Winning the geothermal heat energy in one hole and two-hole systems

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Abstract

The authors, on the basis of calculated computational models for one-hole and two-hole systems (with one or two aquiferous layers) with production and injection well, worked out relative characteristics taking into account the specific working conditions of the both systems. These models allow determining the outlet temperature of water as a function of mass flow of water as well as other parameters describing a geothermal deposit.

Keywords*: geothermal energy, winning of geothermal heat energy, one-hole systems, two-hole systems*

1 Introduction

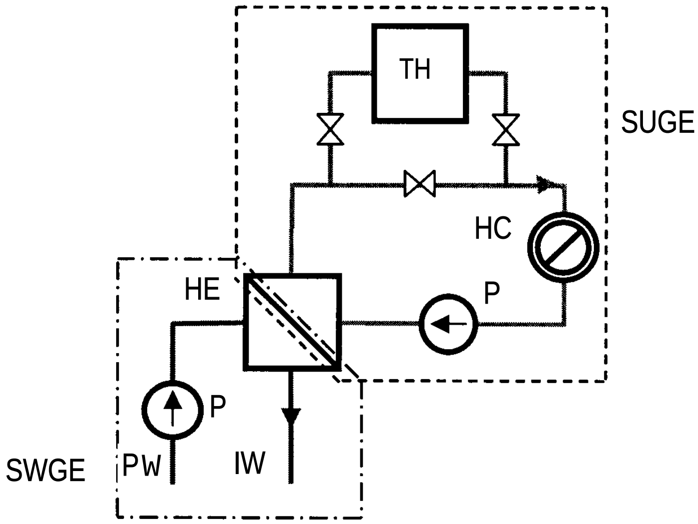
Poland is among the countries which pocesses rich geothermal deposits. The temperature of geothermal water in the deposits varies from 30 to 120°C (Sokołowski at al., 2000).

Exploitation of the deposits is especially beneficial in the region of Szczecin and Łódź. Different solutions of two co-operating systems: a system of winning the geothermal energy (a system with injection and production well) and a system of the heat utilisation are employed in the dependence on temperature of geothermal water and the heat consumers' needs as well as the type of regulation of the water in a heat distribution network. The temperature of geothermal water determines the solution of a system of the heat utilisation. Two basic solutions of it may be employed. The solution using only heat exchangers and top heaters is employed at higher temperatures of geothermal water (Figure 1), whereas the solution with the use of heat exchangers, heat pumps (absorption and compressor ones) and top heaters are employed at lower temperatures of geothermal water (Figure 2). Other solutions taking into account peculiarity of a heat network and the heat consumers based on mentioned solutions are available in the accessible literature (Nowak at al., 2000). Independently of the type of an employed system of utilisation of the geothermal energy, for heating purposes and/or technological ones, it may co-operate through a geothermal heat exchanger with various systems of winning the geothermal energy.

2 Systems of winning the geothermal energy

Two solutions of systems of winning the geothermal energy are considered in this paper. One is the system, which employs a ground-based heat exchanger and the other, which employs a heat exchanger immersed into a geothermal deposit and/or into a rock massif. In the first case a ground-based exchanger injected with the geothermal water mostly operates in two-hole systems with the injection and production well.

Two-hole systems are usually employed in extraction of mineralised geothermal waters. In systems of this kind the temperature of geothermal water extracted to the earth surface as well as the temperature of water injected on a deposit level may be estimated precisely enough with help of known computational models in a relatively simple way. When the flows of drawn-out water are great, the changes of temperature of geothermal water in injection and production conductors are relatively low. However, high expenditure of drilling of the hole in comparison to the total capital cost is a negative aspect of using this method in winning thermal energy. Employing the one-hole injection system may reduce the capital cost. Drilling one hole or the use of existing single holes, made during oil and gas exploration, is an effective way from the economical point of view. One-hole systems may be employed while extracting high-mineralised waters as well as low-mineralised ones. In the second case, the geothermal water extracted to the surface flows through the heat receiving system, usually a heat exchanger. Then, the water is directed into a storage reservoir. The water collected in the storage reservoir may be used as drink water or for farming. Its excess may be directed into natural water reservoirs such as rivers or lakes. In the one-hole system presented above, the conditions of heat transfer in the production well are the same as in a two-hole system. The same computational models may be used then. The situation changes radically in a one-hole system for mineralised waters because in systems of this type, the hole is simultaneously injection and production well. Then the conditions of heat transfer in the well are completely different. At the same temperature of the geothermal water in a deposit, the temperature of extracted water will be lower than the one of low-mineralised geothermal water in a one-hole system or a two-hole one.



