INTERNATIONAL SUMMER SCHOOL
on Direct Application of Geothermal Energy

Under the auspice of the Division of Earth Sciences

BASICS OF GEOTHERMAL DISTRICT HEATING

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1. OVERVIEW

Geothermal water is used since ancient times for many purposes, including space heating. It is quite simple to make the hot water from natural springs flow in channels, trenches or pipes (made of stone or wood in early times) and use it for bathing and space heating.

A district heating system is a system which provides space heating and (or cooling, as well as hot tap water, to a relatively large number of users located in the same area or district. To build a district heating system which uses geothermal water and which operates properly for a long time in almost any atmospheric conditions in a specific area requires now the full co-operation of a team of specialists in different fields of activity.

The geothermal energy has some advantages which makes it quite attractive to use, such as:

- it replaces heat usually produced by burning fossil fuels, with the inevitable emission of CO_2 and in most cases of many other pollutants (CO, SO_2, NO_x, ash, etc.), and which are in many cases imported;
- when correctly designed, a geothermal system causes no pollution;
- the geothermal resources are renewable (in a shorter or longer time, depending on the natural recharge rate), and the exploitation can be managed to be sustainable;
- the running cost of a geothermal system is lower than that of a conventional system.

The geothermal energy also has disadvantages, of which some can be avoided by a correct design, completion and operation of a specific system:

- it is a local resource, being possible to transport with acceptable energy loss and at reasonable costs for limited distances, therefore to use it for district heating the reservoir has to be located relatively close to a community;
- the capital investment is higher than those required for other technical solutions, mainly due to the high cost of drilling and completing the necessary wells;
- the chemical composition of the geothermal fluid might require special measures to avoid scaling and/or corrosion;
- the resource capacity is in many cases not enough to supply the total heat demand in the area, so that other energy sources are still required, in which case it might be difficult to promote and develop the use of geothermal energy, except when it is significantly less expensive than the already available sources;
- the geological risk is usually high in the early stages of the development of a geothermal project, therefore the pre-feasibility and feasibility studies are often difficult to finance.

To develop a geothermal district heating system it is first necessary to identify a geothermal reservoir. Most countries have a national program for geological exploration aimed to identify the underground usable resources. The available data are collected, analysed and archived by a Governmental institution (usually the National Geological Survey), many geothermal rservoirs being already identified this way.

When starting to design a geothermal district heating system it is very important to have an as accurate as possible evaluation of the reservoir capacity (well head temperature and maximum flow rate which can be extracted from the reservoir without producing a too high pressure decrease over the project life time, usually 20-30 years). This is the task of the reservoir engineer. Based on the data collected during exploration and drilling, and mainly by well testing and logging, the reservoir engineer first defines a conceptual model of the reservoir, and when enough reliable data is available, a computer model which can simulate the behaviour in time of the reservoir parameters (pressure and temperature) for different exploitation strategies (production and injection at different flow rates using different wells).

The thermal engineer identifies the potential users located close enough to the geothermal reservoir and assesses the heat demand of each specific type of user (residential building, office building, hospital, school, etc.). The heat demand is calculated for the specific climate conditions in the area, using multi-annual average data for atmospheric air temperature and wind velocity (a district heating system is not designed for unusual cold waves which can occur accidentally). Based on the heat demand of each user, and knowing the available flow rate and temperature of the geothermal water, the thermal engineer elaborates the conceptual design of the district heating system, which has to provide a comfortable indoor temperature for all users all over the heating season. An important objective of the conceptual design is to use as much as possible of the exergy available in the produced geothermal water, which means to have an as low as possible outlet temperature, not only at nominal but also at partial loads. Cascading the utilisation of the geothermal water is usually a good solution to this problem, which improves the economic performance of the project. The detailed design is than necessary for the entire project (transport and distribution pipes, heating system for each user and geothermal heat plant: building, power supply, heat exchangers, pumps, piping, valves, measurement and control equipment, etc.).

