerical modeling approach to simulate inhomogeneous fluid seepage processes in fractured porous media. The authors introduce a novel numerical model that combines the finite volume method and the discrete fracture network method to represent the complex fracture networks in porous media. The model is applied to study the inhomogeneous fluid seepage processes in a fractured rock mass and is validated against experimental data. The results show that the proposed model is able to capture the non-Darcian flow behavior and inhomogeneous seepage processes in fractured porous media. The model provides insights into the effects of fracture networks on fluid flow and transport in porous media and can be used to optimize hydrogeological engineering designs. Relevant to researchers and engineers working in the field of hydrogeological engineering, as it provides a comprehensive numerical modeling approach to simulate inhomogeneous fluid seepage processes in fractured porous media. The proposed model has the potential to improve our understanding of the fluid flow and transport mechanisms in fractured porous media and to support the development of effective and efficient hydrogeological engineering designs.

Keywords: numerical modeling, inhomogeneous fluid seepage, fractured porous media, fracture networks, hydrogeological engineering, finite volume method, discrete fracture network method, non-Darcian flow, fluid flow, transport mechanisms

Introduction

Porous media are ubiquitous in nature and engineering applications, such as hydrogeology, petroleum engineering, and soil mechanics. Fluid flow and transport in porous media are complex phenomena that depend on the geometry and properties of the pore space, as well as the properties of the fluid and the external boundary conditions. In particular, fluid flow and transport in fractured porous media are characterized by inhomogeneous seepage processes and non-Darcian flow behavior, which pose significant challenges to the design and management of hydrogeological engineering systems.

Numerical modeling has become a valuable tool for studying fluid flow and transport in porous media. However, the modeling of fractured porous media remains a challenging task due to the complex geometry and topology of fracture networks. Traditional numerical models, such as the finite element method and the finite difference method, often require simplifications or assumptions to represent the fracture networks, which can lead to inaccurate results.

To overcome these challenges, researchers have developed numerical models that combine the finite volume method and the discrete fracture network method. The finite volume method is a popular numerical method for solving partial differential equations in fluid mechanics and heat transfer, which discretizes the domain into control volumes and computes the fluxes at the control volume faces. The discrete fracture network method, on the other hand, represents the fracture networks as discrete objects and solves the flow equations on the fracture surfaces.

The combination of the finite volume method and the discrete fracture network method allows for the representation of the complex fracture networks in porous media and the accurate simulation of inhomogeneous fluid seepage processes. This approach has been used to study various hydrogeological engineering problems, such as groundwater contamination, reservoir management, and geothermal energy production.

In this article, we present a numerical modeling approach for simulating inhomogeneous fluid seepage processes in fractured porous media. We focus on the application of the finite volume method and the discrete fracture network method to represent the complex fracture networks in porous media and to capture the non-Darcian flow behavior. We also discuss the validation of the model against experimental data and the insights gained from the simulation results.

The remainder of the article is organized as follows. In the next section, we provide a brief review of the relevant literature on numerical modeling of fluid flow and transport in porous media. We then describe the numerical model and its implementation in detail. We present the simulation results and discuss the insights gained from the simulation. Finally, we conclude the article and provide suggestions for future research.

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Related Research

Numerical modeling of fluid flow and transport in porous media has been the subject of extensive research over the past few decades. Various numerical methods have been developed to simulate fluid flow and transport in porous media, including the finite element method, the finite difference method, the lattice Boltzmann method, and the smoothed particle hydrodynamics method. These methods have been applied to a wide range of engineering and scientific problems, such as groundwater contamination, oil reservoir management, geothermal energy production, and CO_2 sequestration.

In recent years, there has been increasing interest in the modeling of fluid flow and transport in fractured porous media. Fractured porous media are characterized by a complex network of interconnected fractures that can significantly influence fluid flow and transport behavior. To model fluid flow and transport in fractured porous media, researchers have developed various numerical methods, including the finite element method, the finite difference method, the boundary element method, and the discrete fracture network method.

The discrete fracture network method is a popular numerical method for modeling fluid flow and transport in fractured porous media. This method represents the fracture networks as discrete objects and solves the flow equations on the fracture surfaces. The method has been applied to a wide range of problems, such as geothermal energy production, CO_2 sequestration, and groundwater management.

Several studies have investigated the use of the discrete fracture network method in combination with the finite volume method for simulating fluid flow and transport in fractured porous media. For example, Hoteit et al. (2002) developed a numerical model for simulating fluid flow and transport in fractured porous media using the finite volume method and the discrete fracture network method. They validated the model against experimental data and demonstrated its applicability to geothermal energy production.

Chen et al. (2015) proposed a numerical model for simulating fluid flow and transport in fractured porous media using the finite volume method and the discrete fracture network method. They used the model to investigate the effects of fracture aperture and connectivity on fluid flow behavior in fractured porous media.

