Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Operation of Geothermal Heat Plant Supplied the Distribution Network with High- and Low-Temperature Receivers Connected in Series in Comparison with Receivers Connected in Parallel

Katarzyna Zwarycz and Wladyslaw Nowak

Department of Heat Engineering, Technical University of Szczecin, Piastow 19, 70-310 Szczecin, Poland

kzwarycz@ps.pl, ktc@ps.pl

Keywords: geothermal water utilisation, medium-enthalpy geothermal water, heat distribution network, high-temperature heat receivers, low-temperature heat receivers

ABSTRACT

In this publication the conclusions of theoretical analysis concerning possibilities of medium-enthalpy (40°C÷90°C) geothermal water utilisation supplying the distribution network, which consists of in-series or parallel connected heat users featuring different operational requirements will become.

The main components of the heating system are production-reinjection geothermal wells, geothermal heat exchanger and peak boiler as an additional heat source. Heat is transferred to the distribution network of receivers equipped with high-temperature heating systems (e.g. radiator heating, tap water) and low-temperature systems (e.g. floor heating, snow melting).

Two different types of configuration are considered: I) users connected to the geothermal heat plant in series; II) users connected to the geothermal heat plant in parallel. In this last arrangement analysis also refers to two variants (IIa, IIb), in of which in first priority have high-temperature receivers instead of second variant where receivers are equivalent.

In calculations it was taken into account variable users' participation of heat demand in total demand for the thermal power. Obtained results will attend to select effective variants of geothermal heat plant operation and to indicate best possibilities of utilization of medium-enthalpy geothermal water.

1. INTRODUCTION

Poland is a country with good occurrence conditions of geothermal water aquifers and their exploitation in many regions. Reservoir water temperatures vary from 30°C to 130°C on depths of 1 - 4 km (Kepinska, 2003). Those aquifers are descended from sedimentary basins, thus it is medium and low-enthalpy geothermal water (Sokolowski, 1997).

Prospective conditions are found in the Szczecin-Lodz Region. Due to mostly high TDS of geothermal water in Poland (1-130 g/l) it is reasonable to use geothermal heat exchanger, which indirectly separates geothermal and network water.

In the one wells' doublet geothermal systems, with production and injection wells, there are applied two main designs of installations in the geothermal power station:

- installation with geothermal heat exchanger only,
- system with geothermal heat exchanger and heat pump, compressor or absorption, in co-operation.

At all events, Polish conditions always require an additional heat source as a peak boiler (Nowak et al., 2000; Sobanski et al., 2000).

This work introduces results of calculation concerning possibilities of medium-enthalpy geothermal water utilization in one wells' doublet geothermal heat plant with geothermal heat exchanger only. Heat is transferred to the distribution network of receivers, which are equipped in high-temperature heating systems (i.e. radiator heating) and low-temperature systems (i.e. floor heating). In both cases, preparing of tap water was taken into consideration.

Two main types of configuration are considered:

I) users connected to the geothermal heat plant in series (Zwarycz, 2000; Nowak, Zwarycz 2001, 2002),

II) users connected to the geothermal heat plant in parallel (Witka-Jezewska, 2000; Nowak, Stachel 2001; Nowak, Zwarycz 2004),

a) high-temperature receivers have priority (heating system with high-temperature receivers modernised by parallel connection of low-temperature users with quantitative regulation). In such arrangement heat supply of the distribution network is common for those two groups of heat receivers and adapted according to regulation diagram of high temperature users with qualitative control,

b) heat receivers are equivalent (heating system supplied the both groups of users separately, which makes enable better geothermal energy utilisation). In such arrangement heat supply of the distribution network is adapted according to quantity-qualitative control.

Temperature and possible to obtain volumetric flow rate of extracted geothermal water as well as accepted solution of heat distribution network, applied water regulation type and also temperature of network return water, which is depend on operating parameters of heat receivers, these elements has a great influence on effectiveness of geothermal energy extraction. Three methods of water regulation: quantitative, qualitative and quantity-qualitative, in those distribution networks are applied.

Obtained results will attend to select effective variants of geothermal heat plant operation and to indicate best possibilities of utilization of medium-enthalpy geothermal water. In this publication are introduced the conclusions of analysis concerning influence of variable users' participation in total demand for the thermal power and influence of variable temperature and volumetric flow rate of geothermal water on the level of geothermal energy utilisation.

2. METHODOLOGY AND ASSUMPTIONS FOR CALCULATIONS

The subject of this work is thermal and fluid-flow analysis for the theoretical types of geothermal heat plant configurations (I and IIab). Obtained results are related with different calculation variants that refer to variable users' participation of heat demand in total demand for the thermal power $\dot{Q}_c$. In all cases, preparing of tap water was taken into consideration.

Each of presented heating systems consists of the geothermal heat plant co-operating with heat receivers. The main components of the heating system are production-reinjection geothermal wells (one wells' doublet), counter-flow geothermal heat exchanger and peak boiler as conventional heat source. Heat is transferred to the distribution network of receivers characterised by different operational parameters.

First type of receivers it is installation equipped in high-temperature heating systems (e.g. radiator heating), where the temperatures of the network water are in function of the outdoor air-temperature. Second type of receivers it is installation of low-temperature systems (e.g. floor heating) running on constant temperatures of network water. All these elements are interconnected by pipelines and bypasses that make possible, if necessary, the flow of the network water between the heat source and heat receivers.