As the chemical composition of geothermal fluids is different for each reservoir (sometimes even for each well drilled in the same reservoir), a chemist specialised in geothermal fluids is usually required to identify and find solutions for the potential scaling and or corrosion problems. The simplest and less expensive solutions shall be used to avoid scaling in the system (keeping the pressure high enough to maintain the CO_2 dissolved in the geothermal water in order to increase the solubility the carbonates, using chemical inhibitors to delay the initiation of scaling, avoiding high turbulence sources, etc.). When the geothermal fluid has a scaling potential, special equipment shall be selected, such as valves with hardened edges (able to break the scale if it forms in time) and with additional seals in order to avoid any possible leaking. Of course leaking should be avoided in the entire system, but mainly in the geothermal part. When the geothermal fluid leaks, the water evaporates and the remaining solids can block the valves and pumps, and make any maintenance work more difficult and of course more expensive. When the geothermal fluid is corrosive, stainless steel is usually used for the geothermal part of the system. In some cases titanium heat exchangers are needed, but these are significantly more expensive. When the entire geothermal part of the system has to be made of special materials resistant to very corrosive agents, the investment cost may be too high for a commercial project.

The economic viability of the projects is evaluated in different stages as more data are available. The conceptual design provides the initial data needed for the pre-feasibility study, for which the investment cost is roughly estimated using usually empirical formulas. For the feasibility study a detailed project enables a more accurate evaluation of the investment cost.

The collaboration of an economist experienced in geothermal district heating systems is in many cases most helpful. Grant funds are available from certain sources to finance the pre-feasibility study (when the risk is highest) and at least partially finance the feasibility study. The most delicate task is usually to find financing for the project, mainly in certain economic environments in which energy from conventional sources is subsidised at least from private users (population), and where energy is a state monopoly. It is usually possible to find banks willing to finance commercial geothermal district heating systems of certain types. The feasibility study has to comply to the requirements of the specific bank to which is submitted, and to clearly show the economic viability of the project, including a reasonable profit for the company applying for the loan. In particular cases it is possible to obtain loans with very low interest rates ("soft loans") from certain banks or financial institutions (World Bank - WB, International Bank for Reconstruction and Development - IBRD, European Bank for Reconstruction and Development - EBRD, European Investment Bank - EIB, Nordic Bank, etc.). The economic performance can be even more improved with grants accessible from certain financing entities such as the Global Environmental Fund (GEF) and the European Commission (EC) in the framework of their environmental programs.

One problem which is in many cases overlooked or considered insignificant, but which can become critical mainly in areas where geothermal energy was not used before is its social acceptance. The population shall be correctly informed about all the advantages and possible disadvantages (if any) of using geothermal energy, or otherwise strange (sometimes stupid) rumours can make the geothermal solution unpopular at such a large scale that the project might have to be abandoned or at least delayed for a long time.

2. SOME SIMPLE TECHNICAL SOLUTIONS

The selection of a technical and economic viable technical solution has to be based on the properties of the available geothermal resource, mainly the chemical composition of the geothermal fluid and the well head temperature and pressure. In many low enthalpy geothermal reservoirs the fluid pressure is below ground level or the exploitable flow rate can be higher than the artesian one, so that deep well pumps are usually used for production. The room heaters are basically of two types, transferring heat to the indoor air mainly by convection (cast iron, steel or aluminium sheet, finned tubes, or pipes, with natural or forced air circulation) and requiring higher inlet temperatures (70-90°C) or mainly radiation by (usually pipes set in walls, floors or ceilings) and requiring lower inlet temperatures (40-50°C). In case the geothermal fluid has no scaling, nor corrosion potential, or when these can be easily avoided at a low cost, it can be used directly as thermal agent in the system. In very rare cases the geothermal fluid complies to the legal specifications for drinking water, and can therefore be also used directly as hot tap water if the temperature is high enough, or after mixing it with cold water to cool it down to the standardised domestic hot water temperature (usually 50-55°C). When the chemical composition of the geothermal water does not allow to use it directly as heating agent and/or as hot tap water, heat exchangers are used to heat cold water. The heat exchangers used in almost all geothermal heat plants are stainless steel plate heat exchangers, which are preferred to shell and tube heat exchangers because of their advantages: higher heat transfer efficiency, large heat transfer surface area for a relatively small volume, not very much higher pressure loss, resistance to corrosion, easy to clean of scaling, not much higher price for the same thermal power. In cases when the geothermal water is too corrosive, titanium plate heat exchangers are used, and in very few case of fluids with a very high scaling potential fluidised bed heat exchanger are used.

