International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

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INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

PERSPECTIVES OF GEOTHERMAL ENERGY USE IN THE CZECH REPUBLIC – ESTIMATIONS FROM NUMERICAL MODELLING

Jiří Maryška[1], Josef Chudoba[1] & Petr Rálek*[1]
[1]The Institute for Nanomaterials, Advanced Technologies and Innovation, Technical University in Liberec, Czech Republic

DOI: 10.5281/zenodo.3742914

ABSTRACT

This contribution summarizes selected results from numerical modelling of enhanced geothermal systems (EGS), adapted to geological conditions in the Czech Republic (CZE). The work was a part of the RINGEN project [14], which has been established to accelerate the progress of geothermal energy use in CZE. Our team from the Technical University in Liberec (TUL) provides the software solution for the estimation of the deep geothermal exchanger behaviour.

A coupled thermo-hydraulic numerical model has been implemented in software Flow123d developed in TUL [2], alongside the COMSOL Multiphysics software [6], serving as a benchmark. The geometry of the fracture network, which constitutes the deep geothermal exchanger, is stochastically generated by our own script in the Python language.

The contribution shows scenarios of various geothermal exchanger depths and set ups, various scaling (from regional to local scale) or operational regimes. The model results have been used as quantitative estimations of the exchanger output and working life, adapted to the (probable) geologic properties at the Litoměřice site, which is one of the most promising areas in CZE. The results are interpreted with aim to determine (predict) a long-term sustainability of the energy mining based on proposed working regime designs.

KEYWORDS: EGS, HDR system, RINGEN project, coupled TH process, discrete fracture network.

1. INTRODUCTION

EGS systems have been recently more or less successfully developed in several countries [1]. The first commercial European projects of similar concept are Soultz-sous-Forets (France), Insheim and Landau (Germany). Other can be found in Habanero and Paralana (Australia), Geysers, Desert Peak and Newberry (USA). At this time, there is no geothermal power plant in the Czech Republic (CZE), either in operation or under construction. Geological conditions in CZE, which is entirely covered with medium temperature regions, are suitable only for HDR (hot dry rock) systems: cold water is injected into a depth of several kilometers, heats up and hot water is produced from nearby borehole(s) (see Figure 1). These systems are very technologically and economically demanding (technologies will probably be economically attainable in the next 10-20 years). Though the geothermal conditions in CZE are not very kind for the power-supply use, they can still be widely exploitable e.g. for heating systems (Figure 1 right). Presented case studies involve both application fields.

As all the geological data and information are widely uncertain before the final drilling, the mathematical (numerical) modeling plays an important role. The character of the numerical model can bridge the data uncertainties by computing various scenarios for various (or perturbed) input data. Results of numerical models can help with making estimations or predictions (for the output of the geothermal heat exchanger, its sustainability etc.). Though the numerical modeling is regularly used in the area of HDR systems, it should be adapted to particular in-situ conditions.

This work is a part of the RINGEN project [14], which is focused on creating professional background for the research into effective utilization of deep geothermal energy. The infrastructure mainly comprises the building of highly specialized geothermal centre at the Litoměřice site, which will concentrate key equipment, technologies and background for research teams of 7 project partners: 3 universities, 3 institutes of the Czech Academy of Science, and the Czech Geological Survey.