2.1 Characteristic of the Geothermal Water

For calculations, the following data of geothermal water were assumed:

- max volumetric flow rate $\dot{V}_{w\max}$ =50,100,150,200 m^3/h
- max temperature $T_{wgz\max}$ =40,50,60,70,80,90°C
- mean mass density ρ_w =1,08 kg/dm^3
- mean specific heat c_w =3,81 kJ/kgK.

2.2 Characteristic of the Heat Receivers

Total heat demand $\dot{Q}_c$ is defined by the following relationship (Nowak, Rogowska 2002; Nowak, Zwarycz 2002):

$$\dot{Q}_c = \dot{Q}_p + \dot{Q}_g \tag{1}$$

where:

$$\dot{Q}_p = \varphi \dot{Q}_c \tag{2}$$

$$\dot{Q}_g = (1-\varphi)\dot{Q}_c\,. \tag{3}$$

Following values of φ were considered into calculations:

$$\varphi = 0;\;\; 0{,}25;\;\; 0{,}50;\;\; 0{,}75;\; 1 \tag{4}$$

Thereby 5 calculation variants of variable users' participation of heat demand in total demand for the thermal power $\dot{Q}_c$ were determined. Total heat demand $\dot{Q}_c$ could be defined also as:

$$\dot{Q}_c = \dot{Q}_{co} + \dot{Q}_{cwu} = \dot{Q}_{co} + \Phi\,\dot{Q}_{co\max}\,, \tag{5}$$

where $\dot{Q}_{co\max}$ is maximal rate of heat for central heating at minimal outdoor temperature $T_{z\min} = -16\,°C$, $\dot{Q}_{co}$ is rate of heat for central heating:

$$\dot{Q}_{co} = \dot{Q}_{co\max}\,\frac{T_w - T_z}{T_w - T_{z\min}}\,, \tag{6}$$

Φ is relation of heat demand for tap water preparing to maximum heat demand for central heating coefficient:

$$\Phi = \frac{\dot{Q}_{cwu}}{\dot{Q}_{co\max}}\,. \tag{7}$$

For the calculations, in Polish conditions, it was assumed that:

- mean specific heat of network water $c_s = 4{,}18$ kJ/kgK ,
- indoor temperature $T_w = 20\,°C$,
- minimal outdoor temperature $T_{z\min} = -16\,°C$,
- boundary temperature of heating season discontinuation $T_{zg} = 12\,°C$,
- maximal rate of heat for central heating at minimal outdoor temperature $T_{z\min} = -16\,°C$ equal $\dot{Q}_{co\max} = 10000$kW ,
- heat demand for tap water preparing is constant for entire year $\dot{Q}_{cwu} = 2000$kW .

In the radiator heating supply T_{gz} and return T_{gp} temperatures of network water are linearly varying with the outdoor temperature T_z, quantity-qualitative regulation is applied there (temperature T_{gz} and mass flow $\dot{m}_g$ of network water is regulate). Network water mass flow for the radiator heating circuit $\dot{m}_g$ was estimated from the following formula:

$$\dot{m}_g = \frac{\dot{Q}_g}{c_s\,(T_{gz} - T_{gp})} \tag{8}$$

In the floor heating supply T_{pz} and return T_{pp} temperatures of network water are independent on outdoor temperature($T_{pz} = 60°C = idem$, $T_{pp} = 30°C = idem$), quantity regulation has application there (supply water mass flow $\dot{m}_p$ is variable, supply temperature T_{pz} is constant). Network water mass flow for the floor heating circuit $\dot{m}_p$ was estimated similarly to the (8) formula.

Amount of the heat transferred through the heat distribution network, in time $\bar{\tau}_1$ to $\bar{\tau}_2$, is defined from equation:

$$Q_c = \tau_0 \int_{\bar{\tau}_1}^{\bar{\tau}_2} \dot{Q}_c d\bar{\tau} = \tau_0 c_s \int_{\bar{\tau}_1}^{\bar{\tau}_2} \dot{m}_s \left(T_{sz} - T_{sp}\right) d\bar{\tau} , \qquad (9)$$

where reduced time is $\bar{\tau} = \frac{\tau}{\tau_0}$.

During the calculations Raiss formula (Szargut, Ziebik 2000) was used, which allows for determine of outdoor temperatures T_z occurrence frequency in function of reduced time $\bar{\tau}$ from the following formula:

$$\frac{T_{zg} - T_z}{T_{zg} - T_{z\min}} = \left[1 - \sqrt[3]{\bar{\tau}} + \bar{\tau}^2 \left(1 - \sqrt{\bar{\tau}}\right)\right]. \qquad (10)$$

Is assumed that supply and return temperatures of heat distribution network medium are defined as linear dependence on function of outdoor temperature T_z :

$$T_{sz} = a + bTz \qquad (11)$$

$$T_{sp} = c + dTz \qquad (12)$$

The network water mass flow $\dot{m}_s$ is defined as relation:

$$\dot{m}_s = \alpha + \beta Tz . \qquad (13)$$

In *quantity-qualitative regulation* coefficients α and β are described suitably:

$$\alpha = \frac{\dot{Q}_{co\max}}{c_s \cdot \left[(a-c)+(b-d)T_z\right]} \cdot \frac{f}{36} \qquad (14)$$

$$\beta = -\frac{1}{36} \cdot \frac{\dot{Q}_{co\max}}{c_s \cdot \left[(a-c)+(b-d)T_z\right]} . \qquad (15)$$

