János SZANYI
Tamás MEDGYES
Balázs KÓBOR
Csilla TARI
András BÁLINT
University of Szeged
szanyi@iif.u-szeged.hu

Technika Poszukiwań Geologicznych
Geotermia, Zrównoważony Rozwój nr 2/2014

EXPERIENCES WITH GEOTHERMAL WATER INJECTION INTO POROUS AQUIFERS

ABSTRACT

Due to certain favourable geological features of Hungary, the utilization of geothermal energy is realized through the availability of a great quantity of geothermal water. Consequently, the disposition of the used geothermal water is a serious challenge, and injection is probably one of the most controversial issues of geothermal energy utilization in Hungary. To date, there is no definitive regulation for this issue.
In order for some common system of criteria to be definable for the optimum operation of geothermal projects in the region, and especially for injection into sandstone, this study has compiled the operational experiences of a number of already functioning systems to summarize the best practices of sustainable operation.

KEY WORDS

Injection, sandstone, geothermal system design, well construction, filter technology

* * *

INTRODUCTION

Geothermal energy is a reliable and environmentally favourable energy source that is used in many countries for electricity generation and direct heating purposes with significant economic and environmental advantages. In spite of being a renewable energy source, geothermal energy is not inexhaustible. If overexploited, the reservoirs may become exhausted and their recovery requires a long time (Gringarten 1978). The long term utilization of a reservoir requires optimal operation and the thorough knowledge of geological, hydrogeological, and geochemical features. Injection is, in most cases, an essential element of sustainable operation (Malate 2003; Bálint 2010).

Injection is a complex, multi-parameter procedure used during the utilization of geothermal energy and refers to the placing of used geothermal fluids into geological formations. There are two types of reservoirs from the point of view of geothermal energy utilization – fractured, karstified aquifers and porous reservoirs. These aquifer types behave differently during injection. This paper focuses on the technical challenges of injection into sandstone, but suggests that injection can – and in a number of cases should – be used in fractured rock formations too.

In the case of Upper Pannonian sandstone aquifers, diversified geological and hydrogeological conditions are encountered. It can be stated that there are no two systems with identical micro and macro environments. In order for some common criteria to be definable for the optimum operation of geothermal projects in the region, this study has compiled the operational experiences of several already functioning systems.

OPERATION OF GEOTHERMAL SYSTEMS

The lifetime of a geothermal project can be set to 50–70 years by proper maintenance activities carried out in due time. The rotating parts (pumps, compressors, etc.) need to be replaced or renovated every 8–12 years, depending on their wear. Unfortunately, only a few of the currently operating systems in Hungary are subject to periodical maintenance, and operators usually carry out only casual troubleshooting activities. The general operation of existing systems can be summarized as follows.

Booster pumps in the engine room pump the degassed medium from the reservoir through pipelines to consumer heating stations (in the case of a few new geothermal projects, the deaerated gas content is collected, cleaned, and used in gas engines for cogeneration purposes). The average yield in winter is a max. 15–25 l/s, and in summer max. 2–10 l/s. The long pipeline network with a narrow cross-section experiences a significant pressure drop of 5–10 bars (depending on the length and diameter). This drop in pressure is to be considered during the selection of the pumps' specifications. The booster pumps in many operating systems operate at a constant rotational speed in a stationary mode. In modern systems, the operation with frequency converters of the booster pumps is controlled by the automatic pressure control system of the pipeline.

In a number of older systems, the heating medium is directly transported through the radiators without any kind of control. The motor valves in the modern consumer heating stations are controlled by consumer heat demands (local temperature-dependent control systems) and transmit the heating medium to the heat exchangers at an amount that satisfies the actual heat demand. Any increase in the heat demand of the consumer systems results in the opening of the relevant motor control valve, a drop in the supply pressure, an increase in the speed of the booster pump in the well's engine room, and the entering of more heating water into the system. The resetting of water production takes place when the heat demand decreases.

In older geothermal systems, the facilities to be heated are able to harness only a part of the medium's thermal content, thus the cooled medium is still hot on occasion. New systems are designed to arrange the consumer network into cascade systems, and the heating circuits with different temperature needs are aligned in the system in order to harness the full heat capacity of the geothermal water. There are many new examples of the following theoretical cascade system in urban communal systems in Hungary (Fig. 1):

1. Urban district heating system – temperature difference of 85/60°C.
2. Independent urban institutions – temperature difference of 60/40°C.
3. Heat supply of urban public bath and its pools (direct feed into the thermal baths in spas) – temperature difference of 40/28°C.
4. Frost and snow removal from public areas – temperature difference of 28/5°C.

