Journal of Physics: Conference Series

Simulation of optimal exploitation of an open geotermal loop

To cite this article: N A Vaganova and M Yu Filimonov 2016 *J. Phys.: Conf. Ser.* **754** 112010

Simulation of optimal exploitation of an open geotermal loop

N A Vaganova[1,2] **and M Yu Filimonov**[1,2]

[1] Krasovskii institute of mathematics and mechanics UrB RAS, S.Kovalevskaya str. 16, 620990, Yekaterinburg, Russia
[2] Ural Federal University, Mira str. 19, 620002, Yekaterinburg, Russia

E-mail: `fmy@imm.uran.ru`

Abstract. Geothermal aquifers are a renewable resource of heat and energy. To encourage these resources open geothermal systems consisting of injection and production wells are commonly used. As a rule, such systems consist of two wells. Hot water from the production well is used and became cooler, and the injection well returns this cold water into the aquifer. To simulate this open geothermal system a three-dimensional nonstationar mathematical model and numerical algorithms are developed taking into account the most important physical and technical parameters of the wells to describe processes of heat transfer and thermal water filtration in the aquifer. Results of numerical calculations, which, in particular, are used to determine an optimal parameters for a geothermal system in North Caucasus, are presented.

1. Introduction

Geothermal energy is a type of renewable energy that encourages conservation of natural resources. According to [1], the geo-exchange systems save homeowners from 30 to 70% in heating costs, and from 20 to 50% in cooling costs, compared to conventional systems. Geo-exchange systems also save money because they require much less maintenance. In addition to being highly reliable, they are built to last for decades. In Russia, the geotermal units development started in the 1960s in Kamchatka region with Paratunskaya GeoTES, where steam and overheated water used to drive turbines and produce electricity. Geotermal units are in exploatation also in North Caucasus, Stavropol and Krasnodar regions. Up to 30 bln of m^3 of geoternal water is produced with the temperature from 80 to 110°C for these purposes. Water with such temperature can be used directly for industrial processes or for heating buildings.

A geothermal open loop system (figure 1) is a system of two wells which drilled to tap an aquifer with hot water. One well is injection, the second is production one. Temperature in production 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. Pressure which is generated by pumps forms a flux of water filtrating by an aquifer porous media (figure 2). During the time of exploitation of the system, cold water is distributed from injection to production well. A basic parameter of optimisation is the temperature of water in the production well. The computed temperatures changing during the years of exploitation are shown in figure 3.

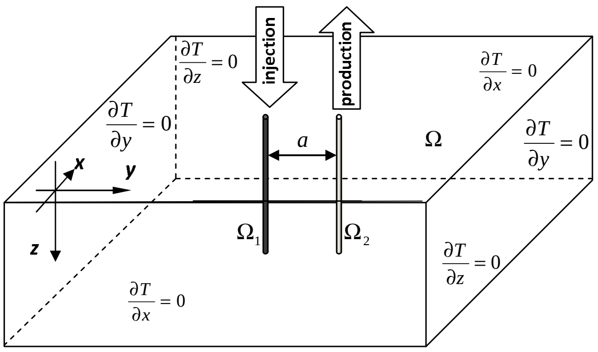


Figure 1. A model of an open geothermal loop.

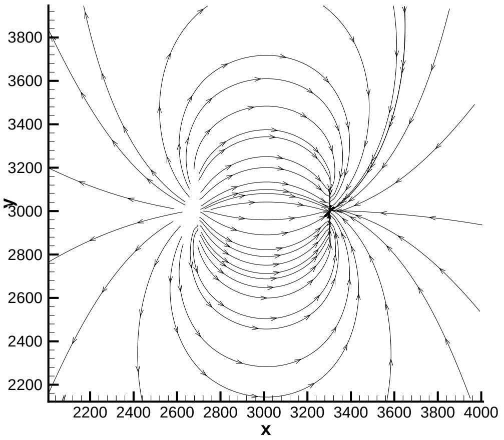


Figure 2. Streamlines of velocity in horizontal plane.