SWGE - a system of winning the geothermal energy,
SUGE - a system of utilisation of the geothermal energy,
HE - a heat exchanger,
P - a pump,
TH - a top heater,
PW - a production well,
IW - an injection well,
HC - heat consumers

Figure 1: Co-operation of the systems: SWGE and SUGE on the basis of a heat exchanger and a top heater.

It applies to the solutions with the use of an intermediate fluid and employing a heat exchanger located in a geothermal deposit and/or a rock massif. In these solutions of heat exchangers the heat carrier from the system of utilisation of the heat is warmed up by the energy from the deposit and/or the rock massif.

For these systems with injection and production wells, on the basis of computational models worked out by the authors, the relations enabled determining the thermal fields of extracted and injected geothermal water or an intermediate fluid, which is the heat carrier, as well as the temperatures at the surface. The latter relation, at given temperature of the injected heat carrier, allows one to determine a flow of gained geothermal energy.

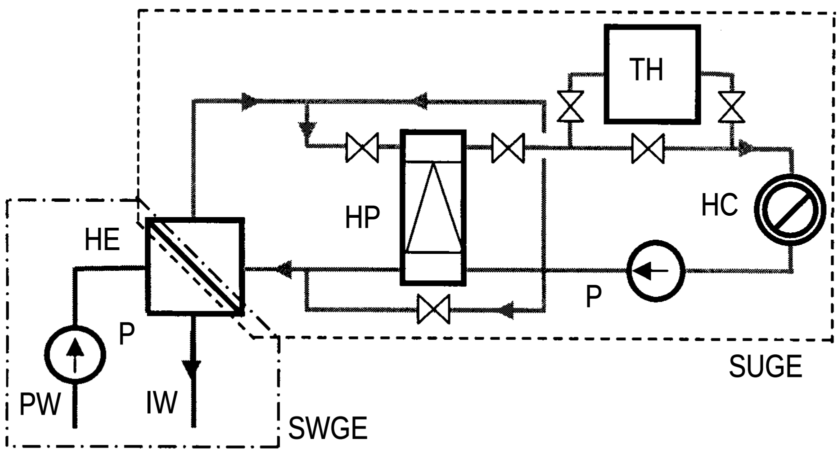


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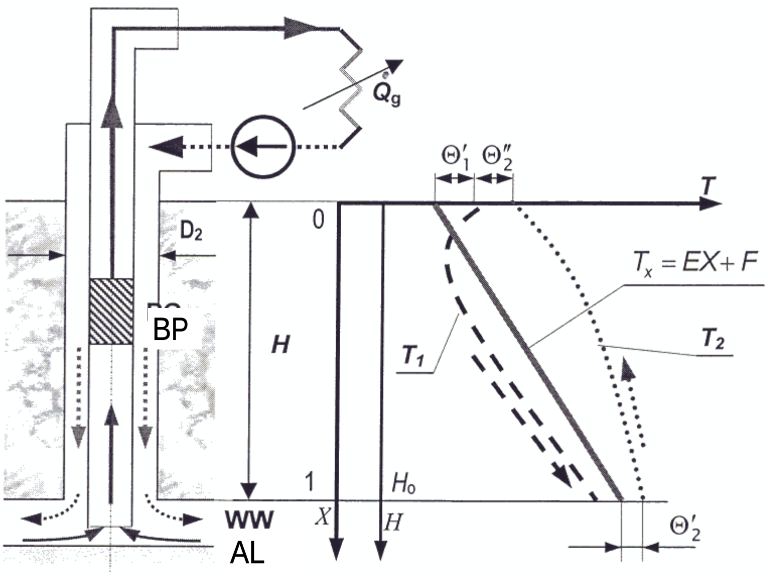
Figure 2: Co-operation of the systems: SWGE and SUGE on the basis of a heat exchanger, a top heater and a heat pump.

