Towards High Performance Simulation of Geothermal Reservoir Systems

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ABSTRACT

Australia has a unique Hot Fractured Rock (HFR) geothermal resource that could potentially provide enough green energy to meet all its energy needs. Geodynamics Limited, an Australian company that is leading the nation in developing HFR geothermal energy, is presently conducting Australia's first HFR field test. Supported by an ARC linkage grant, a novel supercomputer simulation tool is being developed with collaboration of Geodynamics Limited for simulating the highly coupled geomechanical fluid-flow thermal systems involving heterogeneously fractured geomaterials. It addresses the key scientific and technological challenge in developing HFR energy. Namely, it is targeting a new predictive modelling capacity with the potential to yield breakthroughs in understanding how to enhance the flow of water through the geothermal field and how to sustain it over decades such that the trapped heat energy can be extracted.

PANDAS - Parallel Adaptive static/dynamic Nonlinear Deformation Analysis System - is a finite element based software being developed for simulating the geothermal reservoir system. It is built on the long term and ongoing efforts on the software infrastructure construction for the ACcESS Major National Research Facility previously (http://www.access.edu.au) and the AuScope (http://www.auscope.org.au) currently in simulation of crustal dynamics at ESSCC led by the first author. Currently, PANDAS includes the following five key components: PANDAS/Pre, ESyS_Crustal, PANDAS/Thermo, PANDAS/Fluid and PANDAS/Post as detailed in the following:

- PANDAS/Pre is developed to visualise the microseismicity events recorded during the hydraulic stimulation process to further evaluate the fracture location and evolution and geological setting of a certain reservoir, and then generate the mesh by it and/or other commercial graphics software (such as Patran) for the further finite element analysis of various cases; The Delaunay algorithm is applied as a suitable method for mesh generation using such a point set;
- ESyS_Crustal is a finite element method based module developed for the interacting fault system simulation, which employs the adaptive static/dynamic algorithm to simulate the dynamics and evolution of interacting fault systems and processes that are relevant on short to mediate time scales in which several dynamic phenomena related with stick-slip instability along the faults need to be taken into account, i.e. (a). slow quasi-static stress accumulation, (b) rapid dynamic rupture, (c) wave propagation and (d) corresponding stress redistribution due to the energy release along the multiple fault boundaries; those are needed to better describe ruputure/microseimicity/earthquake related phenomena with applications in earthquake forecasting, reservoir engineering, hazard quantification, exploration, and environmental problems. It has been verified with various available results (e.g. see Xing 2006a and references thereafter);
- PANDAS/Thermo is a finite element method based module for the thermal analysis of the metals and the fractured porous media; the temperature distribution is calculated from the heat transfer

induced by the thermal boundary conditions without/with the coupled fluid flow effects in the fractured porous media and the geomechanical energy conversion for the individual/coupled thermal analysis;

- PANDAS/Fluid is a finite element method based module for simulating the fluid flow in the fractured porous media; the fluid flow velocity and pressure are calculated from energy equilibrium equations without/with the coupling effects of the thermal and solid rock deformation for the individual/coupled fluid flow analysis; and
- PANDAS/Post is to visualise the simulation results through the integration of VTK and/or Patran.

All the above modules can be used independently or together to simulate individual or coupled phenomena (such as interacting fault system dynamics, heat flow and fluid flow) without/with coupling effects. PANDAS has been applied to the following issues related with geothermal reservoir systems:

- visualisation of the microseismic events, such as that recorded during the hydraulic stimulation process of Harbanero #1 in the Cooper Basin by Geodynamics Limited, to monitor and determine where/how the underground rupture proceeds during a hydraulic stimulation, to generate the mesh using the recorded data for determining the domain of the ruptured zone and to evaluate the material parameters (i.e. the permeability) for further numerical analysis;
- interacting fault system simulation to determine the relevant complicated dynamic rupture process for both the intraplate and interplate fault systems, such as to simulate the stress/velocity variations of the Southern California (CA) and Southern Australian (SA) fault systems over a long period of time in discrete models with 500,000 nodes constructed using the practical fault data (Xing et al., 2006b and 2007), and to calculate the stress evolution and dynamic rupture process along the faults within a fracture dominated gas reservoir and their potential effects on the fluid flow. This is the first effort in the world to successfully simulate such realistic and complex interacting fault systems using finite-elements efficiently and stably (without any convergence problems);
- geomechanical fluid-flow coupling analysis to investigate the interactions between fluid flow and deformation in the fractured porous media under different loading conditions. A new finite element based numerical modeling of the deformation and fluid flow through fractured porous media is proposed with the special attention to the FEM mesh generation of the fractured media. Based on the available rock image data, the rock structure information including interfaces/fracture boundaries can be extracted through the converted image data and further applied to mesh generation and material permeability calculation. The numerical tests demonstrated the efficiency and usefulness of the proposed algorithm; and
- thermo-fluid flow coupling analysis of a geothermal reservoir system. A geothermal reservoir model in the Cooper Basin has been analysed to determine how to sustain it over decades through the sensitivity analysis of the effects of permeability. In addition, the finite element based numerical solution has also been verified through the comparison with the analytical results (Xu et al., 2007; Xing 2008).

PANDAS will be further developed for a multiscale simulation of multiphase dynamic behaviour for a certain geothermal reservoir system. More details and additional application examples will be given during the presentation.

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