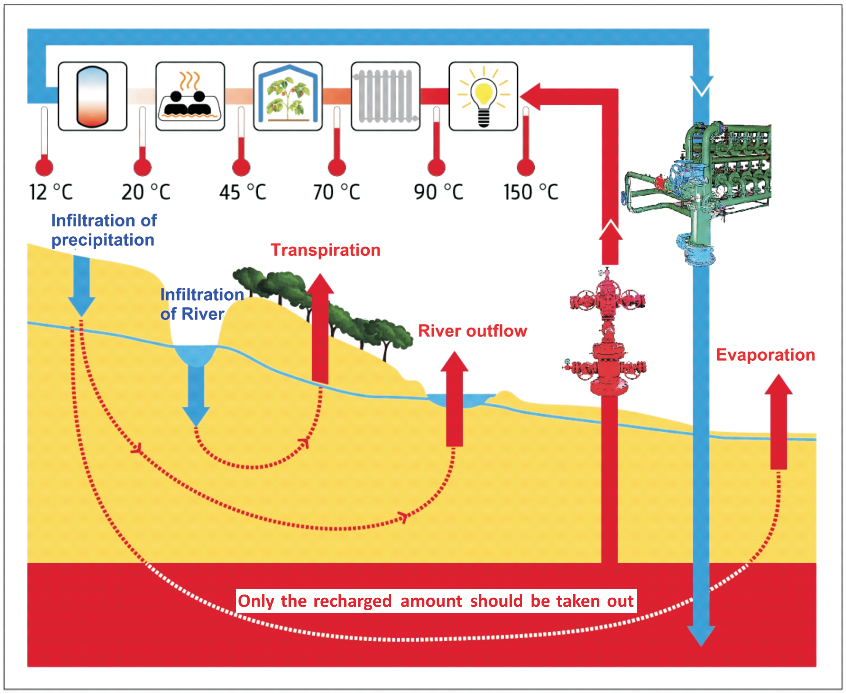

Fig. 1. The optimal cascade geothermal system (Szanyi et al. 2012)

Rys. 1. Optymalny geotermalny system kaskadowy (Szanyi i in. 2012)

The secondary medium of one user appears as the primary medium in another user. This cascade system guarantees the utilization of the extracted geothermal water from a production temperature of 80–90°C down to a temperature of 5–10°C, reaching a total thermal capacity of around 7 MW.

From the last consumer (e.g. pool heat exchanger), the cooled geothermal water reaches – in compliance with the water rights permit – either the over ground recipient (cooling tank, wastewater or rainwater channel, fresh waters, rivers, etc.) through the return pipeline with the help of the installed booster pumps, or the injection buffer tank through an injection pipeline. From the injection tank, the adjacent injection pumps pump the cooled fluid through an over ground filter system and through the injection well into the deep reservoirs close to the production site. The tank's water level controls the operation of the injection pumps.

Geological and technical issues

The chemical composition of waters is defined by their origins, mixing, and the interaction of solute components with rocks and gasses. The chemical composition of the water is an important factor of water production, utilization, and disposition.

Beside the inorganic compounds, the organic content of the sediments also plays an important role in the development of the geothermal water's chemical quality. Due to the high temperature and the long contact time, the dissolved matter content of geothermal waters increases and can contain components that do not occur in younger, shallower, and colder waters. When the equilibrium condition existing between the pore surface and the fluids is disturbed during production by primary and enhanced recovery processes, the mineral matter may dissolve and generate many different ions in the aqueous phase with fine particles being unleashed from the pore surface into the fluid phases. The mobile ions and fine particles in the pore space interact with each other in intricate ways and create severe reservoir formation damage problems (Civan 2007). These territory- and depth-specific factors influence the concentration of solute components in the water in various ways and to different extents.

There are many technical issues related to injection wells that pose serious problems for designers, investors, and constructors. According to the current national regulation for already operating energy systems, the cooled water has to be injected into the same formation it was produced from, creating an equilibrium for the water balance. The demand for temperature equilibrium in the long term is the contrary of that, since it would be more practical to inject the water into different layers so that the producing layer would not be cooled down by the injected, used water (in the case of systems which operate only in wintertime, e.g. district heating systems, the problem is smaller, since the producing layer is at rest during the summer operating break allowing it to be reheated). Good design and high quality construction of production and injection wells are needed to overcome this contradiction. The following section presents a few problems related to the construction of injection wells.

– The positioning of production and injection wells is economical if the wells are close to each other due to the need for a shorter pipeline system. However, the location of the wells cannot always be optimally selected, e.g. due to the built-up density. At the same time, thermal breakthrough can occur in the case of wells positioned too close to each other.
– In some cases, a well that was designed for injection produces more water than (the possibly older) production well does, and the investor / operator may want to change the purpose of the wells in contradiction with the authorization.

