High Performance simulation of geothermal systems:

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Abstract

The project targets the development of a high performance simulation tool for high energy geothermal reservoirs. The model takes into account complex geology including fault networks acting as major heat and mass transfer corridors. It should also account for complex physics coupling the mass and energy conservations to the thermodynamical equilibrium between the gas and liquid phases. A collaboration on this research topic has started since 2014 between the BRGM and the joint INRIA-LJAD team Coffee. A parallel numerical model is currently being implemented in the ComPASS (Computing Parallel Architecture to Speed up Simulation) software during the inter-Carnot postdoctoral fellowship of Feng Xing. The objective of the Cemracs project is to focus on well modelling which is a key missing ingredient in order to perform realistic geothermal studies both in terms of monitoring and in terms of history matching. At reservoir scale, the mesh does not resolve the well which will be modelled as a Dirac source term along the well trajectory connected to the 3D surrounding porous medium and to the 2D faults. The well model will take into account both the two phase liquid gas Darcy flow and the energy conservation.

1 Context and state of the art

Geothermal energy is a carbon-free steady energy source with low environmental impact. In countries with a favorable geological context, high temperature geothermal energy can make a significant contribution to power production. On the French territory, it is already an attractive option in volcanic islands context compared to importing fossil fuel. Today, about 5 pourcents of yearly electricity consumption of Guadeloupe already comes from geothermal energy and it is essential for achieving energetic and environmental targets, according to which the overseas territories should produce 50 poucents of their electricity consumption from renewable resources by 2020 and achieve their energy autonomy in 2030. As for other parts of the world, the geothermal development potential of the Caribbean islands is high and several industrial projects are in preparation or already underway, in French overseas territories (Guadeloupe, Martinique) as well as in nearby islands (Dominica, Montserrat).

Numerical modeling has become essential in all phases of geothermal operations. It is used in the exploration phases to assess the geothermal potential, validate conceptual hypothesis and help well siting. Field development and resource management need quantitative estimation to prevent resource exhaustion and achieve its sustainable exploitation (production/injection scenarios). Finally numerical modeling is also helpful in studying exploitation related industrial risks such as the interaction with shallow water levels (drinking water resources, hydrothermal vents or eruption).

There is a need to develop new efficient and robust simulation tools to go beyong existing code capabilities in terms of geological and physical complexity [13], [15]. In particular such code should be able to deal with fault networks acting as major heat and mass transfer corridors in high energy geothermal reservoirs and also to simulate both under critical and super critical thermodynamical domains. Existing tools such as Tough2 [14], used for more than 25 years in geothermy, are limited to structured meshes and are not able to integrate conductive faults. Moreover, their parallel efficiency is very limited.

The BRGM and the joint INRIA - Laboratoire J.A. Dieudonné (LJAD) team Coffee have started a collaboration in 2014 in order to develop a new code to simulate the flow of the liquid and steam phases coupled with energy conservation and thermal equilibrium in complex geothermal systems. A first prototype has been develop in 2014 during the internship of Riad Sanchez showing the ability to simulate thermal two phase flow models combined with fault networks on unstructured meshes. The development of a more advanced and parallel version has been started in january 2015 during the inter-Carnot postdoctoral fellowship of Feng Xing. The spatial discretization is based on the Vertex Approximate Gradient (VAG) scheme [4], [3], [7] which is a control volume finite element type method with enhanced ability to deal with heterogeneous media and discrete fracture networks. It is implemented in the code ComPASS (Computing Parallel Architecture to Speed up Simulations) started during Cemracs 2012 and deposited at APP in 2014 [6], [8], [1]. The current version of the code has the following main features (see `http://compass-geothermal.fr`):

- SPMD Paradigm
- Fortran 2003 + C/C++ + MPI
- Conforming polyhedral meshes
- VAG scheme
- Discrete fractures with the continuous pressure model [1]
- Fully implicit multiphase compositional thermal model (Coat's formulation)
- Parallelism based on a partitioning of the mesh with Metis
- One layer of ghost cells
- Connected to the solver libraries Petsc [2] + Hypre [9] + Trilinos
- CPR-AMG preconditioner
- Visualization ouputs using parallel vtk format
- Checkpointings using HDF5

It is currently intensively tested using academic test cases.

2 Objectives and working program

The objective of this Cemracs project is to bring the development of the ComPASS code to a level where operational use is possible and real geothermal test cases can be considered. In this regard, wells are central features of geothermal exploitation and we will focus on thermal well modelling.

At the reservoir scale of a few kilometers, the mesh cannot resolve the well boundary with a radius of say 10 cm and the well is modelled as a dirac source term along the well trajectory.

In order to take advantage of the VAG scheme, it is natural to discretize the well trajectory as the union of a set of edges of the mesh. The connection with the 3D matrix and the 2D fault network at each node of the well will be computed using Peaceman's approach [5], [10], [11].

The flow and the thermal model inside the well will be defined in the spirit of what is conventionally done in oil reservoir simulators and will be adapted to the geothermal framework.

The provisional work program will be the following:

- Bibliography and definition of the thermal well model using one "bottom hole" pressure unknown for each well and explicit computations of the pressure drop and thermal losses. The well monitoring will prescribe either a bottom hole pressure or a flow rate together with a maximum (for injectors) or minimum (for producers) bottom hole pressure.
- Definition of the geometry of the wells based on the union of a set of edges for each well.
- Computation at each node of the well of the connection with the 3D matrix and the 2D faults using Peaceman numerical indices which need to be adapted to the VAG discretization.
- Computation of the operating point of a well
- Assembly of the well equations and unknowns in the Jacobian system
- Adaptation of the CPR-AMG preconditioner to include the well additional unknowns and equations
- Validation and test cases

3 Partners, participants and funding

Project partners:

- **BRGM** has pioneered the exploration and exploitation of the geothermal resource on the national territory and aims to develop dynamic modelling tools for geothermal reservoirs in complex geologic systems.
- **Team INRIA-LJAD Coffee** has an expertise in numerical methods for PDEs and scientific computing with applications to energy and environment.
- **Storengy** is presently involved in conventional geothermal systems development in the scope of ENGIE Group and has the strategy to expand its business in this activity.

Project Participants:

- Simon Lopez (BRGM)
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- Jean Frédéric Thebault (Storengy)
- Roland Masson (LJAD-INRIA Coffee team)
- Feng Xing (LJAD-INRIA-BRGM)
- Laurence Beaude (LJAD-INRIA Coffee team)

- Thibaud Beltzung (CEA)
- Konstantin Brenner (Université de Nice Sophia-Antipolis)

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