Geophysical Research Abstracts
Vol. 12, EGU2010-10150, 2010
EGU General Assembly 2010

A modeling approach of the hydro-thermal and chemical processes for managing the deep geothermal resource of the Val de Marne (Paris Basin, France).

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The exploitation of the geothermal resource of the Dogger formation in Paris Basin (between 1500 m and 2000 m depth) for district heating started in the early 1970's with 110 geothermal wells drilled between 1970 and 1985. Technically, exploitations are referred as "doublet operation" the pair of wells involved in the geothermal loop. The warm water is pumped from a production well to the district heating plant where fluid heat is extracted through a heat exchanger to a district heating network. Then, the cooled brine is re-injected in a second well. Inside the reservoir, the wells are open-hole and lie around 1 km apart to protect the producer from the cold front growing around the injector. The reinjection allows the stabilization of the reservoir pressure and protects the surface from brines containing high concentrations of dissolved chemical components (Cl-, SO42-, Fe2+, H2S, CO2) allowing salinities between 5 to 35 g/l.
With the current geothermal revival of the Paris Basin, the exploitation of the resource of the Dogger aquifer is facing new challenges:
• New doublets are implemented and their location must be optimized with regards to the interferences with the existing operations.
• Most of the wells still operating are next to 30 years old. They would need to be restored or shut down for scaling and/or corrosion problems, implying the drilling of new ones.
• Geochemical modeling highlighted that the scaling risk is increasing with time due to the thermodynamic disequilibrium induced by the temperature variation during the heat production. For instance, Iron sulfide (Mackinawite and Pyrite), carbonate and sulfate (Calcite, Siderite, Anhydrite), silica (Chalcedony) and some clay minerals have tendency to precipitate. Mackinawite, Calcite and Siderite are clearly identified in some well scales.
• The resource has been cooled by the 30 years of reinjection. The temperature at the production well is expected to decrease in the coming years as well as the recovered energy.
To tackle these issues, an assessment of the present temperature state of the reservoir and a forecast of its evolution are compulsory and needs the numerical modeling of the hydraulic and thermal behavior of the Dogger reservoir.
A 625 km^2 wide area with a high density of doublets in the vicinity of the Val de Marne department southeast of Paris has been modeled in details.
Flowmeter logs show a high horizontal and vertical variability of hydraulic properties. For building a full 3D reservoir model, the reservoir structure had then to be simplified:
- vertically: i) the productive layers were cumulated together into one global productive layer, ii) the impervious interstrata layers acting as a storage of heat structure were cumulated into one buffer layer, iii) the global productive layer was split in two symmetric parts by this buffer zone, iv) the interstrata rock heat conductivity was enhanced in order to account for the reduction of exchange surface between the productive layers and the buffer layers.
- horizontally, the structure was interpolated between wells in order to account for lateral variability.
The reservoir modeling was carried out following two steps: first a hydraulic model was realized including all doublets to simulate the reservoir pressure field and to determine groups of wells interfering each other; then, a thermal simulation was carried out for each of these groups. Pressure boundary conditions for the thermal submodels were extracted from the global hydraulic model. The computed temperature fields of each of these submodels were finally gathered into a single global and consistent model.
These simulations give the temperature evolution at each production wells for the next 30 years and show the

extension of the cold front in the reservoir. The final map underlines zones where the temperature of the Dogger aquifer remains unchanged and where new doublets could be drilled if the resource matches the needs on surface.