After substitution of adequate number values it is possible to determine the supply T_{sz} and return T_{sp} temperatures and the network water mass flow $\dot{m}_s$ in function of reduced time $\bar{\tau}$:

$$T_{sz} = a + bT_z = a + b\left\{-16 + 28\left[(\bar{\tau})^{\frac{1}{3}} - (\bar{\tau})^2 + (\bar{\tau})^{\frac{5}{2}}\right]\right\} \qquad (16)$$

$$T_{sp} = c + dT_z = c + d\left\{-16 + 28\left[(\bar{\tau})^{\frac{1}{3}} - (\bar{\tau})^2 + (\bar{\tau})^{\frac{5}{2}}\right]\right\} \qquad (17)$$

$$\dot{m}_s = \alpha + \beta T_z = \alpha + \beta\left\{-16 + 28\left[(\tau)^{\frac{1}{3}} - (\tau)^2 + (\tau)^{\frac{5}{2}}\right]\right\} \qquad (18)$$

Allow for expressions (16-18) determination of total heat demand from equation (9) is possible.

In *quantitative regulation* $\dot{m}_s$ is variable, whereas $T_{sz} = idem$ and $T_{sp} = idem$. Conversion to *qualitative regulation* (applied to radiator heating) needs in equation (9) to integrate T_{sz} and T_{sp}, while $\dot{m}_s$ is possible to put outside the integral because $\dot{m}_s = idem$. On the basis of equation (13) noticeable is that $\dot{m}_s = idem$ when $\beta = 0$.

2.3 Qualitative Water Regulation

Alternatives of geothermal heat plant operation with *qualitative regulation* and extracted geothermal heat against total heat demand for heating season illustrates Table 1. Scrupulous analysis of this problem is shown in work (Nowak et al. 2001-2004). For the other types of regulations (quantitative, quantity-qualitative) an adequate tables are also shown in work (Nowak et al. 2001-2004).

In Table 1 horizontal lines shows influence of relation between geothermal water temperature T_{wgz} and network water temperatures T_{sz}, T_{sp} on the amount of used geothermal energy. Vertical columns shows influence of network water mass flow goes through geothermal exchanger, on the extracted geothermal energy.

In the geothermal heat exchanger it was assumed that mean temperature difference is $\Delta\overline{T} = 2K$, and then maximum network water temperature reached in this exchanger is $T_s = T_{wgz} - 2$. In dependence on temperatures T_{sz}, T_{sp} and $T_s = T_{wgz} - 2$ correlation is possible to distinguish 5 regulation diagrams alternatives (a, b, c, d, e), which are taking into account in Table 1.

variant **a** $T_{wgz} - 2 > T_{sz}(\bar{\tau} = 0)$ (19)

variant **b** $T_{sp}(\bar{\tau} = 0) < T_{wgz} - 2 < T_{sz}(\bar{\tau} = 0)$ (20)

variant **c** $T_{sz}(\bar{\tau} = 1) < T_{wgz} - 2 < T_{sp}(\bar{\tau} = 0)$ (21)

variant **d** $T_{sp}(\bar{\tau} = 1) < T_{wgz} - 2 < T_{sz}(\bar{\tau} = 1)$ (22)

variant **e** $T_{wgz} - 2 < T_{sp}(\bar{\tau} = 1)$ (23)

Based on Raiss formula (10) integration limits in equation (9) can be defined as $\bar{\tau}^* = \varphi(T_z)$ and $\bar{\tau}^{**} = \varphi(T_z)$. Then amount of geothermal heat extracted in heat exchanger Q_w and transferred through the distribution network, is possible to describe.

3. GEOTHERMAL HEAT PLANT SUPPLIED THE DISTRIBUTION NETWORK WITH RECEIVERS CONNECTED IN SERIES (SYSTEM I)

The system presented on Figure 1 refers to geothermal heating system I, characterised in section 2, but here high- and low-temperature receivers are connected in series (Zwarycz, 2000; Nowak, Zwarycz 2001, 2002).

Based on results of calculated variants, for heating season and entire year, was organised statements and diagrams of utilised geothermal heat and heat gained from peak boiler, it refers to all variants of heat receivers' participation in total heat demand for the thermal power:

- rate of total $\dot{Q}_c$, geothermal $\dot{Q}_w$ and boiler $\dot{Q}_{ks}$ heat as variability in function of time τ and outdoor temperature T_z,
- rate of extracted geothermal heat $\dot{Q}_w$, for all calculating variants, as function of geothermal water volumetric flow rate $\dot{V}_w$ and temperature $T_{w\max}$.

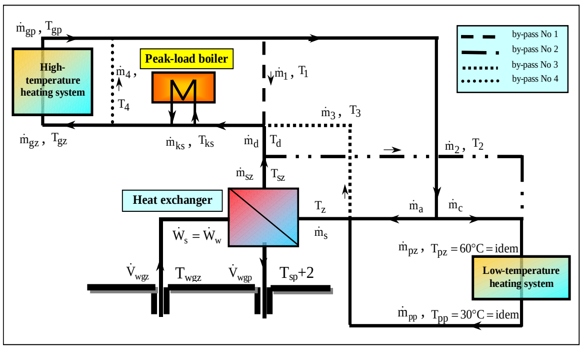

Figure 1: General schematic of the geothermal heating system (I) with the geothermal heat exchanger, peak boiler and <u>in series</u> connected high- and low-temperature receivers.

