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To cite this article: N A Vaganova and M Yu Filimonov 2017 *J. Phys.: Conf. Ser.* **820** 012010

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# A General Model of an Open Geothermal System

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**Abstract.** Geothermal aquifers may be considered as a renewable resource of heat and energy. Internal earth heat may be transported with underground water to the surface by wells, and to not overexploit the aquifer, this water should be returned back. As a rule such systems consist of two wells. Hot water from the producing well is used, as example, for greenhouse complex or other buildings needs, which cools the water, and the injection well returns the cold water into the aquifer. To simulate this open geothermal system a three-dimensional nonstationary mathematical model and numerical algorithms are developed taking into account the most important physical and technical parameters of the wells to describe the heat distribution and thermal water transportation in the aquifer. Results of numerical calculations are presented.

## 1. Introduction

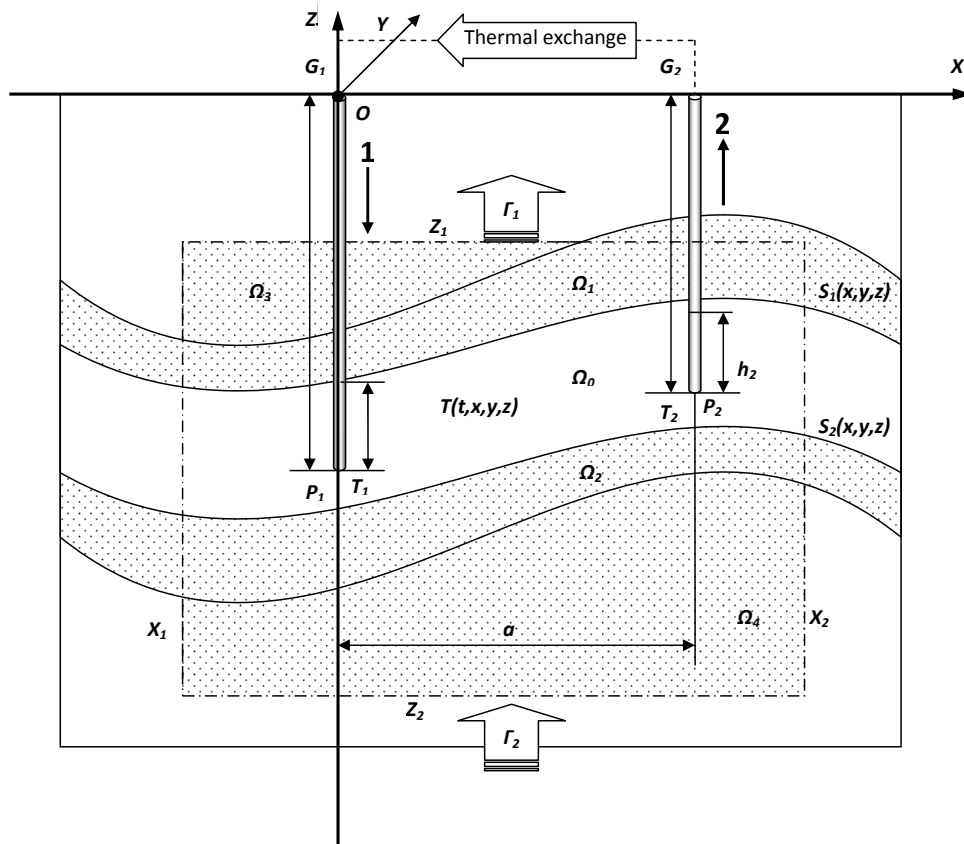
Geothermal energy is a type of renewable energy that encourages conservation of natural resources [1]. The most effective way is direct producing electricity from steam and very hot water (more than 150°C) that can drive turbines. But such resources are in general located in areas with high volcanic activity. Water at intermediate temperatures, from about 50°C to 150°C, can be used directly for industrial processes or for heating buildings. Below 50°C, heat pumps are used to increase the temperature. Even water with a temperature of about 5°C can be used as an energy source, provided there is enough of it. Underground water with medium and low temperature is a widespread energy. In this paper we will consider one type of geothermal systems, which allow to transfer the heat from deeper layers of ground: an open loop. A geothermal open loop system (fig. 1) is a system of two wells which drilled to tap an aquifer with hot water. The wells are injection (1) and producing (2), respectively. Temperature of water in the producing well is determined by temperature in the aquifer. This water then used for heating and then returns by pumps into the injection well with more cold temperature. During the time of exploitation of the system the cold water is distributed from injection to the producing well. The basic parameters of optimisation are the temperature of water in the producing well and the time when the water will be hot enough.

## 2. Mathematical model

The aquifer is a complex system and as a rule may include underground lakes, rivers, and creeks, different porous and waterproofing layer (fig. 1). To simplify the consideration let consider a layer with water filtrating from injection to the producing well.

To simulate underground flows of water in porous media, Darcy's law and law of mass conservation (continuity equation) are used [2]. A convection-diffusion equation with dominant





**Figure 1.** An aquifer with two wells. (1) and (2) are injection and producing well, respectively.

diffusion due to low velocity of filtration is considered. Let  $T(t, x, y, z)$  be the temperature in the aquifer,  $\mathbf{V} = (u, v, w)$  be a vector of filtration velocity. Thermal exchange is described by equation

$$\frac{\partial T}{\partial t} + b \left( \frac{\partial T}{\partial x} u + \frac{\partial T}{\partial y} v + \frac{\partial T}{\partial z} w \right) = \lambda_0 \Delta T, \tag{1}$$

