DEVELOPMENT OF THE HEATING SYSTEM USING GEOTHERMAL ENERGY

by

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The paper presents the results achieved by the project financed by Ministry of Science and Environmental Protection of Serbia during the period 2003-2005. The purpose of the project was determination methodology for designing heating system using geothermal water. Achieved results were implemented in the demonstration installment in factory "Palanački kiseljak" in Smederevska Palanka, Serbia, using geothermal water from the well near by factory.

Key words: *geothermal water, heating system, energy consumption*

Introduction

The heating system in mineral water factory "Palanački kiseljak" in Smederevska Palanka, Serbia, was reconstructed so that geothermal water from the well near by the factory is used. The temperature of the geothermal water varies from 48-50 C and flow value is about 2.5 l/s. The indirect geothermal heating system with supplementary heat source with existing boiler is used. With this system geothermal energy meets the basic heat losses, and existing boiler is put into operation only when outdoor temperature is low (less then 3 C) so that geothermal source is not enough to cover completely heat losses. The heated area in factory with this system is about 1000 m^2.

In the period 2003-2005 year undertaken activities were: well stability test of the geothermal well, hydrodynamic analyses of the well, determining physical and chemical properties of the geothermal water and establishing current production and the steady-state filtration regime.

In the following text basic results achieved during realization of this project are presented.

The existing state of PK1-H geothermal well

The well is 931 m deep, cased with steel pipes. The well construction is shown in fig. 1. The steel well pipe 178.2 mm in diameter has its perforated section at the depth

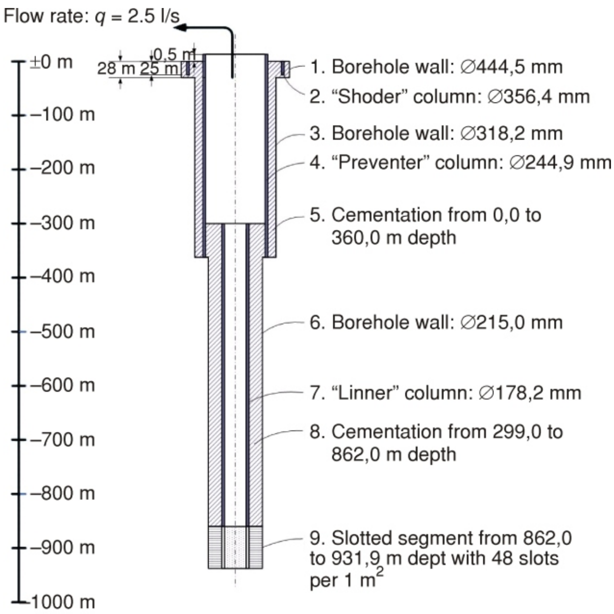


Figure 1. Construction of the geothermal well PK-1/H

from 862 to 931 m. There are 48 perforations per running meter of the pipe to admit water into the well – the intake part of the well.

Company "Naftagas" reported in 1972, upon the well completion, the pressure of 5 atm (positive piezometric pressure of 50 m water column) and inflow of warm mineral water at the rate from 0.6 to 1.79 l/s. The well was hydro dynamically tested in 2002 and 2004. At the end of December 2002, and at October 2004, pressures at the well mouth were 2,5 bar and 1,7 bar, respectively.

Physical and chemical properties of the geothermal water

Water from the well PK-l/H is colorless, salt-acidulous in taste, and slightly sulphur-smelling. Water temperature varies from 48-50 C. The highest ion content is that of hydrocarbonate (HCO_3) within the range from 5.15 to 5.37 g/l. Chloride (Cl) concentrations are between 0.38 and 0.46 g/l. The pH is about 6.5, and total hardness 10 dH. Mineral contents vary within the range from 8.13 to 8.52 g/l, and dry residue at 180 C from 4.63 to 5.29 g/l. The highest contained gas is carbon dioxide (CO_2), from 0.85 to 1.12 g/1. The physical properties, chemical, and gaseous compositions classify well PK-l/H water into the group of sodium hydrocarbonate carbon-acidulous hyperthermal waters. Radioactive constituents are radium (Ra) 0.37 Bq/1, radon (Rn) 18.5 Bq/1, and uranium (U) 0.0003 mg/1.

Langelier and Ryzner index analyzes shows that water have slight scaling and serve corrosion tendency [1-3].