- The quality of the produced water can be a serious problem too. When the water quality of the two wells is very different, or one layer contains unwanted impurities (e.g. hydrocarbons), the used geothermal water must be injected into the same layer it was taken from or it may have to be filtered, as the mixing of the waters of the two wells is not advisable.
- The precipitation of the different components from the produced water due to a drop in temperature and pressure can pose further problems. Gas can be partially eliminated by continuous separation, or it can be kept in solution during heat exchange by maintaining the proper pressure; however, the separation of certain salts and other precipitations cannot be avoided even in professionally constructed, perfectly closing systems, and these can cause serious difficulties during injection. These factors result in an important role for experts in hydrochemistry as well as in filter design.

These problems occur differently in the case of wells built onto fractured karst and sandstone. In karstic formations, even with cautious planning, there is a high risk for a newly constructed well to have poor water-bearing/absorbing capacity. On the other hand, in the case of sandstone, the creation of an optimal filter frame is of high importance since the clogging of the filter frame during injection can pose serious problems. The next section shows a case study of a malfunctioning injection well operated on a sandstone reservoir.

Special problems of injection wells

Injection wells are similar to production wells, but there are several legal, technical, measurement, and construction related problems that arise only with injection wells.

Oil industry operators in Hungary have injected media from water wells for decades to replace collected hydrocarbons in order to maintain layer pressure. The injection technology in the oil industry – due to extra high operational pressures and related expenses – could not be used economically for geothermal systems, and early attempts by the geothermal industry to invent new technologies for injection of geothermal waters into sandstone had been unsuccessful, too. The coaxial geothermal well in Szentes, the geothermal well constructed with traditional perforation in Szarvas, and at the slant production-injection couplet in Szeged are all examples of ill-conceived or poorly executed injection attempts in Hungary. The main reasons for failure were low quality well design and construction, and the poor standards of operation and maintenance.

The currently operating wells were usually built with the following pipe structure (example for the piping of a 2,000-m-deep geothermal production well, external diameter/internal diameter):

- 365/352-mm diameter until 60 m (standpipe),
- $9^5/_8$″ (244/227-mm) until 800 m,
- 7″ (177/162-mm) until 1,800 m,
- $4^1/_2$″ (114/100-mm) until 2,000 m (filtered pipe section).

The pipe structure is relatively narrow, which is excellent for the production of yields of 15–25 l/s. However, it is not suitable for the slow injection of the same amount of fluid into pores of micron size.

In the case of injection wells built on sandstone reservoirs, high injection pressure means extra energy needs. Very often during long term operation there comes a time when the well cannot absorb the necessary water quantity, or the rock frame gets damaged by the great amount of water flowing in at high speed. The following section describes the case of a malfunctioning injection well operated for years and inspected several times during operation (Fig. 2).