Example diagram of total heat demand $\dot{Q}_c$ and rate of geothermal heat $\dot{Q}_w$, for $\dot{Q}_p = 0{,}5\dot{Q}_c$, if $\dot{V}_{w\max} = 100\ \mathrm{m}^3/\mathrm{h}$ illustrates Fig. 3. Amount of extracted geothermal energy for temperatures $T_{w\max} = 60°C$ and $T_{w\max} = 90°C$, in function of $\dot{V}_{w\max}$ illustrates Fig. 3. Utilisation of geothermal heat for variants $\dot{Q}_p = \dot{Q}_c$ and $\dot{Q}_g = \dot{Q}_c$ in $T_{w\max}$ relation is shown on Fig. 4, while for $\dot{Q}_p = \dot{Q}_c$, $\dot{Q}_p = 0{,}75\dot{Q}_c$ in $\dot{V}_{w\max}$ relation – on Fig. 5.

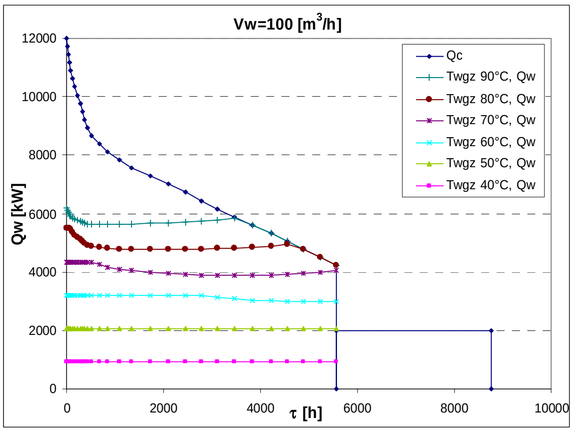

Figure 2: Rate of total $\dot{Q}_c$, geothermal $\dot{Q}_w$ heat in function of time τ, for geothermal water temperatures ranges 40°C÷90°C, $\dot{Q}_p = 0{,}5\dot{Q}_c$.

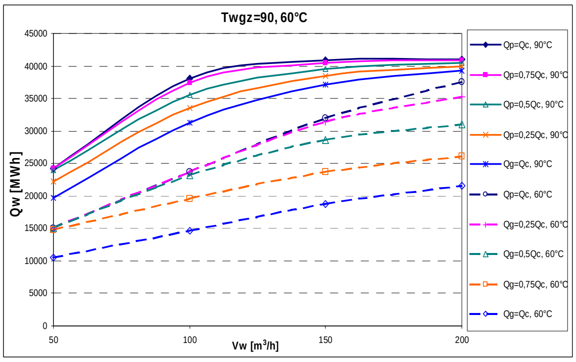

Figure 3: Extracted geothermal energy Q_w in function of $\dot{V}_{w\max}$, for geothermal water temperatures 60°C, 90°C, all calculating variants.

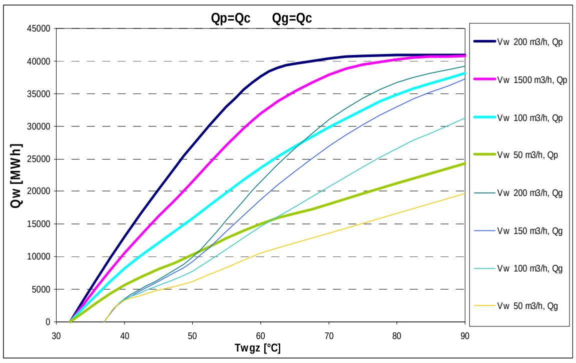

Figure 4: Extracted geothermal energy Q_w in function of $T_{w\max}$, for variants $\dot{Q}_p = \dot{Q}_c$ and $\dot{Q}_g = \dot{Q}_c$, all consider geothermal water flow rates $\dot{V}_{w\max}$ come within.

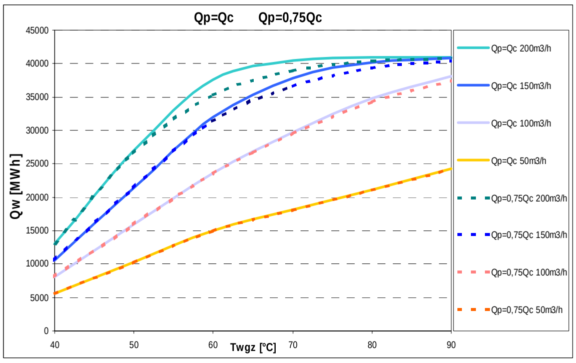

Figure 5: Extracted geothermal energy Q_w in function of $\dot{V}_{w\max}$, for two variants $\dot{Q}_p = \dot{Q}_c$ and $\dot{Q}_p = 0{,}75\dot{Q}_c$, all consider geothermal water temperatures $T_{w\max}$ come within.

Obtained results of all calculated variants, for heating season and entire year, which were organised as statements and diagrams (examples above), leads to the following conclusions:

1) For calculating variant $\dot{Q}_p = \dot{Q}_c$, rate of geothermal $\dot{Q}_w$ and boiler heat $\dot{Q}_{ks}$ are changing linearly in function of τ and T_z. However, for the other variants, those parameters are represented by curves. When increases radiator heating participation of heat demand as well as increases $\dot{V}_{w\max}$ and $T_{w\max}$, then also increases amount of extracted geothermal energy, it is adapted to total heat demand decreasing with increase of outdoor temperature.