Analyses of the heating system operation

Figure 2 presents the scheme of the reconstructed heating system in the mineral water factory using geothermal energy. Indirect geothermal heating system with supplementary heat source with existing boiler is used [4, 5]. The heating system in the factory, before the reconstruction, consists the following components: boiler (K), heat exchanger (B), circulation pump (P), heat emitting units (G), and the pipeline connecting these components. Reconstruction of the heating system consist installation of the additional heat exchanger (A) on the existing pipeline between points 1 and 2, as shown in fig. 2. The flat type heat exchanger is used with plates of AISI 304 stain steel. This type of exchanger and appropriate material is used because of serve corrosion tendency of the geothermal water.

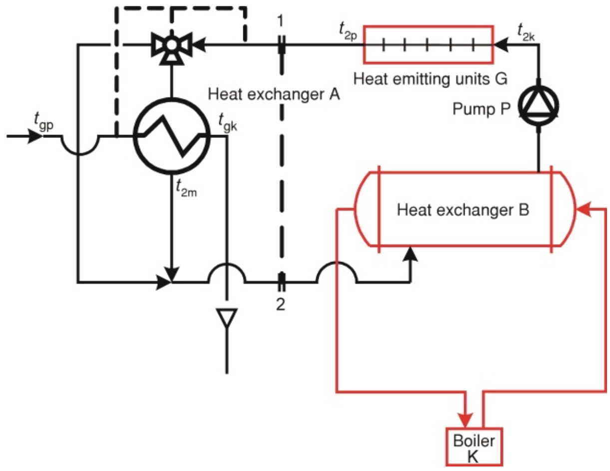


Figure 2. Scheme of the reconstructed heating system in the mineral water factory in Smederevska Palanka

The heat exchanger A is connected to the geothermal source and heat exchanger B connected with existing boiler is now the supplementary source of heat. The circulation pump P ensures a constant water flow rate in the secondary circuit (m_2 = const.). This water is heated while passing through the heat exchangers (A and B) from the initial (t_{2p}) to the final (t_{2k}) temperature defined by outdoor/indoor reset schedule (so-called "sliding regimen" [6]). The heat emitting units (heating elements such as convectors, radiators, *etc*.) provide adequate indoor temperature in the heated object.The temperature of geothermal water as well as the geothermal water flow rate is practically constant during the year (t_{gp} = const., m_g = const.).

Depending on the outdoor temperature, there are three characteristic cases.

(1) The outdoor temperature is high enough. In this case the geothermal source completely meets the required heat losses and the supplementary heat source is not require. Only heat exchanger A operates and there is also excess thermal energy which, if required, can be used for other consumers.

(2) The outdoor temperature is high but not enough. In this case the supplementary heat source is put into operation, so that both heat exchangers (A and B) operate.
(3) The outdoor temperature is low. In this case only heat exchanger B operates and heat exchanger A is shut down because its effective heat duty is zero.

For analyses of heat system two boundary outdoor temperatures are important. The first one is "transient temperature" (t_{pr}) that can be definite as minimal outdoor temperature when only heat exchanger A operates (geothermal source completely meets the required heat losses) and supplementary heat source (heat exchanger B) is not required. The second one is "shut down temperature" (t_{is}) which presents the point when geothermal source (heat exchanger A) is shut down and only supplementary heat source (heat exchanger B) supplies heat energy (case when outlet temperature from the heat emitting units t_{2p} is less or equal with temperature of inlet geothermal water t_{gp}, or $t_{2p} \le t_{gp}$).

Energy consumption analyses of the heating system

For the analysis of reconstructed geothermal heating system (GS) software package for analysis was made. Estimation procedure is as follows.

For every outdoor temperature from nominal (t_{sn}) to critical GS (t_{sprek}) the following parameters are calculated:

$$\frac{\dot{Q}}{\dot{Q}_n} = \frac{t_{2k} - t_{2p}}{t_{2kn} - t_{2pn}} = \frac{t_u - t_{sn}}{t_u - t_s}$$

$$t_{2p} = t_u + \frac{\left(\frac{\dot{Q}}{\dot{Q}_n}\right)^{\frac{1}{1+z}} (t_{2kn} + t_{2pn} - 2t_u) - \frac{\dot{Q}}{\dot{Q}_n}(t_{2kn} - t_{2pn})}{2}$$

$$t_{2k} = t_{2p} + \frac{\dot{Q}}{\dot{Q}_n}(t_{2kn} - t_{2pn})$$

$$\dot{Q} = \dot{Q}_n \frac{\dot{Q}}{\dot{Q}_n}$$

where: t_s [°C] is outdoor temperature, t_u [°C] is indoor temperature, t_{2p} [°C] is outlet temperature from heat emitting units, t_{2k} [°C] is inlet temperature in heat emitting units, Q [W] is heat consumption, n is subscript for nominal (project) conditions, and z is exponent for natural convection.