2. Mathematical model

In simulations of underground flow, Darcy's law and law of mass conservation (continuity equation) are used [2]. A convection-diffusion equation with dominant 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, $b = \dfrac{\sigma\rho c_f}{\rho_0 c_0(1-\sigma)+\rho c_f\sigma}$, $\lambda_0 = \dfrac{\kappa_0}{\rho_0 c_0(1-\sigma)+\rho c_f\sigma}$, ρ_0 and ρ_f are density of aquifer soil and of water, c_0 and c_f are specific heats of aquifer soil and of water, κ_0 is thermal conductivity coeffitient of soil, σ is porosity. The aquifer has an initial temperature T_0, and the temperature in injection well is set as "cold water" with temperature T_1, which returns from production well after using. An 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 $p = p(t,x,y,z)$

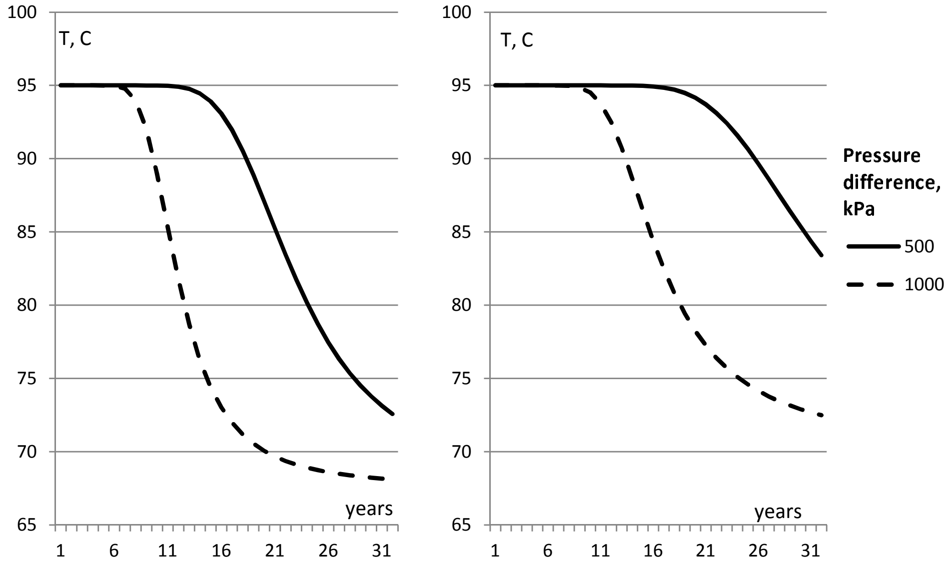
$$\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} + \frac{\partial^2 p}{\partial z^2} = 0 \tag{2}$$

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

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

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

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



(a) (b)

Figure 3. Temperature in productive well during exploitation for two differences of pressure in injection and production wells. The distance between wells is 600(a) and 700(b) m.

The equations (1)–(4) for temperature and pressure in aquifer are 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 is used with splitting by the spatial variables in three-dimensional domain to solve the problem. We construct an orthogonal grid, uniform, or condensing near the ground surface or near the surfaces of Ω_1 and Ω_2. The original equation for each spatial direction is approximated by an implicit central-difference scheme and a three-point sweep method to solve a system of linear differential algebraic 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 velosity of filtered water is determined in the aquifer.

Table 1. Thermal parameters of the aquifer.

	soli	water
Thermal conductivity [W/mK]	2.00	-
Density [kg/m^3]	-	1000.0
Specific heat [J/(kg K)]	-	4.18
Volumetric heat [J/(m^3 K)]	2150	
Filtration velocity [m/s]	$1.7{\cdot}10^{-5}$	
Porousity	0.241	

3. Numerical results

Consider a computational domain be a box 6000 m·6000 m·50 m size (figure 1). Injection and production wells are in the points (2700 m, 3000 m) and (3300 m, 3000 m), respectively. The distance between the wells is 600 m. Initial temperature of water in the aquifer is from 95 to 105°C. Temperature of injected water is 55°C. Soil thermal parameters correspond to Khankal geothermal fields in the North Caucasus and presented in Table 1.

To solve the problems, a finite-difference an 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 the processes are slow and quasi-stable, we use the sequence pressure (steady state)→velosity 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 production and injection wells for 500 kPa ($P_1 = -P_2$=250 kPa) and 1000 kPa ($P_1 = -P_2$=500 kPa). The thermal fields in a horizontal section of the aquifer for 10 and 20 years of exploitation are preseted in figures from 4 to 7. The injection and production wells are denoted by the black and white circles, respectively.

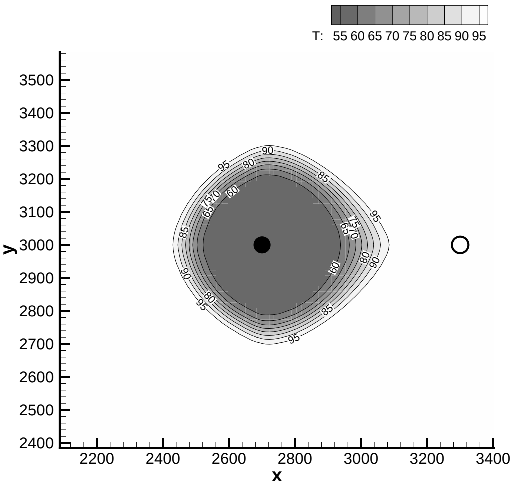


Figure 4. Temperature in aquifer for 10 years of exploitation. Pressure difference is 500 kPa.

