Flow- and Heat-Transport-Simulation with an optimized discretization of the geological structure model

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Abstract Energy generation forecast from deep geothermal resources essentially needs to proof the effectiveness of geothermal heat transfer in the reservoir, especially because of high capital investments. In practical applications different numerical fluid and heat flow simulators are used to describe the heat transport by conduction and advection in addition to the fluid flow. Appropriate numerical methods to solve the fluid flow equations are the finite element (FE), the finite difference (FD) and the volume balance (VB) methods. In a master thesis at WWU/DMT, these methods have been tested to investigate their applicability concerning geothermal reservoirs with dominant water-conducting fault systems.

Key Words Modeling, heat transport, fractured flow, structure builder, numerical simulation, deep geothermal aquifer

Introduction

Heat production forecast from deep geothermal aquifers need effective prognosis tools to calculate the potential resource of energy, the risk of adjacent energy plants influencing each other and a possible effect on other fluid resources. In many cases the relevant deep aquifers are imbedded in dominant fault zones and the water flow occurs mainly on these fault systems. The detailed description of flow in these disturbed aquifers is the major precondition for acceptable results of heat and flow transport simulation. Often, the so called structure builder tool PETREL is used to generate a 3D geological model of deep aquifers. A special feature of PETREL is the accurate reproduction of fault systems. One goal of the project was to realize an effective transformation of structural data from PETREL to the flow and heat transport model simulation tool without any loss of accuracy. In the research project between DMT and the WWU several flow and heat transport models were intensively tested using different discretization methods and were compared with the pivotal question: Which is the best discretization method to simulate fluid flow and heat transport processes in the presence of fault systems?

Methods

Energy generation forecast from deep geothermal resources essentially needs to proof the effectiveness of geothermal heat transfer in the reservoir, especially because of high capital investments. In practical applications different numerical fluid and heat flow simulators are used to describe the heat transport by conduction and advection in addition to the fluid flow. Computer codes which can be used are inter alia FEFLOW (FE) [3], MODFLOW (FD) [4], SPRING (FE) [2] or Reacflow3D (VB) [1]. These methods have been tested to investigate their applicability concerning geothermal reservoirs with dominant water-conducting fault systems.

In this case study the geological and geophysical information of the project area has been used to generate a geological structural model with the program PETREL. This data was made available with especially developed converter programs to the fluid flow and heat transport simulators: the FE, FD and the VB programs. First, the general operability was tested concerning the heat transport mechanisms with a simplified block example, whereby notable similar results were achieved. Afterwards, the real geological 3D structure has been implemented.

At the beginning of the project, the basics of heat transport have been compared using a single block model. The following two figures show the test block with an inclining fault. The head difference over a model extension of 1000 m was 1 m.

The heat transport through the fault is crossing the model area in some days. The heat transport transversal to the main flow direction is shown after a time period of 10 years in figure 2.

Typical differences have been identified for the different methods with respect to the quality of reproduction of the real geological structures and furthermore in the reproduction of the fluid flow and heat transport processes.

In general, it has been figured out that the classical FE and FD method need a very high number of cells or nodes to achieve a reasonably accurate reproduction of the fault to reduce numerical

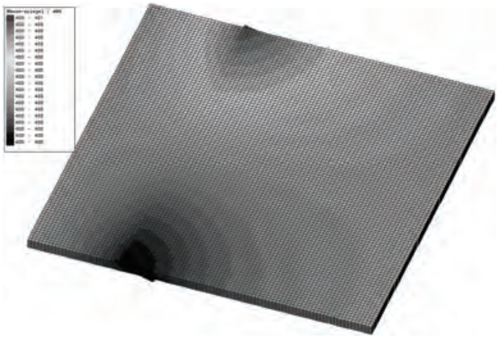

Figure 1 *Block picture of the 10-slice test model – hydraulic heads.*

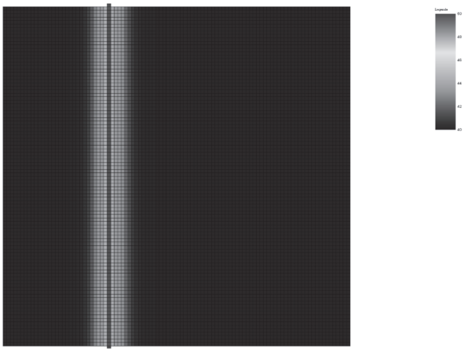

Figure 2 *Heat transport through the fault and transversal after 10 years.*

smearing of the real structures. The flexible process of the volume balance method is qualified to adapt the PETREL generated structure data without loss of information and no additional mesh refinement. In figure 3 the conversion of a real PETREL into a VB model is shown at a depth of 3000 m.