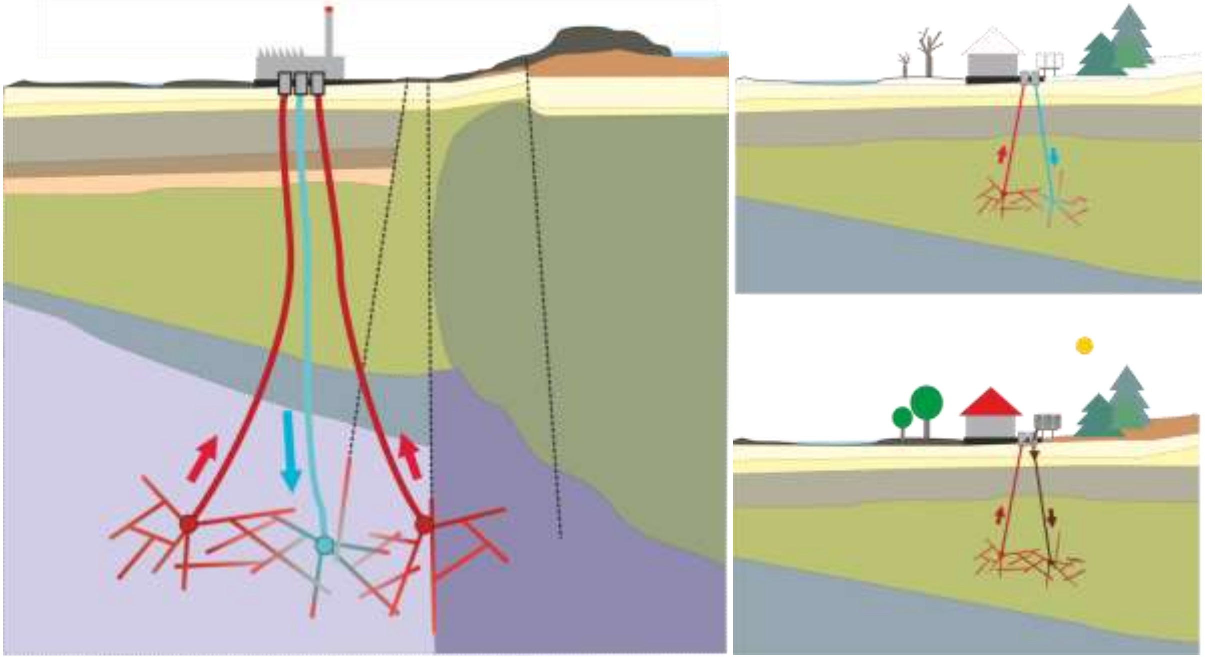

Figure 1. On the left – scheme of the HDR system with one injection well and two product wells. On the right – possible use of a small HDR system suitable for the heating

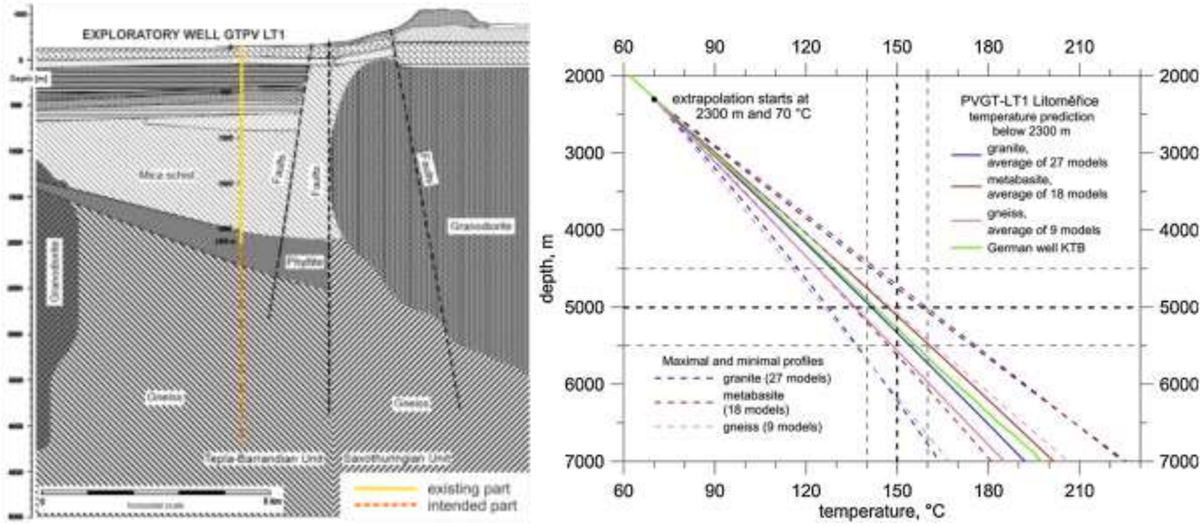

Figure 2. On the left – likely SN vertical geological profile (adapted from [3]). On the right – vertical temperature profiles; geothermic model scenarios [2]

Table 1. Estimated rock properties in Litoměřice area

	density [g.cm^{-3}]	porosity [%]	permeability [m^{2}]	thermal conductivity [W.m^{-1}.K^{-1}]	heat capacity [J.kg^{-1}.K^{-1}]
gneiss	2.66	2.6	10^{-17}	3.1	900
permocarbon	2.5	6	10^{-15}	2.4	800

Table 2. Estimated thermal conditions in Litoměřice area

temperature gradient [K.m^{-1}]	extrapolated heat flux [mW.m^{-2}]	temperature [°C]	
		in 600 m	in 5000 m
0.026	72	26	145

2. LITOMĚŘICE SITE PROPERTIES

The area of Litoměřice town (50 km NW from Prague) represents one of the best sites for probing geothermal technologies and the only place within CZE holding permission for an exceptional earth crust examination. These key assumptions enable the drilling of deep geothermal boreholes down to 4 to 5 km and likely create a geothermal heat exchanger to achieve clean energy from the drilled depth. RINGEN geothermal project stands as an important milestone on the Litoměřice town's path to become a low-emission city.