3 The thermal field of the geothermal water in one-hole system

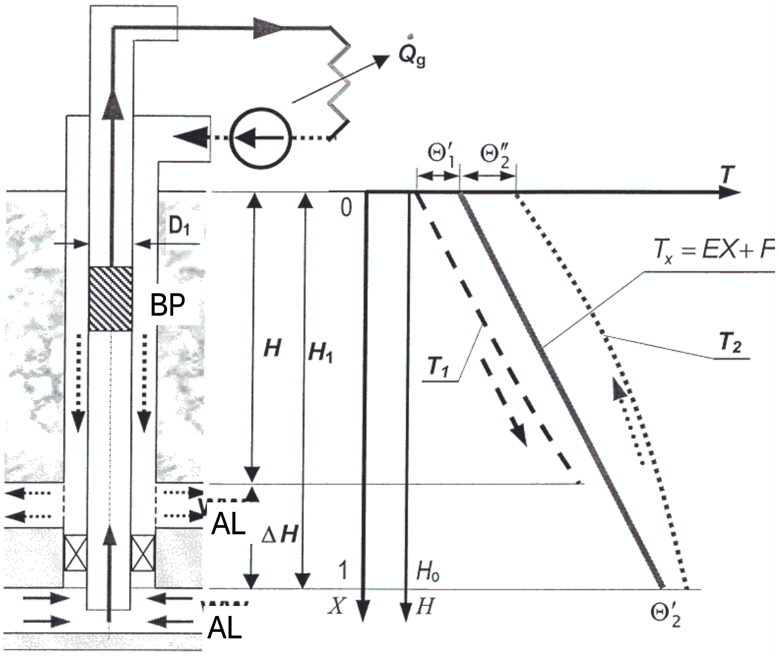
Exemplary solutions for one-hole system of winning the geothermal energy with the use of one or two aquifers are presented in Figures 3 and 4. Each figure includes the thermal field of the extracted geothermal water in the inside pipe and the geothermal water injected through a ring-shaped channel. In one case (Fig. 3) the temperature of injection is lower than the temperature of the earth at the surface whereas in the other case (Fig. 4) the temperature of the water is higher than the one of the earth at the surface.



AL - an aquiferous layer
BP - a borehole pump

Figure 3: One-hole and one-layer system of winning the geothermal energy with the injection and production well and the thermal field of a heat carrier.

In both solutions the same computational model of calculations of thermal fields and the amount of wined geothermal energy as the one given in the paper (Kujawa at al., 2000a) may be used. The only difference is that in the case of a two-layer system the temperature of the geothermal water, which inflows into the inside pipe, is higher than the temperature in a one-layer system.



AL - an aquiferous layer
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Figure 4: One-hole and two-layer system of winning the geothermal energy with the injection and production well and the thermal field of a heat carrier.

Based on the computational model (Kujawa at al., 2000a) the thermal field of the extracted and injected geothermal water may be determined from the following relation:

$$\Theta_1 = -C_2 \exp\left(\nu_2^2 X\right) + C_1 \exp\left(\nu_1^2 X\right), \quad \Theta_2 = C_2 \frac{q_2}{p_2} \exp\left(\nu_2^2 X\right) - C_1 \frac{q_1}{p_1} \exp\left(\nu_1^2 X\right) + \frac{E}{a}, \tag{1}$$

where:

$$C_1 = \frac{\Theta_2' + \Theta_1' \frac{q_2}{p_2} \exp\left(\nu_2^2\right) - \frac{E}{a}}{\frac{q_2}{p_2} \exp\left(\nu_2^2\right) - \frac{q_1}{p_1} \exp\left(\nu_1^2\right)}, \qquad C_2 = \frac{\Theta_2' + \Theta_1' \frac{q_1}{p_1} \exp\left(\nu_1^2\right) - \frac{E}{a}}{\frac{q_2}{p_2} \exp\left(\nu_2^2\right) - \frac{q_1}{p_1} \exp\left(\nu_1^2\right)}. \tag{2}$$