The layout of a very simple geothermal district heating system is given in Figure 1.

This technical solution can only be used when reinjection is not needed (for environmental reasons or to maintain the reservoir pressure) and the reservoir can produce a large enough flow rate of geothermal water with a well head temperature or 20-90°C of drinkable quality. The deep well pump (DWP) feeds the geothermal water into the storage and degassing tank (SDT), from where it flows by gravity or is pumped to the users, where it is used both for space heating and as hot tap water (after mixing it with cold water). The heat depleted water is disposed of in the drainage or sewage system, and can be used before that for snow melting.

In situations similar to the one presented above, but with higher geothermal water temperature, the system presented in Figure 2 can be used. In many countries is considered dangerous to supply the consumers with heating agent with temperatures higher than 90°C. Therefore, a part of the heat depleted geothermal water is returned to the SDT in order to decrease the temperature in the supply network. In both these systems the heating load is controlled by modifying the heating agent flow rate while keeping the supply temperature constant. For the second system (Figure 2), a peak load boiler (PLB) can be added in case the geothermal resource can only supply the base load.

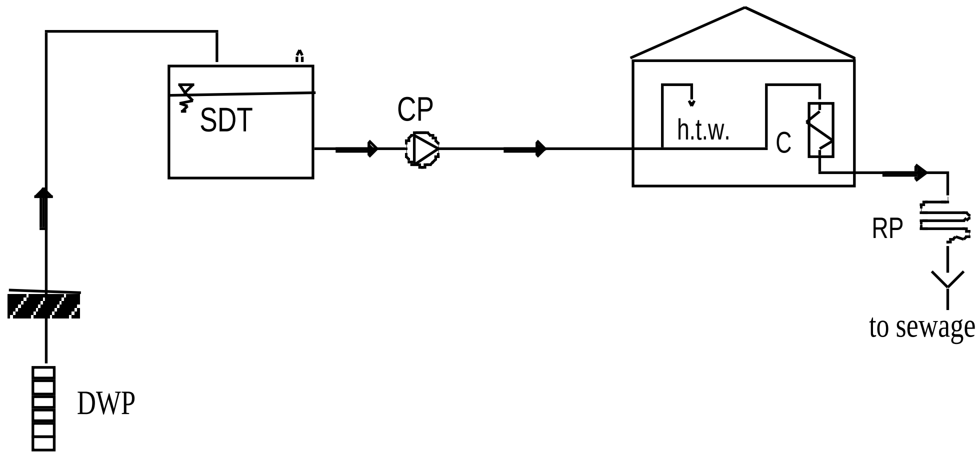

Figure 1: Heating system using directly geothermal water, without return