2) With the decreasing of floor heating participation of heat demand, when $\dot{V}_{w\max}$ and $T_{w\max}$ are invariable, amount of extracted geothermal energy Q_w decreasing, while amount of peak boiler energy Q_{ks} increasing.

3) For the floor and radiator heating, utilisation of geothermal energy Q_w improves with increasing $\dot{V}_{w\max}$, it is especially obvious for $\dot{V}_{w\max} > 100\ \mathrm{m}^3$/h due to correct adaptation of receiving heat with maximal geothermal water volumetric flow rate $\dot{V}_{w\max}$ and temperature $T_{w\max}$.

4) In case of the floor heating, geothermal water temperature $T_{w\max}$ influence on extracted rate of geothermal energy $\dot{Q}_w$ decreasing, with $\dot{V}_{w\max}$ increasing. For the geothermal water temperatures 80°C÷90°C and flow rates 150m3/h÷200m3/h it's observed similar effectiveness on geothermal energy utilisation, while within the range of 100m3/h÷150m3/h – only a small differences.

4. GEOTHERMAL HEAT PLANT SUPPLIED THE DISTRIBUTION NETWORK WITH RECEIVERS CONNECTED IN PARALLEL (SYSTEM IIa AND IIb)

Figures 6a, 6b presented geothermal heating systems, characterised in section 2, but here high- and low-temperature receivers are connected in parallel (Witka-Jeżewska, 2000; Nowak, Stachel 2001; Nowak, Zwarycz 2004).

The system IIa presented on Figure 6a it is with high-temperature receivers modernised by parallel connection of low-temperature users that is high-temperature receivers have priority. The system IIb presented on Figure 6b supplied the both groups of users separately that is heat receivers are equivalent.

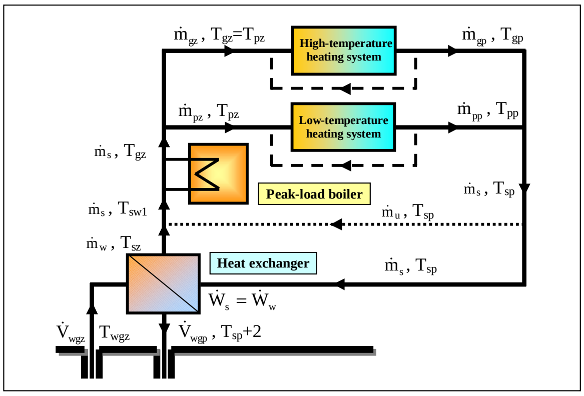

Figure 6a: General schematic of the geothermal heating system (IIa) with the geothermal heat exchanger, peak boiler and high-temperature receivers modernised by parallel connection of low-temperature receivers.

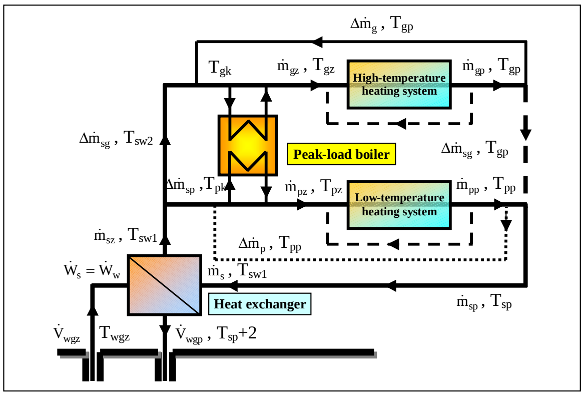

Figure 6b: General schematic of the geothermal heating system (IIb) with the geothermal heat exchanger, peak boiler and in parallel connected high- and low-temperature receivers.

For the systems IIa, IIb calculations and diagrams were carried out like for previous system I, it refers to all variants of heat receivers' participation in total heat demand for the thermal power.

Examples of diagrams presented rate of extracted geothermal heat $\dot{Q}_W$ (system IIa) in function of time τ, for different levels of low-temperature users participation (0, 25, 50, 75, 100%) in total heat demand $\dot{Q}_c$, for geothermal water temperature range 40°C÷90°C and $\dot{V}_{w\max} = 150\ \mathrm{m}^3$/h illustrate Figure 7.

Examples diagrams for the system IIb introduce Figure 8 and Figure 9. For the $\dot{Q}_p = \dot{Q}_c$, $\dot{Q}_g = \dot{Q}_c$ variants, when to the heating system is connected only one heat receiver, it is of no importance if they're connected in series or parallel, thus calculation results for those configurations should be conformable. Above assumption is correct (comparison of Figures 9 and 4).

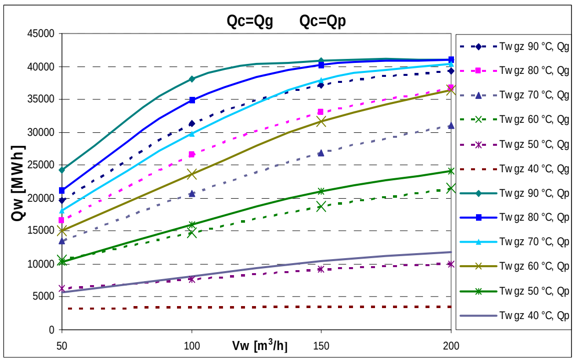

Figure 8: Extracted geothermal energy Q_w as function of volumetric flow rate $\dot{V}_w$, for two variants $\dot{Q}_p = \dot{Q}_c$, $\dot{Q}_g = \dot{Q}_c$, all consider geothermal water temperatures $T_{w\max}$ come within.