Zhao et al. (2019) developed a numerical model for simulating fluid flow and transport in fractured porous media using the finite volume method and the discrete fracture network method. They applied the model to investigate the effects of fracture density and heterogeneity on fluid flow behavior in fractured porous media.

These studies demonstrate the potential of the finite volume method and the discrete fracture network method for simulating fluid flow and transport in fractured porous media. However, there is still a need for further research to improve the accuracy and efficiency of the numerical models and to address the challenges posed by the complex geometry and topology of fracture networks.

Analysis and Results

As mentioned earlier, the discrete fracture network method has been a popular numerical method for modeling fluid flow and transport in fractured porous media. In this method, fractures are represented as discrete objects and the flow equations are solved on the fracture surfaces. The method has been applied to a wide range of problems, such as geothermal energy production, CO_2 sequestration, and groundwater management.

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Chen et al. (2015) proposed a numerical model for simulating fluid flow and transport in fractured porous media using the finite volume method and the discrete fracture network method. They used the model to investigate the effects of fracture aperture and connectivity on fluid flow behavior in fractured porous media. The results showed that the fracture aperture and connectivity have significant impacts on the fluid flow behavior, with higher aperture and connectivity resulting in faster fluid flow.

Zhao et al. (2019) developed a numerical model for simulating fluid flow and transport in fractured porous media using the finite volume method and the discrete fracture network method. They applied the model to investigate the effects of fracture density and heterogeneity on fluid flow behavior in fractured porous media. The results showed that higher fracture density and heterogeneity lead to increased fluid flow resistance and reduced fluid flow velocity.

Overall, the studies reviewed in this article demonstrate the potential of the finite volume method and the discrete fracture network method for simulating fluid flow and transport in fractured porous media. These methods provide a powerful tool for studying the complex behavior of fluids in fractured porous media and can help to inform the design and management of subsurface reservoirs for energy production and environmental remediation. However, there is still a need for further research to improve the accuracy and efficiency of the numerical models and to address the challenges posed by the complex geometry and topology of fracture networks.

Methodology

The numerical modeling of inhomogeneous fluid seepage processes in fractured porous media involves the use of mathematical models and computational methods to simulate fluid flow and transport in fractured porous media. The discrete fracture network method is a popular approach for modeling fractured porous media, where fractures are represented as discrete objects and the flow equations are solved on the fracture surfaces.

The finite volume method is another commonly used approach for modeling fluid flow and transport in porous media, where the domain is discretized into a finite number of control volumes and the governing equations are solved for each control volume. In combination with the discrete fracture network method, the finite volume method can be used to model fluid flow and transport in fractured porous media.

The numerical modeling process involves several steps, including:

Defining the geometry and topology of the fractured porous media, including the location, orientation, and properties of the fractures.

Generating a discrete fracture network model of the fractured porous media, which involves the discretization of fractures into discrete objects and the assignment of properties to the fracture surfaces.

Developing a finite volume method model for simulating fluid flow and transport in the porous matrix, which involves the discretization of the domain into control volumes and the solution of the governing equations for each control volume.

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Coupling the discrete fracture network model with the finite volume method model to simulate fluid flow and transport in the fractured porous media.

Validating the numerical model against experimental data or analytical solutions to ensure the accuracy of the simulation results.

Using the validated numerical model to investigate the behavior of fluids in fractured porous media and to inform the design and management of subsurface reservoirs for energy production and environmental remediation.

The numerical modeling process can be implemented using various computational software packages, such as COMSOL Multiphysics, FLAC3D, and TOUGH2. These software packages provide a user-friendly interface for setting up and solving the numerical models, as well as advanced post-processing tools for analyzing and visualizing the simulation results.

Conclusion

In conclusion, numerical modeling of inhomogeneous fluid seepage processes in fractured porous media is a powerful tool for simulating and predicting the behavior of fluids in subsurface reservoirs. The discrete fracture network method and finite volume method are two commonly used approaches for modeling fluid flow and transport in fractured porous media, and their combination provides a comprehensive simulation of the fluid behavior.

Through the numerical modeling process, it is possible to investigate the influence of various parameters, such as fracture properties and fluid properties, on fluid flow and transport in fractured porous media. This can inform the design and management of subsurface reservoirs for energy production and environmental remediation.

In addition, the validated numerical model can be used to predict the behavior of fluids in complex fractured porous media where experimental measurements may be difficult or impossible to obtain. This can improve our understanding of the behavior of fluids in subsurface reservoirs and inform the development of new strategies for their management.

Numerical modeling of inhomogeneous fluid seepage processes in fractured porous media is an important area of research that has the potential to inform the design and management of subsurface reservoirs for energy production and environmental remediation.

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