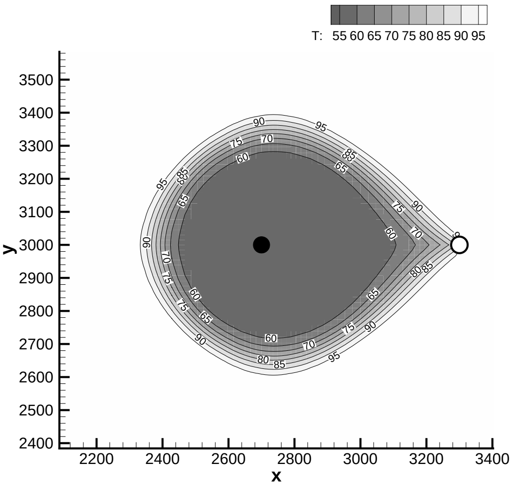


Figure 5. Temperature in aquifer for 20 years of exploitation. Pressure difference is 500 kPa.

An effective life of an open geothermal system depends not only from distance between the wellheads in aquifer (figure 3), but mostly from 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

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

Acknowledgments

This work was supported by RFBR (projects No. 16-01-00401 and No. 14-01-00155), by RF Government (contract No. 02.A03.21.0006, reg. No. 211) and by Program of UB RAS (project No. 15-7-1-13).

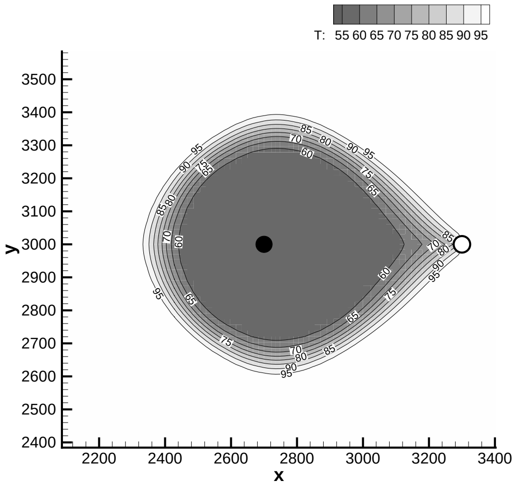


Figure 6. Temperature in aquifer for 10 years of exploitation. Pressure difference is 1000 kPa.

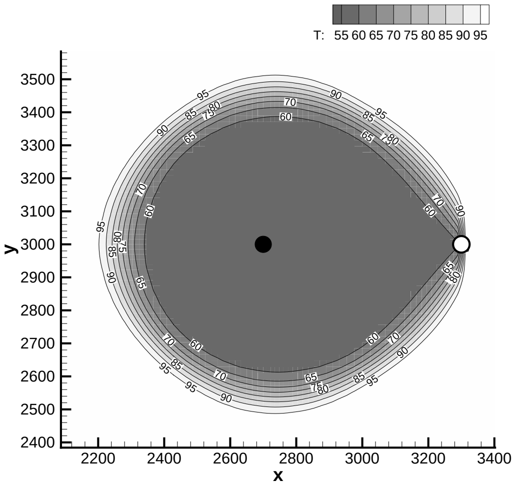


Figure 7. Temperature in aquifer for 20 years of exploitation. Pressure difference is 1000 kPa.

References

[1] Kreith F and Goswami D Y 2008 *Heat Pumps, Energy Management and Conservation Handbook* (Boca Raton: CRC Press)

[2] Polubarinova-Cochina P Y 1977 *Theory of motion of ground water* (Moscow: Nauka)

[3] Vaganova N A 2003 *Proc. Steklov Institute of Mathematics* **S2** S182–93

[4] Vaganova N A and Filimonov M Y 2015 *Lect. Notes Comput. Sci.* **9045** 393–9

[5] Filimonov M Y and Vaganova N A 2014 *Proc. Institute of Mechanics UrB RAS "Problems of Mechanics and Materials Science"* (Izhevsk: Institute of Mechanics UrB RAS) pp 219–22

[6] Chorin A J 1967 *Journal of Computational Physics* **2**(1) 12–26

[7] Samarsky A A and Vabishchevich P N 1995 *Computational Heat Transfer, Volume 2, The Finite Difference Methodology* (Chichester: Wiley)

[8] Bashurov V V, Vaganova N A and Filimonov M Y 2011 *Computational technologies* **16**(4) 3–18

[9] Vaganova N 2014 *AIP Conference Proceedings* **1631**(1) 37–41