Geological Situation

Information about the rock massif at the subject area was partly provided by the existing exploratory well PVGT LT-1 ([9], [12], [13]). Its depth (2100 m) is insufficient for a practical geothermal use, but measured information along with estimates from large-scale geological models made by noninvasive methods confirmed the deep rock interface ([8], [11]). We can assume (1) a compact gneiss rock massif (so called Bílina block) at the depth of 4-5 km; (2) permocarbon sediments at the depth of 0.5 km.

Thermal Conditions

Temperature conditions are estimated by geothermal models ([2] or [3]). The likely geological profile at Litoměřice area is visualized in Figure 2. The used rock properties are listed in Table 1 and Table 2.

Hydraulic Conditions

Pressure distribution at the subject area has been estimated at two altitudes by the additional regional hydraulic model (described in [5]). Resulting pressure gradient has the SN direction for both observed altitudes and is approximately equal to 0.02 mH2O.m^{-1}. If we assume the cross section area of the geothermal exchanger equal to 50 m x 250 m and its hydraulic conductivity between 10^{-4} and 10^{-6} m.s^{-1}, this means that flow through the exchanger varies from 0.25 to 25 l.s^{-1}. Assuming an unfaulted rock outside the exchanger, we can predict an insignificant regional water outflow throughout its operation. This can obviously change for the case of the faulted/fractured rock.

3. NUMERICAL MODELLING

This contribution summarizes the collection of current modeling/computational resources and computational results for selected tasks related to the proposed testing HDR system at the Litoměřice area. A coupled TH numerical model is implemented in the groundwater flow simulator software Flow123d [2], with a stochastically generated fracture network. The commercial software COMSOL Multiphysics [6] served as a benchmark.

Physical model

The main factors in decision making of building the HDR system are its proposed energy output and sustainability. The reasonable approach to the energy output estimation can be made by the coupled thermo-hydraulic model, which is described by 1) the heat conduction equation and 2) the Darcy flow and continuity equations for both porous media and fractures. The combined porous media/fracture network model can provide e.g. information about the pressure or water flow-rate distributions and how they are influenced by the eventual changes of fracture properties in time.

Our models do not count for induced mechanical processes in the fractures or in the massif. In the RINGEN project, the modeling of coupled hydro-mechanical processes is in development simultaneously with other activities. Some results and experience notes on this field is a subject of the paper [4].

Geometry – model variants

Three types of geometries (see Figure 3, Table 3) of the deep geothermal exchanger with different scales were made with the use of available geological information:

1) Regional model: large-scale model geometries with different horizontal diameters from 2, 3 and 4 km, covering the whole vertical profile up to the surface. The exchanger is simplified to the bounded volume of a rock with a high hydraulic conductivity. The large-scale model serves primarily for the estimation of the thermally unaffected boundary for the small-scale model (the modeled area should be large enough to have boundaries, which are thermally unaffected by the exchanger; however, geometry that is too large increases computational demands).

2) Local model: small-scale model geometry with the diameter of 2 km with the exchanger composed of a discrete fracture network (DFN).
3) Small-scale model geometry with the diameter of 1.2 km with DFN. It is similar to model geometry 2.

The HDR configuration contains one injection well and one production well for both scales, with the distance between them 100 m for models 1-2 and 50 m for model 3. Both wells are represented by 2 m long cylinders (interacting parts of the wells).