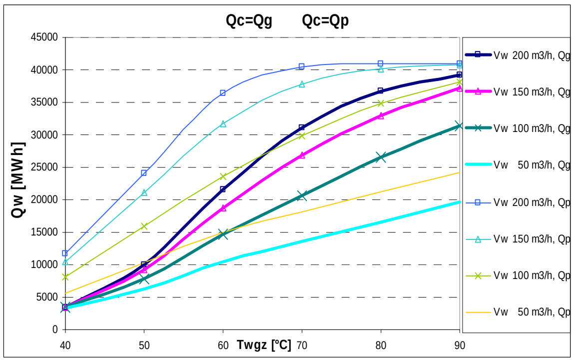

Figure 9: Extracted geothermal energy Q_w as function of geothermal water temperature $T_{w\max}$, for two variants $\dot{Q}_p = \dot{Q}_c$, $\dot{Q}_g = \dot{Q}_c$, all consider max volumetric flow rates come within.

After calculations and diagrams analysis the following conclusions are observed for system IIa (Figure 6a):

1) For calculating variant $\dot{Q}_g = 0{,}25\dot{Q}_c$ at maximum extracted geothermal water temperatures peak boiler working only at extreme low outdoor temperatures, as well as maximal utilisation of geothermal exchanger heating power is possible only for small temperatures range. With outdoor temperatures increase heat demand is decreasing what leads to decreasing of geothermal energy utilisation. At the lowest geothermal exchanger supplying temperature i.e. 40°C peak boiler works over entire heating season. At decreasing of geothermal water flows heating power utility level for different supplying temperatures is decreasing too.

2) For $\dot{Q}_g = 0{,}5\dot{Q}_c$ variant, geothermal energy utilisation level, at variable supplying temperatures is greater at higher flows and decreases together with decreasing of extracted geothermal water flow rate.

3) For $\dot{Q}_g = 0{,}75\dot{Q}_c$ variant is observed that at supplying temperature i.e. 40°C geothermal exchanger it is not used even at the lowest outdoor temperature. Only at condition, when network water temperature at input of exchanger is lower than geothermal exchanger water temperature output, it starts working on. The same dependence is observed for $\dot{Q}_g = \dot{Q}_c$ variant.

4) For $\dot{Q}_p = \dot{Q}_c$ variant, linear constant value of geothermal energy utilisation is observed, which is due to constant supplying and return floor heating temperatures. At the highest geothermal water temperature ($T_{w\max} = 90°C$) geothermal energy covers heating power demand for entire heating season, however according to decreasing of heating power in time geothermal energy is not used effectively.

In this heating system (IIa), at geothermal water temperatures $T_{w\max} = 40{,}50{,}60°C$ and low outdoor temperatures, exists an additional necessity of network water heating in peak boiler without geothermal exchanger usage, because return network water temperature (geothermal exchanger supply) is higher than output water temperature from this exchanger.

For considered calculation variants in system IIb, which is shown on Figure 6b, except above listed conclusions is observed also:

1) Effect of geothermal energy Q_w utilisation decrease, in accordance of assumption that were made. Geothermal water flow rate supplying geothermal exchanger is matched to carry out condition $\dot{W}_w = \dot{W}_s$. From assumption is resulting that return geothermal water temperature T_{wgp} is about 2 K higher than network water temperature on the exchanger input. Therefore geothermal return water temperature from geothermal exchanger increasing, i.e. power of exchanger decrease because temperature difference $\Delta T = T_{wgz} - T_{wgp}$ is decreasing.

2) Above described effect is observed also for $\dot{Q}_g = 0{,}5\dot{Q}_c$ and $\dot{Q}_g = 0{,}25\dot{Q}_c$ variants, but it's decreasing at lower volume flow rate in opposition to preview heating system (IIa).

3) In system IIb is observed very low increase of geothermal energy Q_w utilisation with increase of volumetric flow rate $\dot{V}_{w\max}$ for variants $\dot{Q}_p = 100\%, 75\%\,\dot{Q}_c$, when in system IIa influence of $\dot{V}_{w\max}$ increase for this cases is appreciable. The rest of calculation variants ($\dot{Q}_p = 50\%, 25\%, 0\%\dot{Q}_c$) have lower influence on geothermal energy Q_w increase in system IIa in comparison with rest of system IIb variants.

5. CONCLUSION

This paper introduces issues of thermal power influence of the heat receivers connected in series or parallel, on the geothermal heat plant operation. Discussed influence is appreciable, especially when heat receivers characterised by different operational parameters, like in analysed above examples. First type of receivers it is installation equipped in high-temperature heating systems (e.g. radiator heating), where the temperatures of the network water are in function of the outdoor air-temperature. Second type of receivers it is installation of low-temperature systems (e.g. floor heating) running on constant temperatures of network water.

