HEAT RECOVERY FROM THERMAL WATERS USED FOR HEATING BY HEAT PUMP BEFORE BACK-INJECTION

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Abstract

The heat energy recovered from the fluid produced by deep thermal wells is used very economically for heating buildings – covering the heat demand – and supplying utility hot water. After cooling the in-taken fluid must be injected back into the reservoir water layer. The temperature of back-injection is usually equal to that of the return line and the water still contains quite significant energy amount. Before injecting-back this heat energy can be recovered by the heat-pump technology, and fed back into the basic heating system. In this way the very expensive investment of new production and injection wells is avoidable. Authors prove this on the theoretical base and with a practical case in the present article.

Introduction

The thermal water itself for purposes of balneology as well as the inherent heat energy of the thermal water is utilized at a considerable degree today as well. With the increase in prices of conventional energy carriers, its account in the heat-energy market gets higher and higher. The government aims an increased role to the utilization of geothermal energy already in the medium-term planning (*Nemzeti Megújuló Energia Hasznosítási Cselekvési Terv* – National Action Plan on Utilization of Renewable Energy) as well [1]. By the *NCST*, in accordance with the sustainable power-resource management, an especial attention must be paid to the conservation of the natural treasure inhered in the geothermal fluid in the course of building new capacities up which usually requires the back-injection or the further utilization with the suitable purpose.

There is a considerable energy potential in increasing the role of geothermal energy in the heat-supply systems which is already a usual heating way in certain fields in Hungary (e.g. in horticultures) today as well. In the case of utilization of geothermal energy, besides the direct cost of the installation of well and the back-injection, the expenditure of the building of the heat-supply and distribution system is significant due to which the financing conditions often mean a limit factor.

In the present paper, such a method of the heat utilization is discussed which increases the efficiency of the recovery of geothermal energy, helps the sustainability in the view-point of environment protection, and yields a considerable reduction in costs as well.

The energetic professionals, theoretically and in practice, have dealt with the increasing of the efficiency of thermal-water use for a long time. Büki G. has presented a detailed analysis on this topic in the issue of January 2011 of Energiagazdálkodás [2]. Authors, accepting and following the theoretical bases of his work, discuss also the practice of the utilization in the present paper.

Supply for heating demands and peak heat cosumption

Base of investigation

In the example, the (incidentally well operated) utilization of thermal-water heat of an actual country town [1] has been taken as the base and the conditions of the improvement are investigated. (The data base used here does not cover exactly the present situation because the development is continuous in the town. Approaching the real data, authors preferably present a further modernization option.)

Basic data:
Producing well
- Bottom depth of thermal well: 1 462 m
- Maximum temperature of off-take thermal water: 64 to 68 ºC
- Carbonate hardness of off-take thermal water: 303 CaO (30,3 ºdH)
- Maximum volumetric flow rate of production: 130 m^3/h
- Volume of energetic thermal water: 280 000 m^3/yr
- Volume of thermal water for balneology: 80 000 m^3/év

Back-injection well
- Bottom depth of thermal well: 1 600 m
- Gravel-packing of thermal well: 1 309 to 1 333 m, 1 353 to 1 365 m, 1 392 to 1402 m
- The handling diagram of thermal water before injection back is shown in Fig. 1
- Temperature of back-injection: 48 °C

In order to protect the thermal-water resource, it is allowed to inject only perfectly pure fluid (thermal water) back into the reservoir water layer. This requires a suitable storage and filter system (Fig. 1).