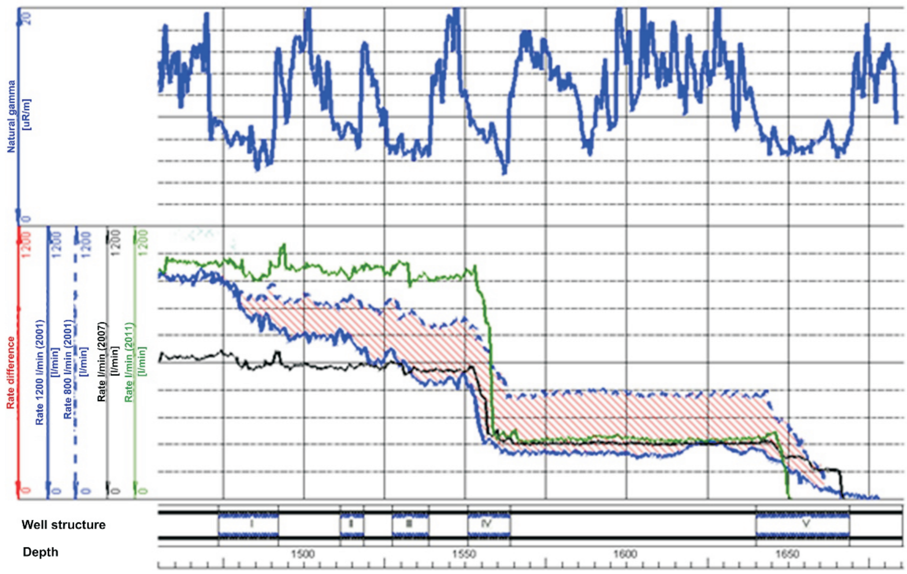

Fig. 2. Multiple inspections of an injection well

Rys. 2. Kontrole różnorodnych parametrów otworu zatłaczającego

The injection pressure increased during the operation of the well, and the flow measurement showed that the two lower filters produce 76%, and the upper three 24%. After acid washing and cleaning, the rate improved – the upper three filters produced 47%. Figure 2 shows that all filters are in good quality sandstone according to the natural gamma ray log, thus each filter should function at approximately the same rate. This was almost realized after the regeneration of the well (2nd measurement). After a few years, the injection pressure rose again. According to the flow measurement, the upper three filters produced only 10%, while filter no. IV produced almost 2/3 of the total yield (3rd measurement). Four years later, the situation worsened; the upper three filters did not produce at all, filter no. IV produced 74%, and filter no. V 26% (4th measurement). The production of filter no. IV became more and more punctual, and the bottom of the well filled up to the middle of filter no. V. All these facts indicated that there had been a filter break at the top of filter no. IV. The reason could be that almost all the filters became clogged during the years of operation and the water had to be injected through a smaller active filtering section with increasing pressure, and this caused the breaking of the filter. It is clear that the condition of injection wells has to be continuously monitored and inspected, and the necessary interventions, e.g. regeneration of the filter (frame), carried out in time.

PRINCIPLES OF INJECTION TECHNOLOGY

Construction principles of injection wells

The contemporary construction equipment and technology of geothermal wells are usually far less sophisticated than the machinery used in the oil industry. The main driving force of geothermal operations is the reduction of expenses, which has a negative impact on the quality of construction and the cleanness of the sludge technologies, and can cause irreversible damage in the absorbing passages.

In many instances the filtering of the media to be injected and the dynamics-free operating conditions are not rendered enough attention. These situations also lead to premature blockage of the pores and the sporadic collapse of the formation frame.

With regard to these facts and the theoretical issues of injection, the following aspects are to be considered during the design and construction of injection well structures:

- The well structure has to comply with the optimum energetic and hydrodynamic requirements.
- Accurate deep filtering and filter frame stabilization technologies are to be applied.
- The pollution of the water-bearing layers must be avoided during the well drilling.

Based on experience, a 2,000 m deep geothermal injection well constructed on a sandstone aquifer should have the following structure:

- 20″ (508/488-mm diameter) until 60 m (standpipe),
- $13^{3}/_{8}$″ (340/320-mm) until 800 m,
- $9^{5}/_{8}$″ (244/227-mm) until 1,800 m,
- $5^{1}/_{2}$″ (140/126-mm) until 2,000 m (filtered pipe section expanded).

Figure 3 shows that the pipe diameters of the suggested well structure are larger than the “classic” production well pipe diameters. This well structure allows the increase in the weight and volume of the water column, a fact that plays an important role in the moderation of the flow velocity and turbulence of the fresh media and of the demand for surface pressure boost. Furthermore, it enables the accurate installation of the washed, classified bed of gravel into the borehole below the filter pipe (320 mm), enabled by the 4.35-cm-wide (227-140/2) opening between the two lower pipe columns.

During the well construction, the sludge treatment and technological activities of the drilling works must be carried out and supervised by professional companies with excellent references. This guarantees the cleanness of the works and the safety of pores. The com-