It was found that amount of utilised geothermal energy Q_w increase with the increase of:

- maximal volumetric flow rate of geothermal water $\dot{V}_{w\max}$,
- maximal geothermal water temperature $T_{w\max}$
- low-temperature receiver participation in total heat demand $\dot{Q}_{\mathrm{c}}$.

Advantageous effects of geothermal energy utilization with particular event of floor heating use are observed. In that case of the floor heating, geothermal water temperature $T_{w\max}$ influence on extracted rate of geothermal energy $\dot{Q}_w$ decreasing, with $\dot{V}_{w\max}$ increasing. For the geothermal water temperatures 80°C÷90°C and flow rates 150m^3/h÷200m^3/h it's observed similar effectiveness on geothermal energy utilisation, while within the range of 100m^3/h÷150m^3/h – only a small differences.

Great influence on effectiveness of geothermal energy extraction has:

- temperature and possible to obtain volumetric flow rate of extracted geothermal water,
- accepted solution of heat distribution network (common or separate heat supply of the distribution network for different heat receivers),
- applied water regulation type
- temperature of network return water, which is depend on operating parameters of heat receivers.

Directly utilisation of low, medium enthalpy geothermal water, especially in heating systems with parallel connected receivers, could bring good environmental and economical benefits.

Polish Scientific Committee for Research, Grant No. 8T10B04721, has funded the paper.

REFERENCES

Kepinska, B.: Current geothermal activities and prospects in Poland – an overview, *Proceedings*, European Geothermal Conference EGC 2003, Szeged, Hungary, (2003).

Nowak, W., and others.: Ocena efektywności energetycznej i ekonomicznej systemów ogrzewczych zasilanych wodą geotermalną o średniej i niskiej entalpii, (Estimation of energetic and economic efficiency of heating systems supplied medium and low-enthalpy geothermal water), *Research project* (State Committee for Scientific Research), KBN No. 8 T10B 047 21, (2001-2004), in Polish.

Nowak, W., Sobański, R., Kabat, M., Kujawa T.: Systemy pozyskiwania i wykorzystania energii geotermicznej, (Systems of extraction and utilization of geothermal energy), Szczecin, Publisher: Technical University of Szczecin, (2000), in Polish.

Nowak, W., Stachel, A.: Modeling of thermal-hydraulic processes of geothermal energy extraction and utilization, *Transactions of the fluid-flow machinery*, **No.109**, (2001).

Nowak, W., Rogowska, A.: Wpływ rodzaju regulacji wody sieciowej na ilość pozyskiwanej energii geotermalnej (The influence of water regulation type in district heating network on the amount of geothermal energy extraction), *Proceedings*, XVIII Zjazd Termodynamików, Muszyna, (2002), **vol. III**, 841-848, in Polish.

Nowak, W., Zwarycz, K.: The effect of thermal power of the heat receivers connected in series to the distribution network upon the geothermal heat plant operation, *Proceedings*, XI Internationale Tagung Forschung Praxis und Didaktik im Modernen Maschinenbau, Fachhochschule Stralsund, Stralsund, (2001), 91-98.

Nowak, W., Zwarycz, K.: Wykorzystanie energii wody geotermalnej o średniej i wysokiej entalpii w systemach ogrzewczych z regulacją ilościowo-jakościową (Utilization of medium and high enthalpy geothermal water energy in heating system with quality-quantitative regulation), *Proceedings*, XVIII Zjazd Termodynamików, Muszyna, (2002), **vol. III**, 857-864, in Polish.

Nowak, W. Zwarycz, K.: Evaluation of geothermal heat utilisation possibilities in heat plant co-operating with heat receivers connected in parallel, *Proceedings*, XIV International Symposium, Forschung-Praxis-Maschinenbau, Germany, Stralsund, (2004).

Nowak, W. Zwarycz, K.: Estimation of geothermal heat plant operation co-operating with two groups of heat receivers connected in parallel, *Proceedings*, Second International Conference on Contemporary Problems of Thermal Engineering, Gliwice-Ustroń, Poland, (2004), 131-138.

Sobański, R., Kabat, M., Nowak, W.: Jak pozyskać ciepło z Ziemi (How to obtain the heat from the Earth), Warszawa, Publisher: Centralny Ośrodek Informacji Budownictwa (2000), in Polish.

Sokołowski, J.: Metodyka oceny zasobów geotermalnych i warunki ich występowania w Polsce (Evaluation methodology of geothermal resources and their occurrence conditions in Poland), *Proceedings of Polish Geothermal School*, III Kurs, Kraków – Straszęcin, Publisher: GA i CPPGSMiE PAN, (1997), in Polish.

Szargut, J., Ziębik, A.: Podstawy energetyki cieplnej (Fundamentals of thermal power engineering), Warszawa, Publisher: Wydawnictwo Naukowe PWN, (2000), in Polish.

Witka-Jeżewska, J.: Wpływ mocy, równolegle podłączonych odbiorników ciepła do sieci, na pracę ciepłowni geotermalnej (The thermal power influence of the heat receivers connected in parallel on the geothermal heat plant operation), *master's thesis*, supervisor: Władysław Nowak, Department of Heat Engineering, Technical University of Szczecin, Szczecin (2000), in Polish.

Zwarycz K.: Wpływ mocy, szeregowo podłączonych odbiorników ciepła do sieci, na pracę ciepłowni geotermalnej (The thermal power influence of the heat receivers connected in series on the geothermal heat plant operation), *master's thesis*, supervisor: Władysław Nowak, Department of Heat Engineering, Technical University of Szczecin, Szczecin (2000), in Polish.