For specified layout it can be said that in general heat consumption ($\dot{Q}$) is covered with geothermal heat exchanger ($\dot{Q}_{GT}$) and additional heat source ($\dot{Q}_B$):

$$\dot{Q} = \dot{Q}_A + \dot{Q}_B \quad \text{where} \quad \dot{Q}_A = \dot{Q}_{GT}$$

(1) If then $t_{gp} > \; t_{2p}$ then GS will operate with geothermal heat exchanger A with heat duty:

$$\dot{Q}_{GT} \quad \dot{m}_2 c_{p2} (t_{gp} \quad t_{2p}) P_{GT}$$

where: t_{gp} [°C] is inlet temperature of geothermal water, m_2 [kg/s] is flow rate of secondary water, c_{p2} [J/kgK] is specific heat capacity of secondary fluid, and P_{GT} is heat exchanger efficiency [7, 8].

There are two possible cases:

– if $\dot{Q}_{GT} \quad \dot{Q}$ then the outlet water temperature is:

$$t_{2m} \quad t_{2p} \quad \frac{\dot{Q}}{\dot{m}_2 c_{p2}}$$

and heat exchanger must be tuned ($\dot{Q}_{GT} \quad \dot{Q}$) in order to satisfy temperature regime, *i. e.* flow rate of geothermal water through apparatus has to be lowered. In this case additional heat source is not needed ($\dot{Q}_B \quad 0$), and

– if $\dot{Q}_{GT} \quad \dot{Q}$ then the outlet water temperature is:

$$t_{2m} \quad t_{2p} \quad \frac{\dot{Q}_{GT}}{\dot{m}_2 c_{p2}}$$

In this case additional heat source B has to be connected to heating system with heat power:

$$\dot{Q}_B \quad \dot{Q} \quad \dot{Q}_{GT}$$

In order to estimate the influence of chosen heat exchanger A on the usage of geothermal energy the maximal theoretical heat power must be calculated according to:

$$\dot{Q}_{GT\,max} \quad \begin{matrix} \dot{m}_2 c_{p2} (t_{gp} \quad t_{2p}) \text{ for } R_{GT} \quad 1 \\ \dot{m}_2 c_{p2} (t_{gp} \quad t_{2p}) \text{ for } R_{GT} \quad 1 \end{matrix}$$

where R_{GT}, is heat capacity ratio [7], and minimal theoretical power of additional heat source is:

$$\dot{Q}_{B\,min} \quad \dot{Q} \quad \dot{Q}_{GT\,max}$$

(2) if then $t_{gp} \quad t_{2p}$ heating system works only with additional source $\dot{Q}_B \quad \dot{Q}$, and $\dot{Q}_{GT} \quad 0$.

Finally, it is possible to estimate the energy consumption on the basis of the heating season:

$$Q \quad \overset{t_{sprek}}{\underset{t_{sn}}{}} f_d (t_s) \dot{Q}(t_s) \tau_d \quad [\text{kWh}]$$

where: $f_d(t_s)$ [day/year], number of days with outdoor temperature t_s, $\dot{Q}(t_s)$ [kW] heat power of GS when the outdoor temperature is t_s, and τ_d [h/day], working hours of the GS per day.

Heat energy from the heat exchanger A for one heating season (energy savings) is:

$$Q_{\mathrm{A}} \quad {}_{t_{\mathrm{sn}}}^{t_{\mathrm{sprek}}} f_{\mathrm{d}}(t_{\mathrm{s}})\dot{Q}_{\mathrm{A}}(t_{\mathrm{s}})\tau_{\mathrm{d}} \quad [\mathrm{kWh}]$$

where: $\dot{Q}_{\mathrm{A}}(t_{\mathrm{s}})$ [kW], is heat power for outdoor temperature t_{s} ($\dot{Q}_{\mathrm{A}} \quad \dot{Q}_{\mathrm{GT}}$).