The temperature of the extracted geothermal water for $X = 0$ may be calculated from the following relation:

$$\Theta_2'' = C_2 \frac{q_2}{p_2} - C_1 \frac{q_1}{p_1} + \frac{E}{a} = \frac{\left(\Theta_2' + \frac{E}{a}\right)\left(\frac{q_2}{p_2} - \frac{q_1}{p_1}\right) + \Theta_1' \frac{q_1}{p_1} \frac{q_2}{p_2} \left[\exp\left(\nu_1^2\right) - \exp\left(\nu_2^2\right)\right]}{\frac{q_2}{p_2} \exp\left(\nu_2^2\right) - \frac{q_1}{p_1} \exp\left(\nu_1^2\right)} + \frac{E}{a}, \tag{3}$$

Whereas the flow of the wined geothermal energy may be calculated from the following relation:

$$\dot{Q}_g = \dot{W}\left(\Theta_2'' - \Theta_1'\right). \tag{4}$$

4 The thermal field of an intermediate fluid in a geothermal heat exchanger

Geothermal heat exchangers immersed in an aquiferous layer, with the use of an intermediate fluid, and co-operating directly with the ground-based heat receivers may be used instead the one-hole solutions of winning the geothermal energy with the use of a ground-based heat exchanger supplied with the geothermal water from a one-hole system with the injection and production well described in paragraph 3. These exchangers are called geothermal exchangers or geothermal probes. They have two parts. One part of a double-pipe exchanger is located into an impervious rock massif, whose temperature is changing linearly. The other part (the head of a geothermal exchanger) is immersed in a geothermal deposit, where the heat is extracted. The computational model of geothermal exchangers which enables determining a flow of heat taken by the part of the exchanger immersed in a geothermal deposit are described in the papers (Kujawa at al., 1998, a, b, 2000b, 2002). Two kinds of solutions of the immersed part were discussed. The impact of the heat capacity of a geothermal water flow was not taken into account. In both cases it was assumed that the thermal field as well as the coefficient of heat transfer from a geothermal deposit into a heat carrier is known.

However, in all cases it is possible to take into consideration the impact of the conditions of heat transfer in the other part of the double-pipe exchanger on the temperature of the carrier in the output of the exchanger. But the appropriate computational model describing the heat transfer in a double-pipe must be used.

Two basic solutions of one-hole geothermal heat exchanger: Field type one and spiral-tube one are considered here. The solutions are presented in Figure 5. An adequate graph of temperature fields for both alternatives is shown in Figure 6. The difference between both alternatives is only when a wall (inside pipe) which separates a heat carrier in one-hole system allows heat transmission between injected and extracted fluid.