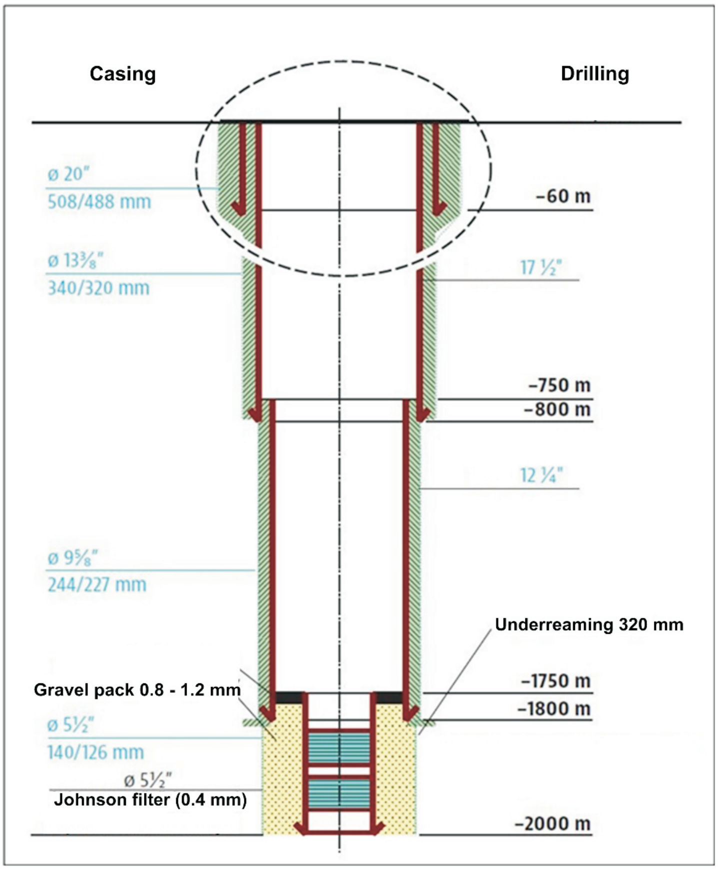

Fig. 3. Suggested structure of a 2,000 m deep geothermal injection well

Rys. 3. Sugerowana konstrukcja otworu chłonnego o głębokości 2000 m

pression of gravel instead of the gravitational technique is also an obligatory requirement during the creation of the deep gravel filter. The injection well can be further optimized through the widening of the well structure and with the use of a 7″ filter pipe. The larger the diameter of the lower charge to be filtered and the higher the number of water absorbing layers that can be filtered, the greater the permeable cross-section; thus the flow velocity of the fluid entering the layer is reduced.

The current well construction technologies enable the placement of a bed of gravel of several hundreds of metres in the underreaming, if the leaning of the well can be minimized. It is necessary to strive to connect as many filterable layers as possible, based on the geophysical measurements, and making it possible to increase the absorption capacity by low injection velocity. The most important injection-related requirements can be fulfilled with the observance of the above-mentioned aspects.

Surface filtration, the filter prototype

Sandstone reservoirs in Hungary – especially those of Upper Pannonian sandstones – are less cemented, meaning that they are of low or medium solidity. They have a relatively high clay content and badly classified grain sizes, thus they are caving, and the probability of blocking is very high. Due to the modification of the chemical or physical features of the geothermal water during cooling and traveling in long, aboveground pipelines, the water to be injected can contain a great amount of suspended matter. As a result, surface and deep filtration, scale formation, and/or other precipitations and organic separations can occur in the area of the injection. The above phenomena, combined or separately, can result in the presence of migrating solid materials in the formation. It can be stated that the accurate treatment and the surface and deep filtration of the medium to be injected are pillars of the sustainability of injection. The bed of gravel, as an artificial filter, carries out the deep filtration. The final surface filtration technology is influenced by hydrochemical analyses and test run experiences with the geothermal system. The filtration capacity depends on the pore size of the sandstone. The blocking of passages with a diameter of 10–15 microns can be avoided with the presence of floating matter smaller than 10 microns. Metal filters are not suitable for this, thus they have to be installed in combination with other filtration technology.

The suggested filtration technologies are as follows:

- Mechanical (strainer) metal filters that catch the larger impurities and waste materials.
- Cloth filters combinable with mechanical filters to catch micron-sized pollutions. They can be connected by filtering capacity, increasing the efficiency and safety of the filtration.
- Gravel filters or sand filters, where a classified and washed bed of gravels in a steel tank catches all the impurities. This technology enables the counter-current washing of the filtering material, thus allowing periodical cleaning and regeneration.
- Hydrochemical filtration systems.

The location of the filters should be near the injection well in an environment that allows for maintenance at any time and in any weather (e.g. in the well's machine room). A main feature of the studied geothermal systems and of the majority of the geothermal waters inspected during the course of this analysis is that the alteration of their physical features (pressure and temperature change) can be accompanied by the formation of precipitation, a fact that requires the installation of several filtration points within the system. The final, fine surface filter has to be installed near the injection well. This ensures that the eventual precipitations and detachments in the pipe section after the filter cannot reach the well.

This research has resulted in the design of a new filter (TF-I / patent pending) built based on operational experiences and feedback from maintenance personnel. It is the horizontal combination of a metal filter and a cloth filter (Fig. 4). The new filter consists of the following units:

– 1 steel frame
– 12 filter cartridges complete
– distribution line
– 1 collecting line
– 2 butterfly valves
– 12 ″ ball taps
– 1 remote pressure gauge, 0–6 bars
– Fitting elbows, pipes, fittings, appliances

Fig. 4. TF-I filter system (patent pending)

Rys. 4. System filtrów TF-I (oczekujący na opatentowanie)