Energy from the supplementary heat source B (existing boiler) for one heating season is:

$$Q_{\mathrm{B}} \quad {}_{t_{\mathrm{sn}}}^{t_{\mathrm{sprek}}} f_{\mathrm{d}}(t_{\mathrm{s}})\dot{Q}_{\mathrm{B}}(t_{\mathrm{s}})\tau_{\mathrm{d}} \quad [\mathrm{kWh}]$$

where: $\dot{Q}_{\mathrm{B}}(t_{\mathrm{s}})$ [kW], is heat power of supplementary source for outdoor temperature t_{s}.

Fraction of the geothermal energy in overall heat consumption, on the basis of one heating season, is Q_{A}/Q.

Energy saving of the heating system

Fuel saving based of measured data

In virtue of data of consumption of heating oil it can be concluded that after the introduction of GS system the savings were about 10%, *i. e.* about 250 l of oil per month or 1,5 t per year.

Factory is planning to increase the geothermal heating and to introduce geothermal energy in process of bottle washing. In that case energy savings will be even bigger.

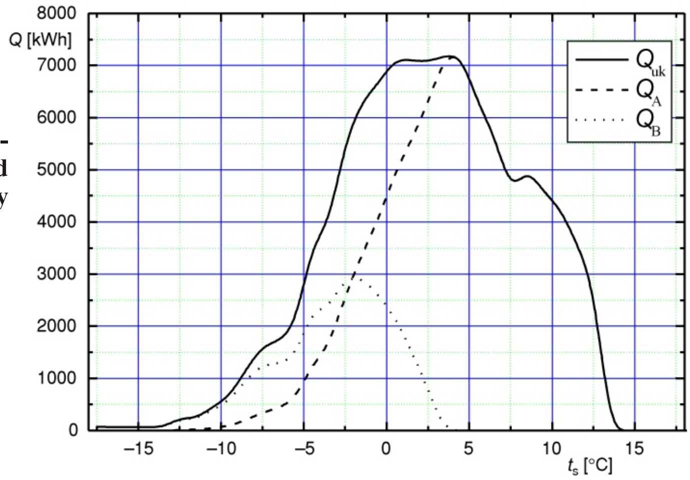
Energy saving analyses of the demo heating system

Analysis of the system parameters show that nowadays when geothermal mass flow rate is 2.5 l/s, and temperature of geothermal water 48 °C, it is possible to save about 7.5 tons of fuel oil per heating season or 82,6 MWh heat energy (assuming heat capacity of fuel oil Hd = 40 MJ/kg).

Existing heat exchanger type TRACO LSL1-42 was tested for critical working regime at outdoor temperature 2,5 °C, when the heat power of apparatus is 37.7 kW, and geothermal water temperatures 48/44,4 °C. When this regime is translated to nominal conditions maximal heat power of apparatus is Q_{n} 92 kW. For outdoor temperatures greater than 2,5 °C geothermal heating system has enough power to cover heat consumption of the heated objects, and there is no need for additional heat source. When the outdoor temperature is lower than –13,5 °C geothermal heat exchanger is disconnected from the heating system and only additional heat source works. It must be noted that, for these calculations, the geothermal water flow rate was 2.5 l/s, heat efficiency of apparatus 0.8, and the nominal temperature in secondary loop 50/70 °C. If the meteorological data are incorporated in calculations it can be concluded that the savings in heating system is 77.28% on the basis of heating season.

Figure 3 presents annual heat consumption of reconstructed heating system in the factory "Palanački kiseljak".

Fifure 3. Annual heat consumption of reconstructed heating system in factory "Palanački kiseljak"



Conclusions

The result of the project is the definition of the methodology for design and construction of the heating systems based on geothermal energy. In the mineral water factory in Smederevska Planaka demo heating system using geothermal water was built. With this system the savings were about 10% or about 1.5 t of oil per year.

According to our calculations:

- nominal heat power of heating system for which the maximal usage of geothermal energy is achieved is 92 kW (if the geothermal water flow rate 2.5 l/s, heat efficiency of apparatus 0.8, nominal temperature in secondary loop 50/70 °C), and
- it is possible to save 77.28% or 82,6 MWh per heating season which is equivalent to 7.5 t of fuel oil with Hd = 40 MJ/kg.

In case that geothermal water flow rate increases to 10 kg/s it can be possible to save about 30 t of heating oil per one heating season. Savings can be even greater if the geothermal energy is used beyond the heating season for fabrication process in factory.

Acknowledgments

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