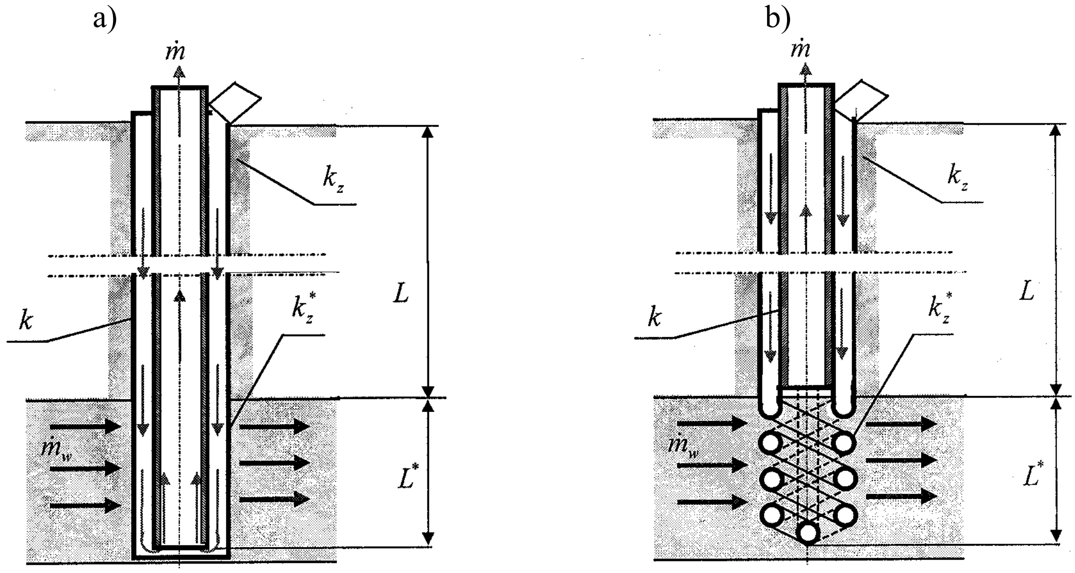


Figure 5: A double-pipe vertical heat exchanger (an adiatermic inside pipe) with the head as: a) Field exchanger, b) Spiral-tube exchanger.

Considering the solution when a perfect insulation is between injected and extracted heat carrier in both parts of a heat exchanger is assumed there are the same relations. Firstly the relation for the first part of a double-pipe heat exchanger when the inside pipe is perfectly insulated is considered.

On the basis of a general computational model published in (Kujawa at al., 1998a) when the inside pipe is insulated the following relation is obtained: $\Theta_1'' = E/b + (\Theta_1' - E/b)\exp(-b)$. The relation allows one to determine temperature on the inflow into the head of an exchanger.

In both cases there is the same simple computational model for this part of an exchanger (the head), which is immersed in a geothermal deposit. Possible differences will result from more advantageous conditions of heat transmission in a spiral-tube head. Based on results obtained in (Kujawa at al., 1998a) temperature of a heat carrier on the output from the head, which equals temperature of the carrier on the earth's surface may be expressed as follows:

$$\Theta_1^{*''} = \left(\Theta_1'' - \frac{\dot{W}}{K^*}E^*\right)\exp\left(-\frac{K^*}{\dot{W}}\right) + \frac{\dot{W}}{K^*}E^*, \qquad \text{where: } \dot{W} = \dot{m}c_p,\ K^* = k\pi D_2 L_o^* . \quad (5)$$

Considering a heat exchanger with a spiral-tube head reduced heat transfer coefficient is bigger and in the first approximation may be assumed that its value is about 15 percent higher than the heat transfer coefficient for Field type exchanger. It means that: $K^* \cong 1.15\, K^*_{Fielda}$

A flux of winning heat is determined from:

$$\dot{Q} = \dot{W}(T_2'' - T_1'), \quad \text{where: } T_2'' = T_2' = E^* + F^* - \Theta_1^{*''},\ T_1' = F - \Theta_1' . \qquad (6)$$