The filter system consists of 2 × 6 pieces of 1,310 mm long steel cartridges with a diameter of 219 mm that were placed horizontally onto a steel frame. The height of the frame allows comfortable filter maintenance. According to the specifications of the filter system, one cartridge is able to filter 8–10 m^3 of precipitating geothermal fluid per hour. The TF-I system is designed for the continuous filtration of 60 m^3 of geothermal water per hour, based on operational experiences with working geothermal systems and the operational results of the current research and development analyses. Each cartridge contains a steel filter frame with a 3 mm perforation, a length of 1,200 mm, and a diameter of 133 mm (the quality, precipitation, and "operation" of the geothermal water defines the dimensions of the perforation; a smaller perforation can be blocked faster by scale formation). The filter frame is welded to the blank flange of the cartridge. A fitting elbow connecting to the collecting line is welded to the other side of the flange. The blank flange closes onto the cartridge with a gasket and is fastened with eight releasable screws. The fine filter of the system is pulled over the filter frame. This is a cloth bag with an internal diameter of 130 mm and a filtration capacity of 10 microns. It is fastened with a releasable aluminium clamp. The material of the cloth bag is closely woven felt. The distribution line of the system can be found above the steel cartridges, connected by welding to the sheath of each cartridge. One piece of remote pressure gauge (6 bars) is installed on the common pipe section before the filter. The reinforcement of the welded frame allows the moving of the system by crane or forklift truck.

The operation of the filter system

During continuous operation, the fluid to be filtered arrives to the filtering distribution line, is filtered, and flows through the open block of 6 cartridges to the collecting line. The taps of the other block of 6 cartridges are closed.

The filtered fluid flows back to the pipeline network or to the injection wellhead. The critical value of 5–5.5 bars at the pressure gauge before the filter cartridges indicates an impurity clogging the filter bags. In such cases, continuous filtration can be guaranteed with the elimination of the first block by opening the taps of the other block of 6 cartridges. When switching to the new filter, the pressure on the gauge drops, and the filter frame with the filter bag can be removed from the contaminated filter cartridges (Fig. 5). The cartridge and the filter frame can be cleaned (with a high-pressure cleaner), and the cloth filter can be washed or changed.

The maintenance periods of the filters are defined by the composition, separation features, and the hydrochemical parameters of the filtered medium. When the critical pre-filter pressure is exceeded, the impurity may pass through the cloth filter and pollute the deep filters of the injection well.

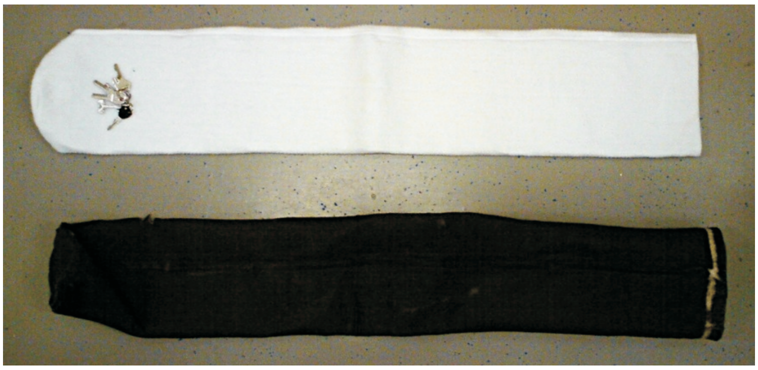

Fig. 5. Cloth filter before (above) and after usage (down)

Rys. 5. Filtr tkaninowy przed (na górze) i po użyciu (na dole)

The injection pump system

The injection pump system includes one or several hot water pumps that can be operated within a wide range of the number of revolutions (Fig. 6). With today's modern pumps, it is sufficient to have one reserve pump beside the operating one. The following aspects are to be considered for selection of the pump's dimensions:

– optimum quantity delivered to the work point,
– for $5^1/_2''$ filtration, maximum 40 m^3/h,
– for 7″ filtration, maximum 60 m^3/h,
– pumping head – maximum 60 m,

– controllable pressure range – 1–6 bars,
– minimization of current consumption.

The injection pumps can be installed in the direct vicinity of the well, or in the machine room located several hundreds of metres away from the well. The solution is adapted to the power supply, the acceptance potentials of the used water, and the site features.

The heavy and light current control system is an important element of the injection technology. It supplies electricity to the pumps, protects the engines, guarantees compliance with the safety and security requirements, facilitates the efficient, economical, and automatic functioning of the injection, and supports a telemonitoring system. It consists of an electric control cabinet, heavy current appliances, an ammeter system, a frequency converter, a PLC, a remote water flow meter, a remote thermometer and pressure gauge, a lighting system, and a security camera and alarm system.

Fig. 6. Injection plant: wellhead, filters, pumps

Rys. 6. Zakład zatłaczający: głowica odwiertu, filtry, pompy

Buffer tank

The steel or waterproof reinforced concrete buffer tank installed on the ground surface or sunk underground is an essential unit of the injection plant. Its purpose is to ensure the uniform and fluctuation-free operation of the pumps. The upper cleaning hole and the lower discharge system enable the periodical cleaning and draining of the tank.

In the case of indirect geothermal utilization technologies (the fluid is produced at bubble-point pressure, followed by a "heat exchange" and quick injection, while a secondary pipeline system supplies heat for the consumers) the buffer tank can be eliminated.