Table 3. Model variants

model	dimensions width [m] x height [m]	working depth [m]	number of elements
1 – deep regional	6000x6000	5000	280 000
2 – deep local	2000x2000		400 000
3 – shallow local	1200x1200	600	180 000

Table 4. Case studies

model	flow rate [l.s^{-1}]	regime		
1 – deep regional	23.5	continuous	---	---
2 – deep local	11.5, 23.5, 47		cyclic with intervals	
3 – shallow local	1.8			cyclic with recharging and intervals

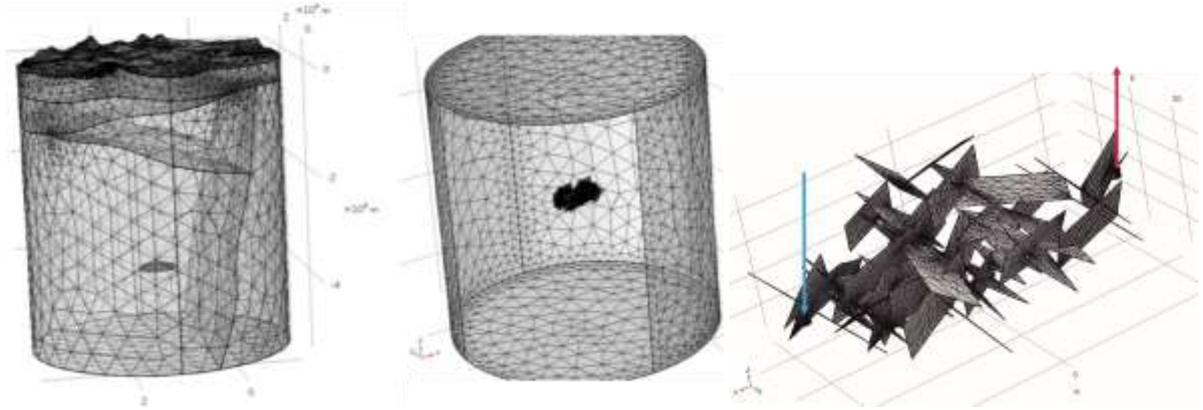

Figure 3. Discretized geometries. On the left – regional model covering the surroundings about 4 km. In the middle – local model with a fracture network. On the right – an example of DFN

The algorithm, generating the DFN, is described in [5]. It uses the conventional Poisson process ([15], **Error! Reference source not found.**) with conditions of network connectivity and a correction of defect cases (e.g. small intersections or close parallel fractures).

Boundary and Initial Conditions

Thermal boundary and initial conditions appear from proposed in-situ values (see Table 2). The initial vertical temperature distribution is then determined by the temperature gradient. This initial temperature distribution on the lateral sides of the modelled domain also stands as Dirichlet boundary condition for the temperature. The heat flux is prescribed on the bottom side of the modelled domain. The open boundary is prescribed for the upper side.

Initial distribution of the pressure head is determined by the results of the regional hydraulic model. This initial distribution on the lateral sides of the modelled domain again stands as Dirichlet boundary conditions for the pressure head.

Boundary conditions for injection and production wells are of two types. On the injection well surface the boundary flux is prescribed (either constant or time-modulated – see next paragraph). On the production well surface, the constant pressure equal to initial pressure head is prescribed.

4. CASE STUDIES

Various case studies were computed on particular model geometries. They are summarized in Table 4.

Continuous vs. Cyclic Regime

In general, the sustainability of the exchanger can be significantly prolonged by properly selected seasonal intervals, mostly during the summer, when none or small output is required. The intervals allow warming-up of the exchanger proximal neighborhood from the more distant environment or even to recharge the exchanger by the heated water from the surface (e.g. in the case of the green energy over-production).

Regional Model (Model 1)

The regional model results served to presumption of the minimal size of the diameter for the local deep model, so that it does not significantly affect the results of production temperature (and the heat output). The diameter of 2 km was stated as sufficient for the local model geometry. The results from the regional model are not presented here (see [5] for more details).

Deep Local Model with DFN (Model 2)

The local geometry was made with various stochastically generated fracture networks. The results (production temperature and output) for the continuous regime differ by less than 1% (it can be explained by the fact that dimensions of networks were similar, the network was always connected and the inject boundary condition has been set via prescribed boundary flux). Thus the graphs below show the values belonging to one particular fracture network configuration. Higher variations (in order of 10 percent) were for the input pressures necessary to provide the required flux, as well as for the pressure space distribution. Other statistically evaluated results from a large number of stochastically generated DFN are discussed in [4] in more detail (with the task being slightly different).

Computation on the deep local model was made with three variants of the injection flow rate: 11.5, 23.5 and 47 ls-1. In the cyclic regime, the single yearlong cycle consisted of: 0.05-year long linear increase from zero to the maximal flow rate; 0.65-year long period of maximal flow rate; 0.3-year injection break (zero flow rate).