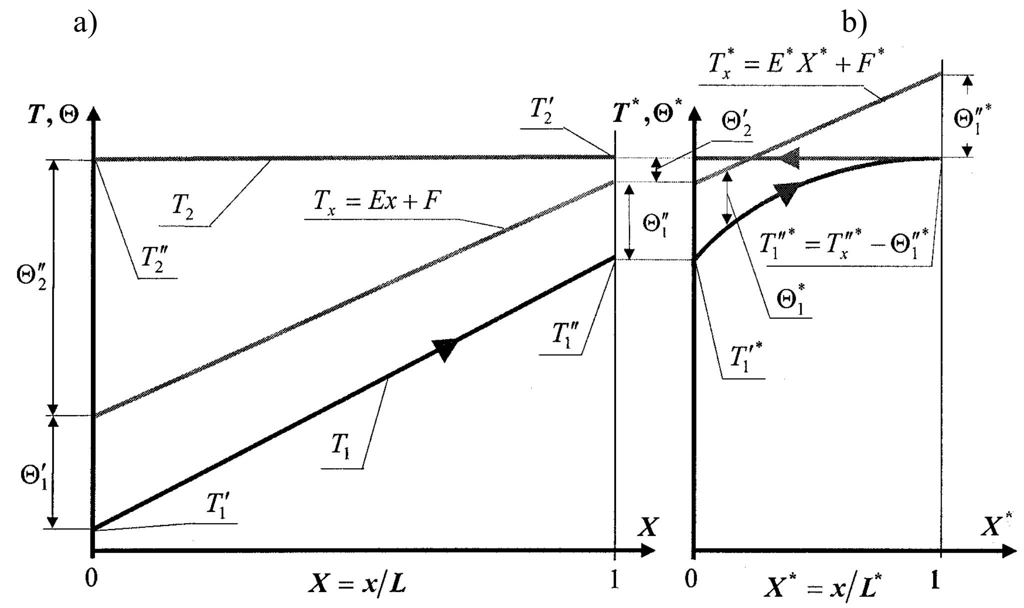
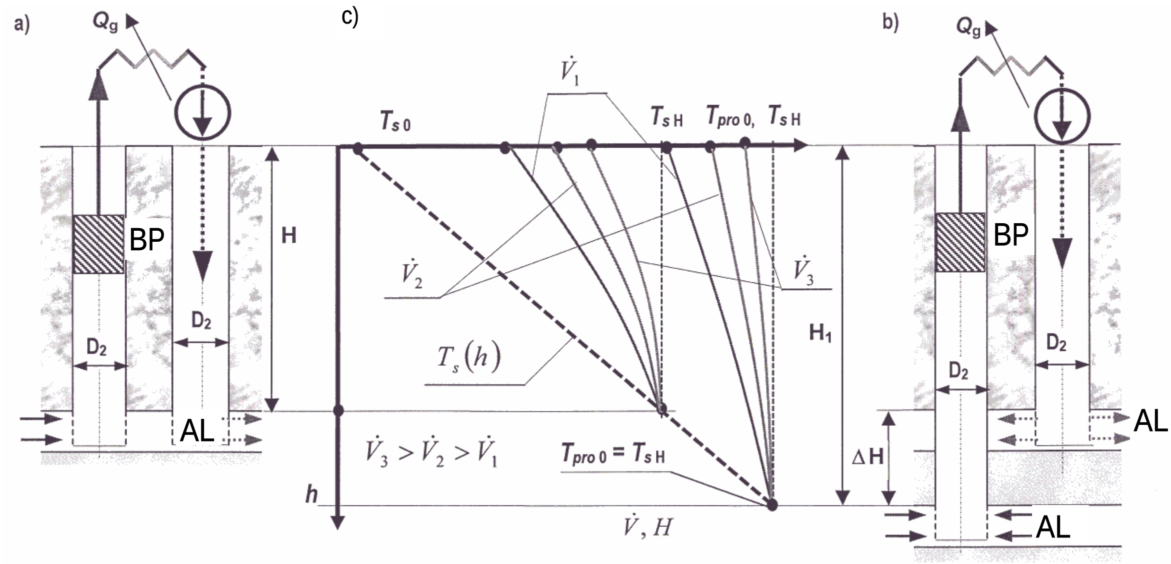


Figure 6: Temperature field of fluid: a) in the first part of a heat exchanger, b) in the other part of a heat exchanger.

5 The thermal field of the geothermal water in two-hole system

Two-hole systems may operate as one-layer systems (Figure 7a) or two-layer ones (Figure 7b). In both cases mineralised geothermal water is drawn out from a deposit with a deep well pump immersed into the production well and it is directed to the main heat exchanger.

Geothermal water heats the water in a heat distribution network in the exchanger. Then the water is directed to the injection well and pumped into the same aquiferous layer when one-layer system is considered (Fig. 7a). Considering two-layer system geothermal water is injected into an aquiferous layer situated above the layer, which is drawn out from (Fig. 7b). In both cases the amount of winning geothermal energy depends on a flux of extracted geothermal water, which is affected by the temperature of extracted as well as injected geothermal water. When there are two aquiferous layers, water is extracted from the layer situated lower than the one whose temperature is higher. In both cases the same computational model is valid. The only difference is that temperature of geothermal water at the depth H (Fig. 5.1a) is taken into account when one-layer system is considered. While considering two aquiferous layers, temperature of geothermal water extracted from the layer situated lower at the depth H_1 must be taken into account (Fig. 7b).