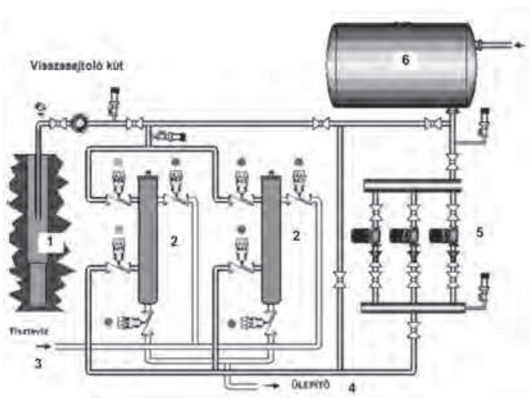

Figure 1. Handling of thermal water before back-injection
1 – back-injection well, 2 – filters, 3 – rinsing filters with clean water, 4 – settling of mineral component and other polluting materials filtered out, 5 – pumps, 6 – storage tank

[1] Veresegyház

Table 1. Data of energy consumption in 2006-2007

Number of consumers in the town	Heating power demand kW	Utility hot water peak demand kW	Utilized geothermal energy GJ	Equivalent natural gas m^3/yr
11	1580	445	14200	406000

Starting from the above basic data, the calculations were carried out; Table is shown with the purpose of control.

Goal: *Cooling the fluid with high temperature of back-injection; utilization of the heat quantity gained in this way and improvement of the system with this; and, instead of new improvement by well drilling, creating a system that better assists the sustainability*

Thermal-water heating and heat pumping before injecting back

Heat pumping for peak power

Fig. 2A shows the heating purpose utilization in the town taken as an example in the basic case. Eventually, by a simplex heat exchange (Fig. 3), the off-taken heat is used for purpose of heating and utility hot water.

If one would like to utilize the remnant heat content before the back-injection, the heat pumping technology should be applied (Fig. 2B). According to the capacity of the operating well, the mass flow rate of the output thermal water is $\dot{m}$ = 27.7 kg/s (1000 m^3/h) and its temperature is T_{TK1} = 68 °C (Fig. 4). In peak periods, the temperatures of heating water are T_{FE}/T_{VF} = 58/38°C; for the sake of simplicity, its mass flow rate is taken equal with the former value.

In the basic case, the output thermal water is cooled down to T_{VSO} = 48 °C ($\dot{m}$ = thermal water, $\dot{m}_{fv}$ = mass flow rate of heating water).

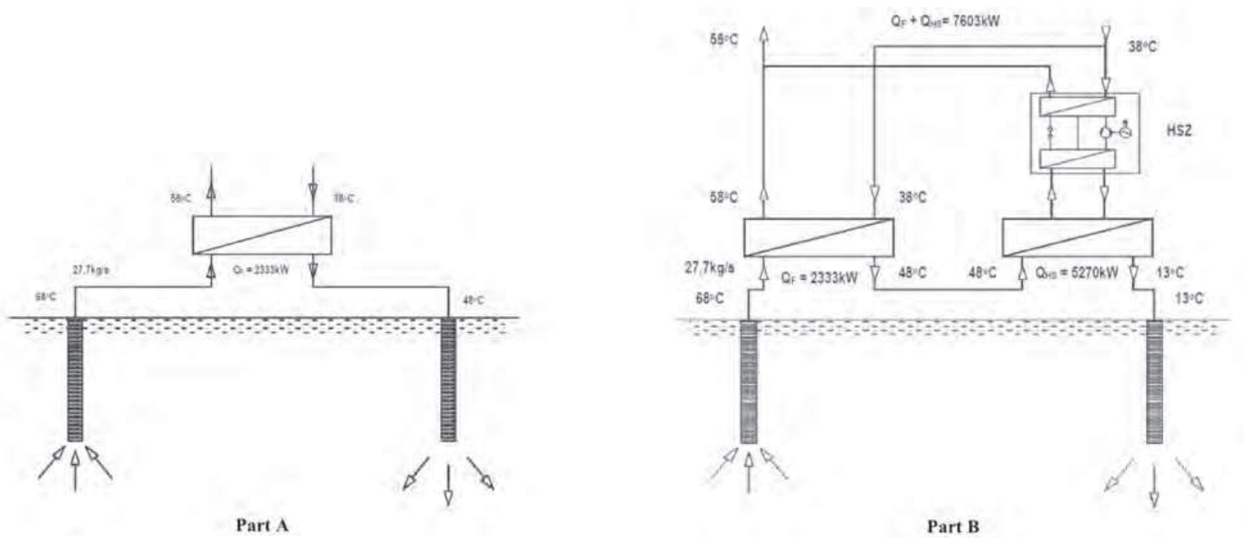

Figure 2. The original (A) and the „improved" version (B) (fulfilling the increased demands)