The operation of the injection plant

The used geothermal fluid – with quantities varying by different temperatures – arriving from the heating consumers through the pipeline is received by the buffer tank. Here, the solid impurities are eventually deposited.

The tank's water level regulates the operation of the injection well. Accordingly, when the predefined water level is reached, the frequency converter starts to increase automatically the pump's number of revolutions at a very low speed. The maximum pump revolution (50 Hertz) can be reached in 60 seconds. The opposite occurs when the water level drops under the switch level; the pumps stop slowly. The purpose of this regulation is the creation of a system close to a stationary, fluctuation-free, and dynamics-free operation, which is ideal for the well's operation.

The pump pumps the fluid through one part of the surface filtration system (six cartridges) and through the wellhead to the filtered deep layers.

The gauges installed in the system measure the following parameters:

- water level of the buffer tank (mm),
- pressure before the surface filter (bar),
- pressure after the surface filter (=wellhead pressure (bar)),
- fluid temperature (°C),
- injected quantity (m^3/h).

The PLC records the parameters and forwards them to the PC in the control centre (Fig. 7).

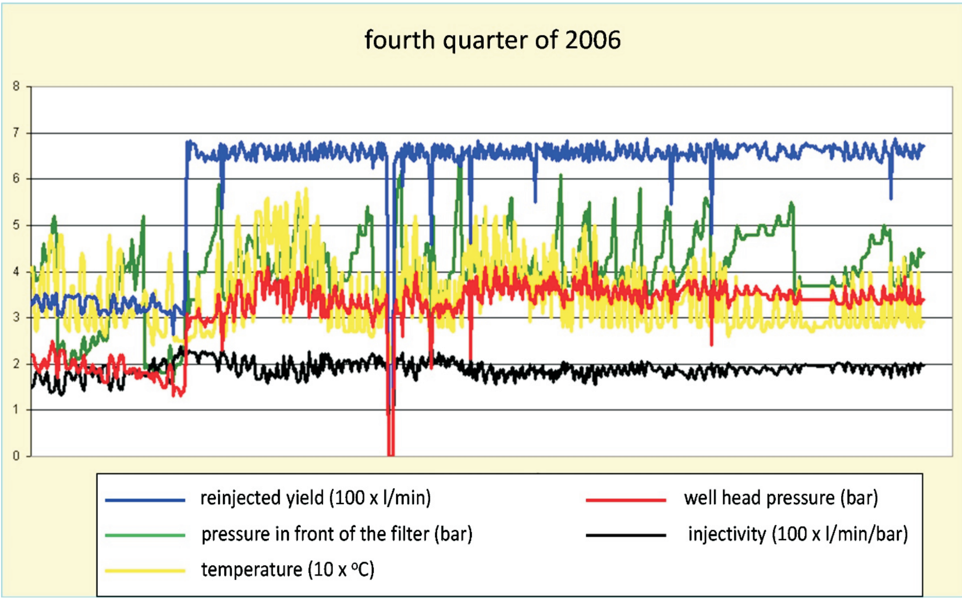

Fig. 7. Quarterly data of the injection plant

Rys. 7. Dane kwartalne z zakładu zatłaczającego

Critical operational parameters and their impact:

- The pressure value before the filter indicates clogging. This value shall not exceed 5–5.5 bars, since it can push the impurities through the filter and these can pollute the well.
- The pressure value after the filter shall not regularly exceed 4–5 bars. Readings above this value indicate the blocking of the gravel filter, and eventually the reduction of the absorbing capacity of the reservoir's pores.
- The quantity of the injected water shall not exceed 40 or 60 m^3/h, since this can result in the overload of the reservoir, jeopardizing the sustainability of injection. This value is set by programming the frequency converter.

When the critical operational parameters are reached, the computer in the control centre emits an audio signal for the dispatcher, who takes care of the necessary interventions or informs the maintenance personnel.

THE MAINTENANCE OF THE INJECTION PLANT

The optimal structure of an injection plant is shown in Figure 8. At least every 5 years the computer-aided monitoring system provides annual water level measurements, both at a state of rest and during operation, hydrochemical analysis of the injection well, as well as complex analyses with gauges according to the variation of operational parameters. In case of a regular increase in the wellhead pressure (5 bars), the following interventions are necessary at the end of the heating season:

- filter cleaning with compressor, hourly water sampling, and visual inspection,
- rewashing with hourly water sampling and visual inspection,
- bottom hole cleaning, high-pressure regeneration of the filter structure with packer,
- layer cleaning, layer opening, acid treatment.