AL - an aquiferous layer, BP - a borehole pump

Figure 7: Two-hole and one-layer (a), two-layer (b) system of winning the geothermal energy with the injection and production well and the thermal field of a heat carrier (c).

The thermal field of extracted geothermal water, based on the equation of heat energy balance for elementary high of the production well, may be calculated from the following relation, which presented in Kujawa at al., (2002). When $T_{pH} = T_{sH}$, what mostly occurs in typical solutions, the relation is written as:

$$T_{pro0} = T_{sH} - (\nabla T_s)_H H + \frac{(\nabla T_s)_H}{A}\left(1 - e^{-AH}\right) \quad (7) \quad \text{or} \quad T_{pro0} = T_{so} + \frac{(\nabla T_s)_H}{A}\left(1 - e^{-AH}\right), \quad (7a)$$

where: $A = \pi D_1 k_z / \dot{W}_{pro}$; $\dot{W}_{pro} = \dot{V}_{pro}\rho_{pro}c_{pro}$.

Adequate designations are in Figure 7c, where the effect of a volume flux of geothermal water on its temperature in a production well is shown. The relation that determines the extracted geothermal water flux is: $\dot{Q} = \dot{W}\left(T_{pro0} - T_{inj0}\right)$, The relation is right when it is assumed that a flux of extracted geothermal water equals a flux of injected geothermal water $\dot{V}_{pro} = \dot{V}_{inj}$. Then $\dot{W}_{pro} = \dot{W}_{inj} = \dot{W}$.

Temperature of injected water has a substantial impact on a flux of winning geothermal energy. The temperature is strictly connected with temperature of water in a heat distribution network running back from the heat sinks if the water is used for heating purposes.

6 Results of the calculations and conclusions

The computational models of various solutions of geothermal heat exchangers presented here, allowed one to perform exemplary calculations. Thus the diagram in Figure 8 illustrates the impact of the level of insulation of the top part of a geothermal heat exchanger on the thermal field of a flow of gained geothermal energy $\dot{Q}$ as well as the temperature rise of a heat carrier ΔT. It clearly follows from the diagram that the given depth of a geothermal layer relates to strictly determined value of the insulation of the top part of a geothermal heat exchanger, at which $\dot{Q}_g = \dot{Q}_{g\,\max}$ (the dash line).