In case "A", the heating peak power is provided by this thermal water:

$$Q_{ACS} = Q_F = \dot{m}c(T_{TK1} - T_{VSO}) = 27{,}7 \cdot 4{,}2(68 - 48) = 2333 \text{ kW}$$

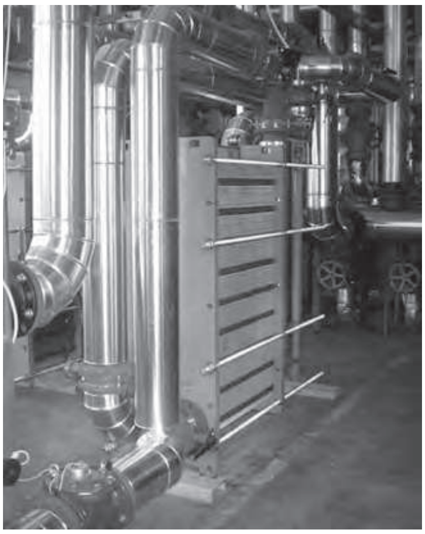

Figure 3. Plate heat exchangers before the heating circuit

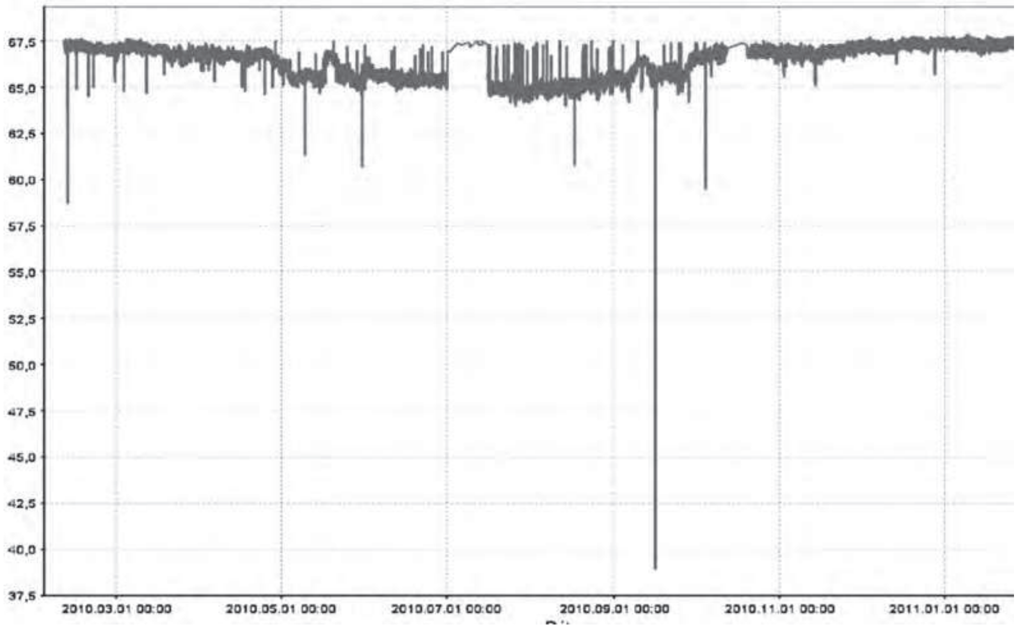

Figure 4. Temperature of thermal water

In the system with heat pump (B), the effluent thermal water of 48 °C temperature from the direct utilization is cooled down to about T_{vsi} = 13 °C temperature and the heating water can be heated up from the return temperature of 38 °C to the outgoing temperature of 55-58 °C. (The heating-water temperatures are equal to those of the heating water produced directly by thermal water.) With these temperatures, the coefficient of performance (COP) of the heat pump is relatively well estimable:

$$\varepsilon_f = (COP =) \frac{T_{FE}}{T_{FE} - T_{VS1}} \nu = \frac{331}{331-286} 0,6 = 4,4$$