Shallow Local Model with DFN (Model 3)

Small-scale local model has been meant to simulate a heating system for an apartment house, for which the output of ca. 50kW is sufficient. Input flow rate 1.8 l/s was estimated to obtain the required output. Beside the continuous regime, two variants of cyclic regime were simulated: (a) 0.3-year injection break (zero flow rate); (b) 0.2-year long recharging (pumped water is warmed up by 40 °C and injected back to the underground, see Figure 1 low right) + 0.1-year injection break (zero flow rate). The working part of the cycle is the same as for the Model 2.

5. RESULTS AND DISCUSSION

Simulations times for particular tasks were within the limits of 0.5-1 hour.

Deep local model

Results for the continuous regime with three different flow rates are shown in Figure 4. Resulting values from Flow123d are slightly overestimated in comparison with COMSOL but preserve the development shape. Figure 5 shows a comparison between the continuous and cyclic regime. The output difference in favor of the cyclic regime is growing in progressing time, so a properly chosen cyclic regime can prolong the life time of the exchanger significantly. It should be mentioned that the case study does not take into account processes which could occur during the intervals (e.g. a silting of fractures due to the chemical reactions). Simulated outputs after several years of operation are obviously insufficient for the power-supply use.

Shallow local model

More promising are the simulation results for the shallow exchanger, used for the heating (Figure 6). The cyclic regime with seasonal intervals can keep the sufficient output for tens of years. Even better results can be obtained if the redundant energy (from green sources) is deposited in the underground.

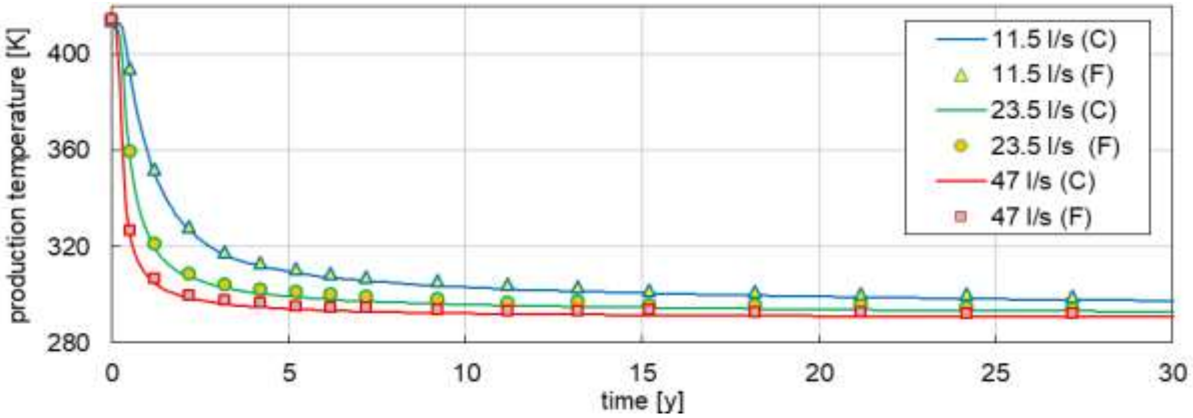

Figure 4. Model 2. Time progress of the production temperature – a comparison between COMSOL Multiphysics (lines) and Flow123d (symbols)