In this example relevant fault systems are generated as a separate balance element "fault".

FD and FE methods generally are able to discretize the fault with adequate accuracy, but only by the help of many additional elements. But in the reality, the faults cannot be supposed in general to be vertical and the geological units to be exactly horizontal. Figure 4 shows the differences.

These results show that without additional mesh refinement with the VB method equivalent or better results can be achieved while FE/FD methods need a much higher number of cells or nodes. Using the VB method, the characteristics of the faults with a very high fluid flow velocity are not blurred by the involvement of elements with unrealistically high porosity to represent the faults. For this reason the VB method allows to simulate very high fluid flow velocity along the fault plane. The following figure shows a model discretization realized with the FE and the VB methods to calculate the temperature-field after a transport time of 20 years in radial direction from the input well and along the fault. This result shows that the discretization of a PETREL geological model using an FE - model for fluid flow and heat transfer simulation needs a relative high number of nodes to reproduce the fault system adequately. Otherwise the structure is blurred, unless this problem is compensated by the use special techniques to add the fault systems parallel to the normal geological permeability.

The same geological region as displayed in figure 5 but now discretized with the VB method is shown in figure 6. Give attention to the fine elements representing the fracture:

In the second phase of the research study, the VB method has then be used in a real application of the planning of a geothermal power plant. The data base for these further investigations was an

Figure 3 *Discretization with the Volume-Balance method.*

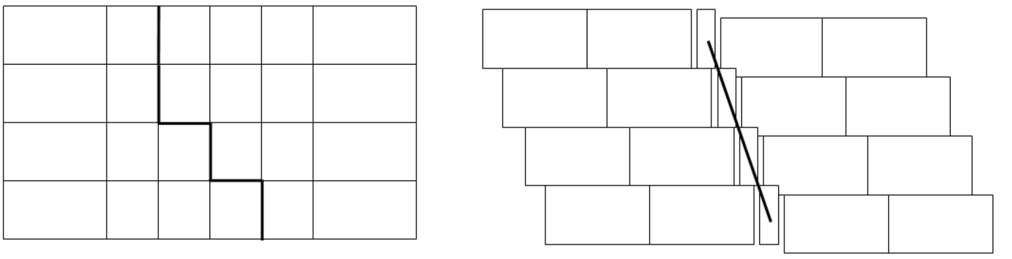

Figure 4 Different discretization of FE/FD methods in comparison to the VB method.

existing PETREL-Model based on a 3D seismic survey describing the geological units and the dominating fault system. This 3D PETREL-Block-Model is shown in figure 7.

In a first valuation no disadvantages have been discovered using big volume elements and connect these with additional small connection elements for the fault. The conductance of the fault is exactly reproduced.

Comparing the results of the transport process there have been found out strong advantages of using the VB method over the FD/FE discretization methods:

- A high fluid flow velocity in the fault is usually related to an adequate low heat storage capacity of the fault itself. Using big discretization elements (e.g. with high porosity) the short transition time for fluid or heat in the fault will not be calculated precisely enough.
- An alternative approach to avoid this problem in FD/FE discretization is to use a two-porosity system for the fault elements or to use the VB discretization method with special "fault" elements representing its special physical properties.

The flexible VB method is able to accept and maintain the exact original structure of a PETREL geological 3D model without any changes of the model structure. An additional routine has been implemented to insert additional volume elements inside of the fault to reproduce the fault with accurate conductance and realistic storage coefficients.