ν = 0.6 is the loss factor

With this, the heating power of the heat pump is –

$$Q_{HSZ} = \dot{m}c(T_{VSO} - T_{VS1}) \frac{\varepsilon_f}{\varepsilon_f - 1} =$$

$$= 27,7 \cdot 4,2(48-13) \frac{4,4}{4,4-1} = 5270\ kW$$

Consequently, this value is 2.25 times greater than the achieved heat power in the basic case (A; direct heat utilization). The two cases together perform –

$$Q_{EGY} = Q_F + Q_{HS} = 2333 + 5270 = 7603\,\mathrm{kW}$$

The heat-power value with the peak heat power increased to 2.4-fold of that of the basic case.

In sum, the heat pumping results in a significant increase in heat content and better utilization of the thermal water as well as a lower temperature of the fluid to be injected back. The coefficient of performance can be considered as an advantageous value.

Heat pumping of thermal water at partial load

The value of the coefficient of performance is greater during the year than that in the peak heat-power season. Fig. 5A demonstrates the required degree of heat pumping as a function of external temperature while Fig. 5B – as a function of user demands during the year. (For the better perspicuity, the utility-hot-water supply is neglected.)

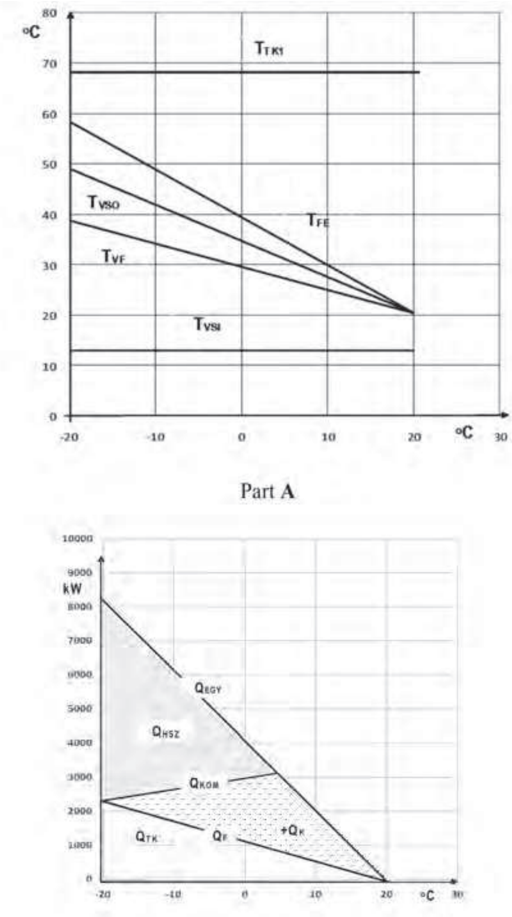

Figure 5. Temperature values of the thermal water and the heating (A), and the heat performances (B) as functions of the environment temperature
(with the original and the heat-pump solution)

Line $\dot{Q}_F$ indicates the heating power in the basic case and line $\dot{Q}_{EGY} = 4{,}4\dot{Q}_F$ – in the case of heat pumping. The heat power performed by thermal water with mass flow ṁ is –

$$\dot{Q}_{KOM} = \dot{m}\,c(T_{TK1} - T_{VSO})$$

The running of the heat pump ceases when the thermal water alone is capable of covering the actual heat demand loading the net:
and expressing it with temperatures –

$$\dot{Q}_{KOM} = \dot{Q}_{EGY} \text{ that is}$$

$$\dot{m}\,c(T_{TK1} - T_{VSO}) = 3{,}4\,\dot{m}\,c(T_{FE} - T_{FV})$$

The searched value is at about 4 °C environment temperature.

$$T_{FE} - T_{VF} = \frac{T_{TK1} - T_{VSO}}{3{,}4}$$

The heat demands covered by thermal water is indicated by the range Q_{TK} in the basic case, and the range $+Q_K$ in the case of heat pumping while the part Q_{HSZ} shows the heat demand covered by heat pumps. According to Fig. 6, the demand for heat production by heat pump (Q_{HSZ}) will be of shorter period while the direct heat use of thermal water increases in the extended heat demand in a year. (This means also that, instead of heat pumps due to the lower use efficiency, natural-gas boilers could be applied for the peak load as well; this would result in a bivalent system.)