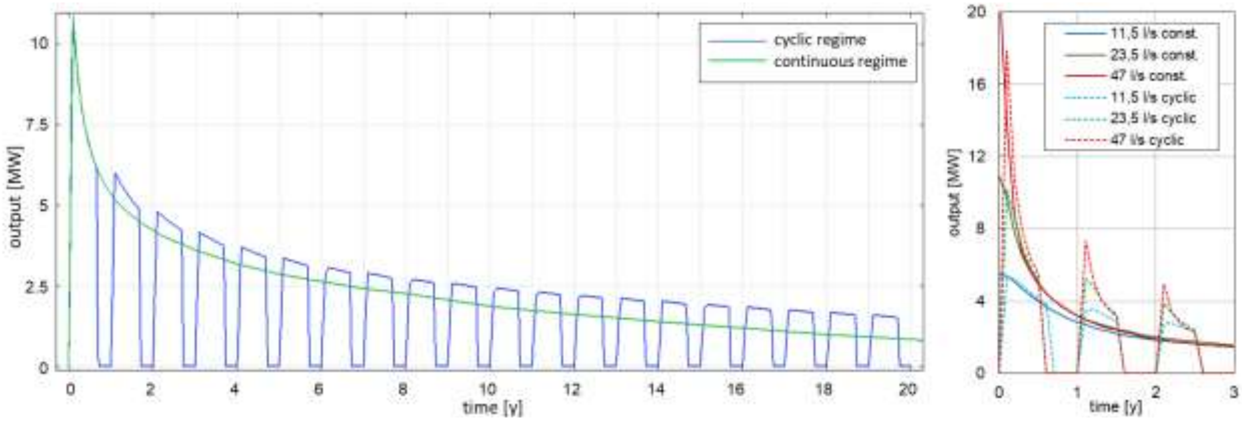

Figure 5. Model 2. Time progress of the exchanger output – comparison between the continuous and the cyclic regime. Left – 20 year simulation for inject flow rate 23.5 ls^{-1}. Right – first three years for various inject rates

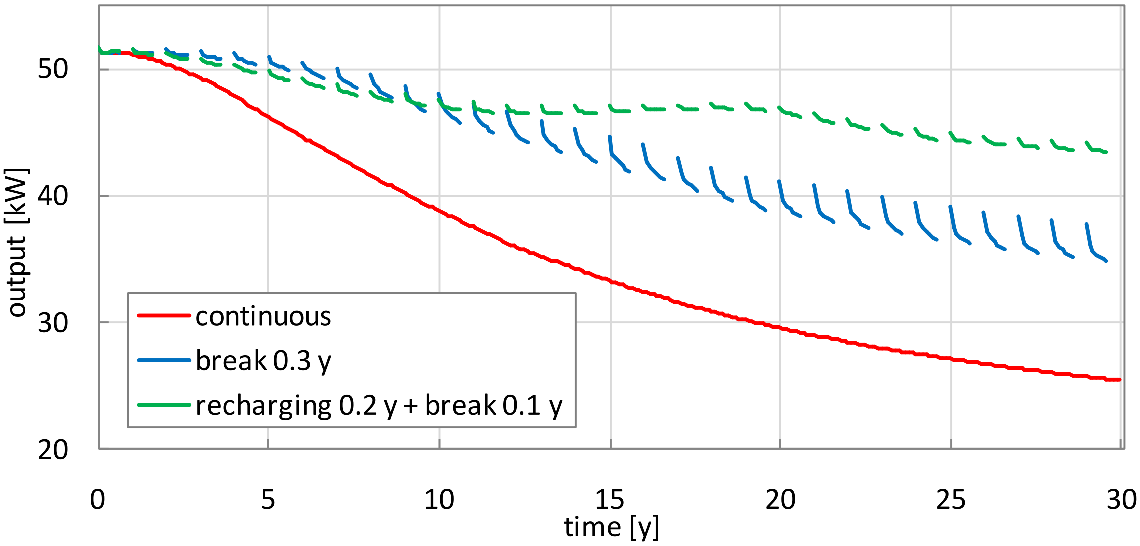

Figure 6. Model 3. Time progress of the exchanger output – comparison between the continuous and cyclic regimes

6. CONCLUSION

The use of geothermal energy in the Czech Republic is in its very beginning phase. This work and its possible future improvement (e.g. an inclusion of mechanic processes) should help to improve the scientific and technical background for geothermal development in the CZE. The model geometries are largely fit to its prospective usage at the Litoměřice area, where the first Czech HDR system is planned. Nowadays, the cost-effective use of the geothermal energy in the geological conditions in CZE is very questionable, while the exploitable outputs after several years of operation are insufficient for the power-supply use. But even so the conditions allow building smaller HDR systems with lower outputs, suitable e.g. for heating systems.

We confirmed an applicability of the DFN/porous media concept in modeling HDR. From the basic thermal balance perspective, the regional porous media model is fully adequate. The discrete fracture network approach is though needed as an instrument of deeper insight into geothermal exchanger behavior for eventual mechanically induced changes in the fracture properties (not included in the problem formulation at present).

7. ACKNOWLEDGEMENTS

Research Infrastructure RINGEN is supported from targeted support program by Ministry of Education Youth and Sports reg. no. LM2015084 and from Operational Programme Research, Development and Education reg. no.CZ.02.1.01/0.0/0.0/16_013/0001792.

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