Conclusions

In general all tested methods are able to describe the fluid flow and heat transport in fractures and porous media. Differences were obtained by considering realistic fault and fracture structures. While a realistic PETREL 3D model uses different grid structures in different model slices and even within the same slice for best geometrical representation of the reality, only the VB method is able to use exactly the same grid-structure over all model slices. However, in reality the geological layers are not really horizontally and the fractures not vertically. Therefore, FD and FE types of models need compromises concerning the discretization to avoid vast number of elements. Only the VB method is able to adopt the model structure exactly from the PETREL structure. Another disadvantage of FE and FD models is the way how struc-

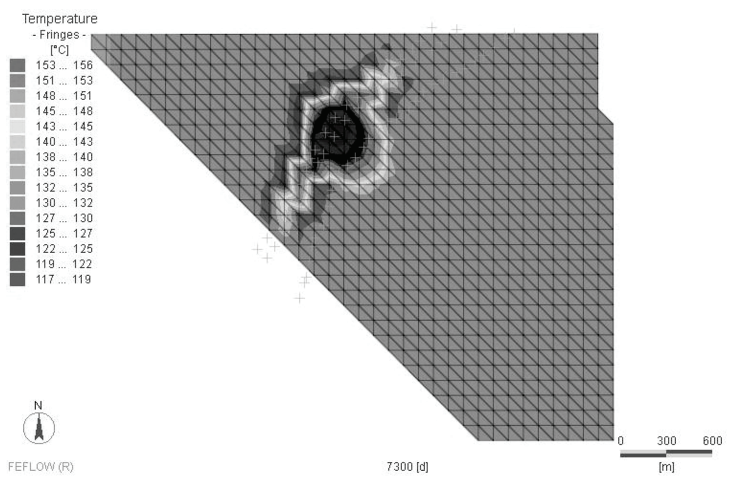

Figure 5 Modeling of fluid flow and heat transport with FE-grid (20 years).

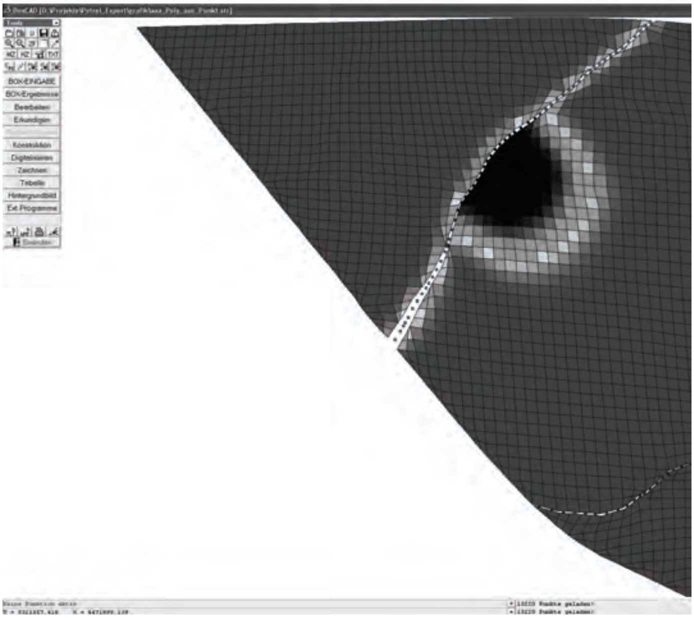

Figure 6 *Modeling of fluid flow and heat transport with VBM (20 years).*

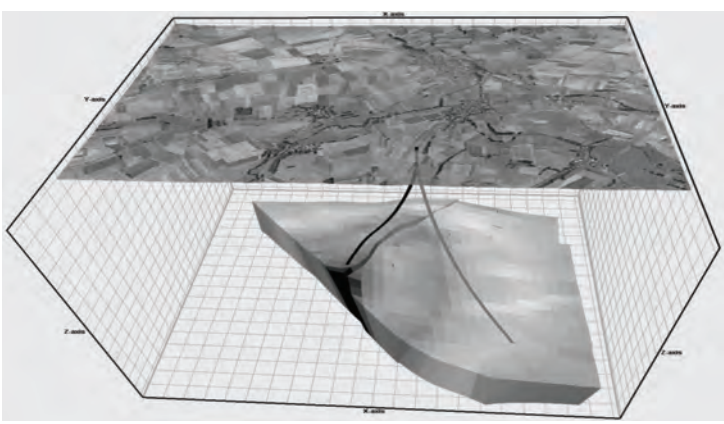

Figure 7 *Real test area and deep aquifer for heat production.*

tures are to be implemented. Mostly, they have tools to import fault structures automatically by adding additional fracture-connections beside of the geological permeability of the aquifer. By using this method of FE or FD discretization, the transition time of heat or fluid is determined by the storage effect of the big element. However, the realistic storage effect in a fault is determined by a very low amount of the fluid. In comparison, the explicit description of the fault in the VB method is able to calculate the real transition time in the fault.

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