With the same equipment, the value of coefficient of performance increases with the decrease in heat production. Fig. 7 shows the temperature (T_{FE}) of hot water produced by heat pump and the consequently expected changing in the coefficient of performance.

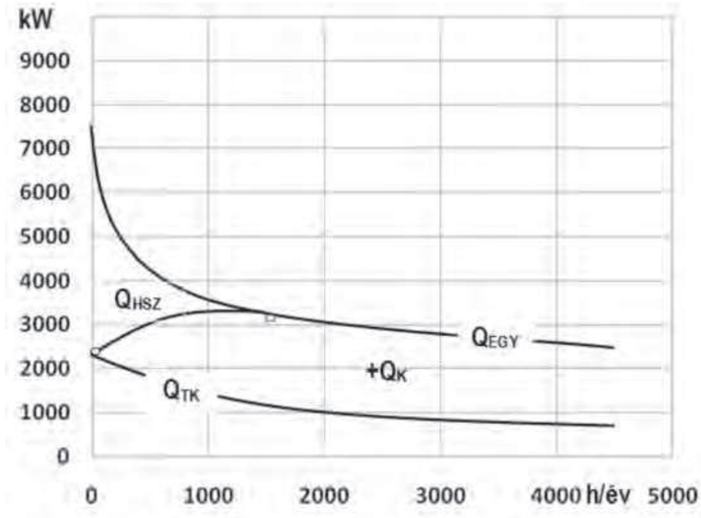

Figure 6. The load-duration diagram of the heating year with and without heat pumping

$$\varepsilon_f = COP = \frac{T_{EGY}}{T_{EGY} - T_{VS1}}\nu$$

It appears from the figure that the annual average coefficient of performance (seasonal performance factor $\bar{\varepsilon}_f = SPF$ – already not a performance ratio but really the gained-to-input energy ratio in kWh/kWh) considerably betters the peak-season coefficient of performance.

$$\bar{\varepsilon}_f = \frac{Q_{HSZ}}{E} > \varepsilon_{fcs} = \frac{Q_{HSZcs}}{P_{cs}}$$

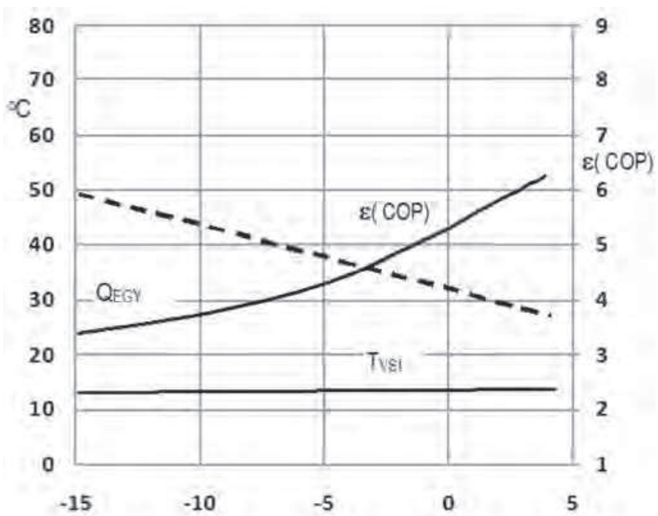

Figure 7. Changing in coefficient of performance of the peak-load heat pump

Energetic characterization of heat pumping

For the correct evaluation, the efficiency of the consumed electric energy has to be compared with that of the modern gas heating.

The electric energy input of the heat pump is E_V and the energy content of the used natural gas is E_G.

The efficiency of the input electric energy is $\eta_E = E_V/E_G$.

The efficiency of the natural-gas is η_K.