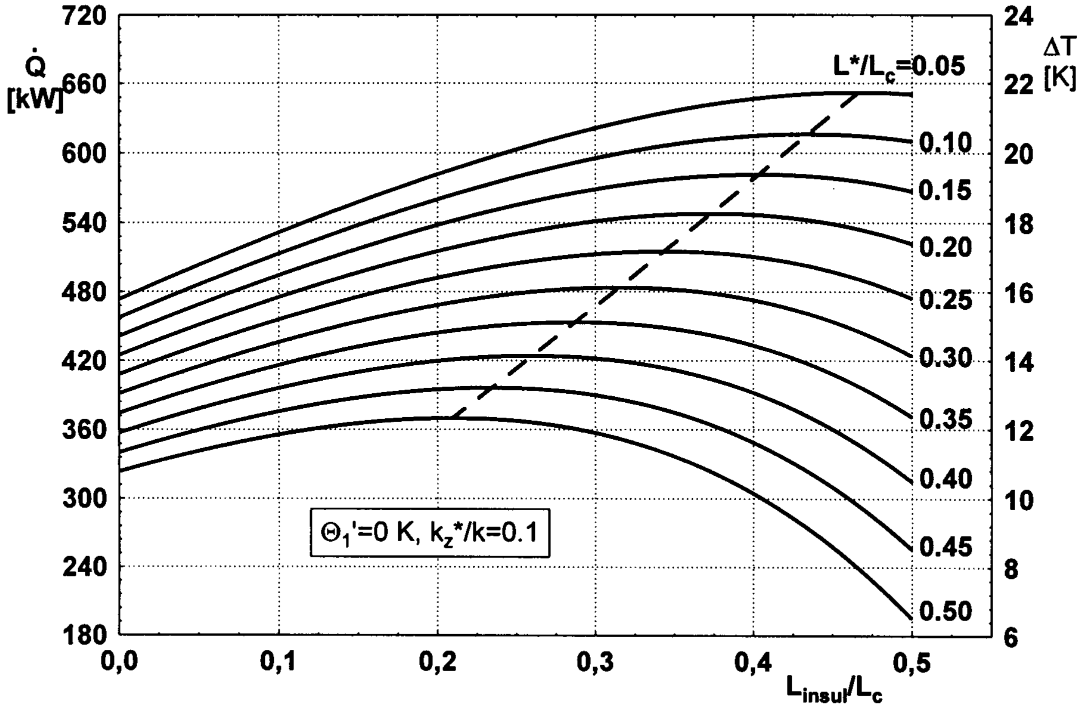


Figure 8: The impact of the insulation level of the top part of a geothermal heat exchanger L_{insul}/L_c and the thickness of a geothermal layer L^*/L_c on the flows of gained geothermal energy $\dot{Q}$ and the temperature rise of a heat carrier ΔT ($\dot{W} = 30,000$ W/K).

Figure 9 illustrates the amount of gained geothermal energy for various solutions of insulation of a geothermal probe with the intermediate fluid. The increase in the value of heat capacity of a heat carrier $\dot{W}$ causes that extreme of the amount of gained heat occurs. Further increase in the length of insulation does not bring any quantitative effects – the amount of gained geothermal energy decreases.

Other results and conclusions will be presented at the Conference.

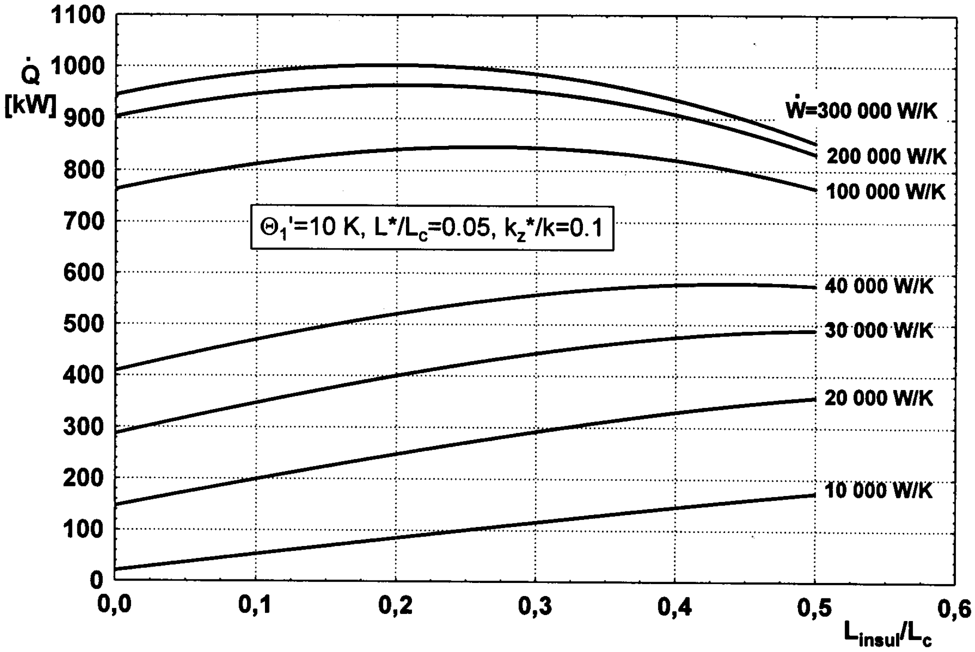


Figure 9: The impact of the insulation level of the top part of a geothermal heat exchanger L_{insul}/L_c and the heat capacity of a geothermal carrier $\dot{W}$ on the flows of gained geothermal energy $\dot{Q}$ for selected parameters of a geothermal deposit.

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