NOMENCLATURE

c	- mean specific heat, kJ/kgK
$\dot{m}$	- mass flow rate, kg/s
T	- temperature, °C
$\dot{Q}$	- heat demand, kW
Q	- heat energy, MWh
$\dot{W}$	- thermal capacity of heat flow, kW/K
$\dot{V}$	- volumetric flow rate, m^3/h
ρ	- mean mass density, kg/dm^3
τ_0	- duration of heating season, h
τ	- duration of outdoor temperature T_z, h
$\bar{\tau}$	- reduced time, -

SUBSCRIPTS

w	- geothermal water
s	- network water
ks	- peak boiler
wgz	- extracted geothermal water
wgp	- injected geothermal water
g	- radiator heating
p	- floor heating
gz	- radiator supply
gp	- radiator return
pz	- floor supply
pp	- floor return
co	- central heating
cwu	- tap water
c	- total
sz	- distribution network supply
sp	- distribution network return

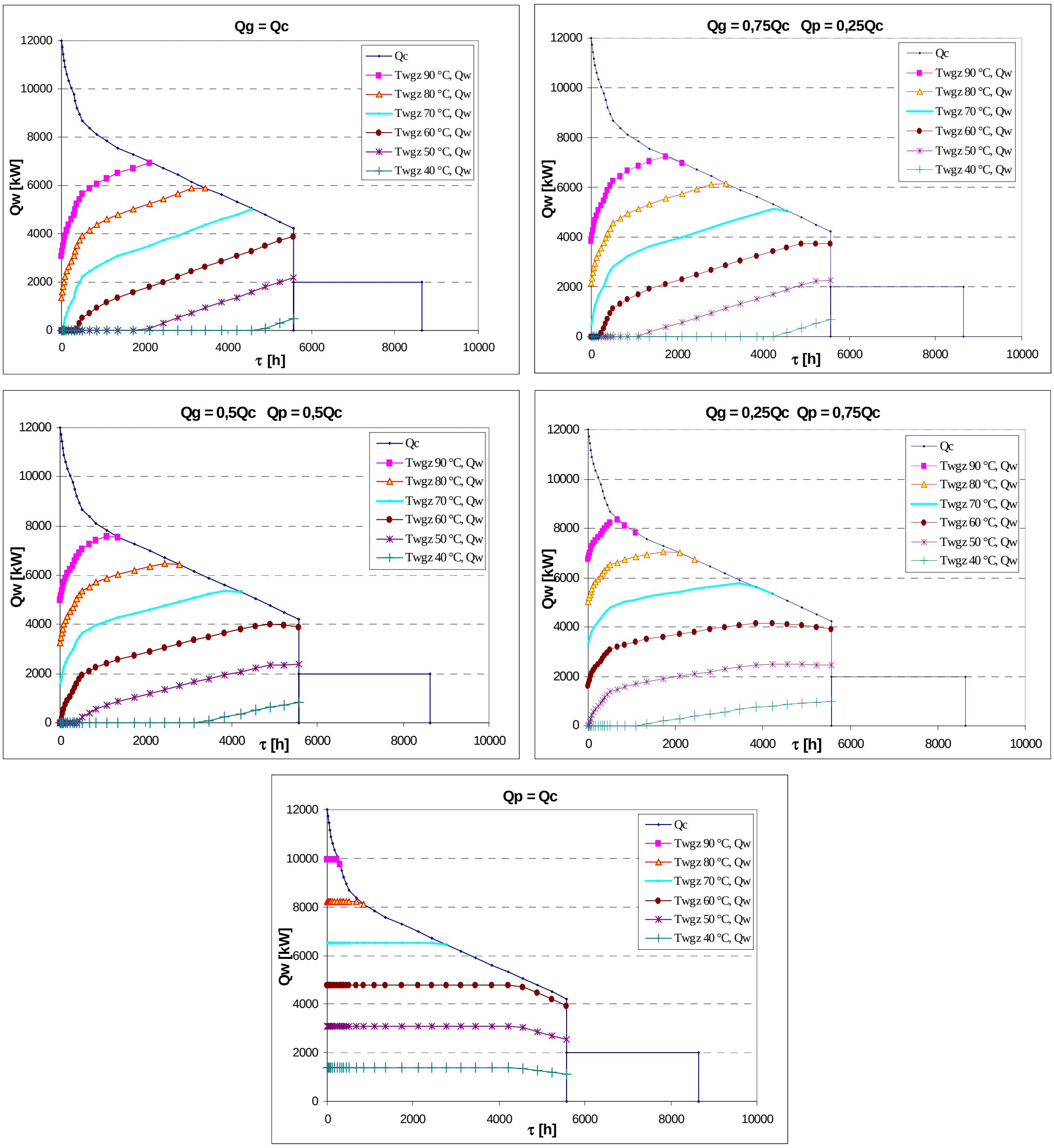

Figure 7: Rate of extracted geothermal heat $\dot{Q}_{\mathrm{w}}$ in function of time τ for different levels of low-temperature users' participation (0, 25, 50, 75, 100%) in total heat demand $\dot{Q}_{\mathrm{c}}$, $\dot{V}_{w\max} = 150$ m^3/h.

Table 1: Qualitative regulation. Statement of diagrams illustrates total heat demand and geothermal energy extraction as function of heating season period.