The annual average performance coefficient must exceed the ratio of the two efficiencies (Büki, 2010) [7]:

$$\bar{\varepsilon}_f > \frac{\eta_K}{\eta_E}$$

For the account of the consumed electric energy [7], the recovered geothermal heat can be considered as renewable energy if the average performance coefficient is –

$$\bar{\varepsilon}_f > \frac{1{,}15}{\eta_E}$$

This means that the heat production with heat pump has to be compared only with the condensation boiler of the best efficiency.

The efficiency of the heat production by heat pumping obviously increases with increase of the performance coefficient of the heat pump and electric-energy generation [7]. In the case of the further cooling of the thermal water, approximately an average coefficient of performance (COP) of 4 to 4.7 is gained which is 60 to 80 % of the achievable value (see Fig. 7).

Economical advantages

What does it mean in an actual case for the user in operating costs or in initiating a new improvement (according to the concrete example of the chosen settlement)?

In the heating season, the heat performance as an average is 3200 kW (Fig. 6) or 11 520 MJ/h. With the natural gas of a heating value of 34 MJ/m^3, this means a gas consumption of 434 m^3/h (with 100 % boiler efficiency). With the price of 136 Ft/m^3 of natural gas and in the case of 4500 h/year use, the heating cost is 207.2 million Ft per year.

With heat-pump heating, the electric-energy consumption is 3200/4,4COP = 727 kWh. If the energy price is 31.50 Ft/kWh, the energy cost per year is 103 million Ft in the season of 4500 h/yr.

The difference of the two values is the saveable sum by heat pumping – 104.2 MFt/yr. The investment cost of the heat-pump system itself (with e.g. 5270 kW, about 520 million Ft as a total) recovers in 5.8-6.5 years in comparison with the gas heating

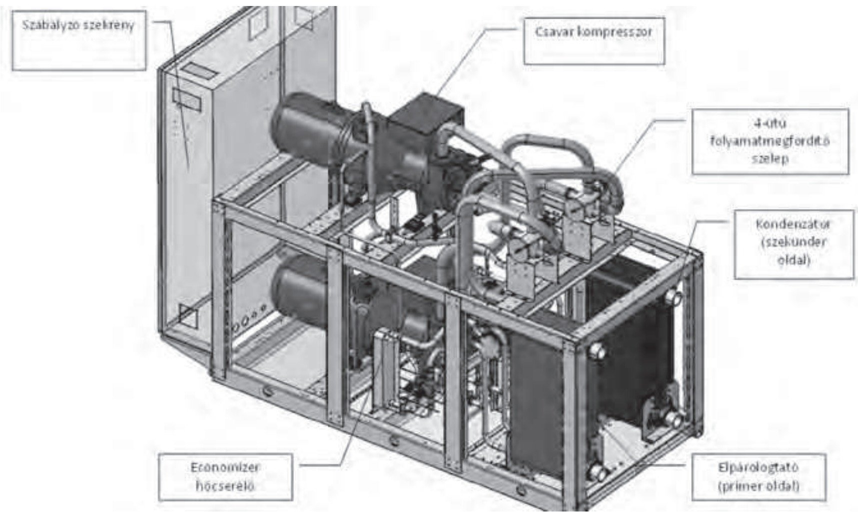

Figure 8. Construction of a modern heat-pump unit

A *further investment* advantage is that the planting of 2 new well units fit to the maximum performance (i.e. 4 well-drillings together with the back-injection) gets needless; the invested cost would be 2 to 2.5-fold of the installation of heat pumps.

According to NCST, a discount electric-energy tariff is applied in the case of utilization of geothermal energy by heat pump that improves its economical advantage. At the same time an extra regulation can be expected that "The estimated annual SPF value must be minimum 4.2 with the heat pumps built on the base of ground heat probes, ground collectors and ground water wile 4.0 with other heat pumps – certified by the adequacy declarations of the manufacturer and the project manager". It must be taken the total amount of the electric energy consumed during the heating season into consideration for calculating the values of SPF – the electric energy used for cooling must not be taken into account.

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