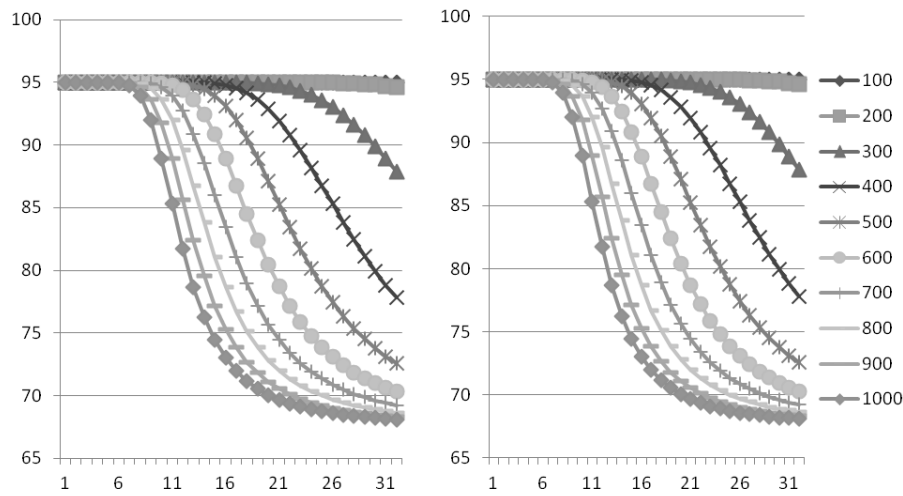
here  $b = \frac{\sigma \rho c_f}{\rho_0 c_0 (1 - \sigma) + \rho c_f \sigma}$ ,  $\lambda_0 = \frac{\kappa_0}{\rho_0 c_0 (1 - \sigma) + \rho c_f \sigma}$ ,  $\rho_0$  and  $\rho_f$  are density of aquifer soil and of water,  $c_0$  and  $c_f$  are specific heats of aquifer soil and of water,  $\kappa_0$  is thermal conductivity coefficient of soil,  $\sigma$  is porosity,  $(u, v, w)$  is vector of velocity of water filtration in the soil. The aquifer has an initial temperature  $T_0$  and in injection well temperature is set as “cold water” with temperature  $T_1$ , which returns from the producing well after using. Analytical approach to describe filtration processes meets difficulties and restrictions [3] so it is necessary to use numerical methods [4, 5].

To compute the velocity we use pseudoviscosity method with splitting by physical processes [6]. We solve an equation for pressure  $p = p(t, x, y, z)$

$$\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} + \frac{\partial^2 p}{\partial z^2} = 0 \tag{2}$$

with the following boundary conditions for the surfaces of injection and producing wells

$$P(t, x, y, z) \Big|_{\Omega_1} = P_1 - \rho g z, \quad P(t, x, y, z) \Big|_{\Omega_2} = P_2 - \rho g z. \tag{3}$$



(a) (b)

**Figure 2.** Temperature in the producing well for different pressure values [kPa] in injection and producing wells in dependence with time of operation [years]. The distances between wells are 600m and 700m in figures (a) and (b), respectively

At the lateral boundaries of  $\Omega$  for temperature and pressure we set the zero flux conditions. Size of the computational domain are large enough as to avoid the influence of the boundary conditions. Due to low velocity of filtration we can use a steady-state flow to describe convective transport terms in equation (1). To compute the components of velocity we may use the following equation for the previously obtained pressure field [6]:

$$\frac{\partial p}{\partial t} + \nabla \mathbf{V} = 0. \tag{4}$$

The equations (1)–(4) for temperature and pressure in aquifer is solved using a finite difference method based on an approach of works of A.A.Samarskii and P.N.Vabishevich [7]. A finite difference method with splitting by the spatial variables in three-dimensional domain is used to solve the problem. We construct an orthogonal grid, uniform, or condensing near the layer boundaries or to the surfaces of the wells. The original equation for each spatial direction is approximated by an implicit central-difference scheme and a three-point sweep method to solve the system of linear algebraic difference equations is used. This approach was successively used for the problems of describing a thermal trace from underground pipeline taking into account filtration and evaporation of fluid from soil surface [8, 9]. After finding the pressure field, a vector of velocity of filtered water is determined in the aquifer [10, 11]. It is also possible to take into account in the model a phase transition [12, 13].

### 3. Numerical results

To solve the problems a finite-difference implicit central-difference upwind scheme and a three-point sweep method is used with splitting by the spatial variables in three-dimensional domain with orthogonal grid, uniform, or condensing near the surfaces of wells. For computing pressure  $p$  an iterative steady-state method is used with so called “weak” boundary conditions. Because of the processes are slow and quasi-stable we use the sequence pressure (steady state)→velocity

field (steady state)→temperature in dependence with time. Computations are carried out with 1 day time step for 31 years.

We present the results of calculations for the differential pressure between producing and injection wells in the range from 100 kPa ( $P_1 = -P_2=50\text{kPa}$ ) and 1000 kPa ( $P_1 = -P_2=500\text{kPa}$ ). Effective life of an open geothermal system depends not only from distance between the wellheads in aquifer (fig. 2), but mostly from the power of using, i.e. value of pressure difference. The pressure in the wells may be changed due to seasonal needs variation or others restrictions.

#### 4. Conclusion

A model of geothermal aquifer is considered. This model includes both temperature distribution in underground layers and fluid filtration in porous media. This model is a base for computer simulation of an open geothermal loop consisted of two wells: injection and producing.

Computations allow simulate different regimes of exploitation and to estimate parameters of the open geothermal system, in particular to determine an appropriate distance between injection and producing wells and pump pressure depending on the operating conditions of the geothermal system. Investigations of different types and forms of injection and producing wells will follow.

##### 4.1. Acknowledgments

This work was supported by RFBR projects (16-01-00401).

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