The periodical elutriation of the buffer tank depends on its necessity (every month during operation), while the annual cleaning of the tanks' interiors is suggested. The maintenance of the aboveground filters depends on the contamination values of the gauges installed before and after them. The maintenance is completed with the replacement of the cloth elements of the combined filters and the high-pressure cleaning of the metal filter frame and the filter structure. The maintenance of booster pumps is regulated by the producers. The inspection of the heavy and light current systems is regulated by standards; their annual maintenance is recommended.

The extension or absence of critical value or periodical maintenances or interventions can result in damages, the correction of which could be very expensive or impossible.

This research was funded by the European Commission's Seventh Framework Programme. (*Geothermal Communities – demonstrating the cascading use of geothermal energy for district heating with small scale RES integration and retrofitting measures GEOCOM* project, Grant Angreement No. TREN/FP7EN/239515/"GEOCOM". Project website: http://www.geothermalcommunities.eu/).

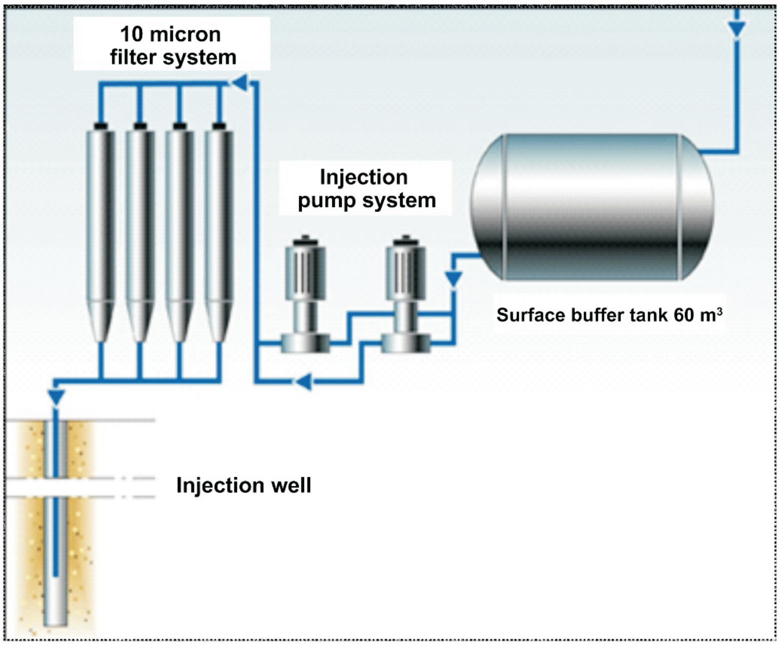

Fig. 8. Technological units of the injection plant

Rys. 8. Jednostki technologiczne zakładu zatłaczającego

REFERENCES

BÁLINT A., 2010 — Termálvíz visszasajtoló kutak környezetének hidrodinamikai modellje (Hydrodynamic model of the surroundings of thermal reinjection wells) – Thesis, University of Szeged.

CIVAN F., 2007 — Reservoir formation damage, Second Edition. Elsevier.

GRINGARTEN A.C., 1978 — Reservoir lifetime and heat recovery factor in geothermal aquifers used for urban heating. – Pageoph. 117, pp. 297–308.

MALATE R.C.M. 2003 — Management of geothermal resources: PNOC-EDC experience. IGC2003 – Short Course. The United Nation University. Geothermal Training Programme. Reykjavík, Iceland. pp. 153–183.

SZANYI J., KOVÁCS B., CZINKOTA I., KÓBOR B., MEDGYES T., BÁLINT A., 2012 — Sustainable reinjection into sandstone reservoirs in Hungary, Abstract volume of the 39th International Association of Hydrogeologists Congress, Niagara Falls, Canada, p. 377.

DOŚWIADCZENIA W ZATŁACZANIU WÓD GEOTERMALNYCH DO ZBIORNIKÓW POROWYCH

STRESZCZENIE

Dzięki korzystnym warunkom geologicznym stosowanie energii cieplnej na Węgrzech związane jest z dostępnością dużej ilości wód termalnych. W konsekwencji jednak ich zrzut stanowi poważne wyzwanie, a zatłaczanie należy zapewne do najbardziej kontrowersyjnych zagadnień związanych z wykorzystaniem energii geotermalnej w tym kraju. Do chwili obecnej problem ten nie został uregulowany prawnie. Powinien zostać opracowany system kryteriów umożliwiających optymalne funkcjonowanie projektów, zwłaszcza jeśli wiążą się one z zatłaczaniem zużytych wód do piaskowców. W niniejszym artykule zebrano doświadczenia działających systemów, w których prowadzone jest zatłaczanie, w celu podsumowania najlepszych praktyk zrównoważonej eksploatacji wód termalnych.

SŁOWA KLUCZOWE

Zatłaczanie, piaskowce, projektowanie systemów geotermalnych, konstrukcja otworu, technologia filtrów