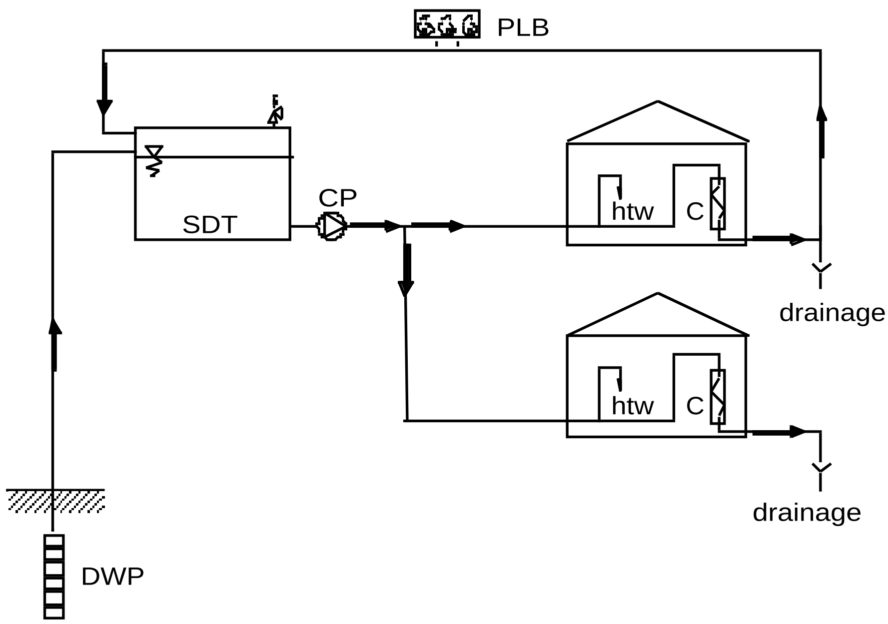

Figure 2: Heating system using directly geothermal water, with return

When the geothermal fluid has a scaling and/or corrosion potential which does not allow it to be used directly, or when reinjection is needed for environment protection or to maintain the reservoir pressure, the technical solution presented in Figure 3 can be used.

In order to use as much as possible of the exergy content of the geothermal fluid already extracted from the reservoir, it is possible to cascade the heating agent from users with convection space heaters (requiring higher inlet temperature) to users with radiation space heaters (requiring lower inlet temperature). The final return temperature in the secondary network is therefore lowered even at high loads, so that more heat is extracted from the available geothermal fluid, which is reinjected at a lower temperature. This option is usually viable in new housing developments, or when part of the consumers have anyhow to be fully renovated.

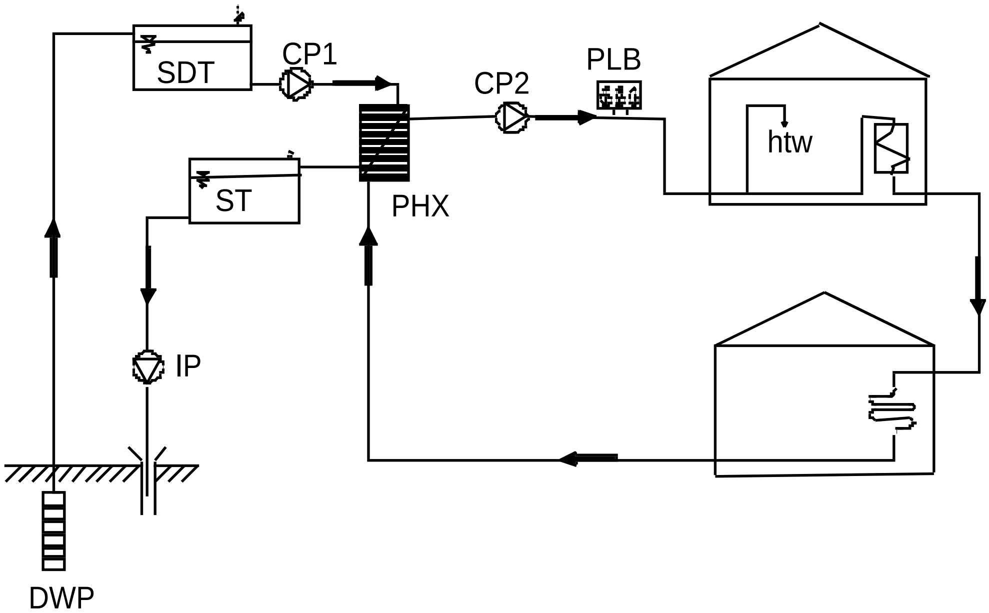

Figure 3: Heating system closed loop secondary network

In system of this type (Figure 3) the heat load is usually controlled by modifying the geothermal fluid flow rate in the primary plate heat exchanger (PHX) and consequently the supply temperature in the secondary network. The deep well pump (DWP), the injection pump (IP), and the circulation pumps (CP1 and CP2) have usually frequency converters for variable speed drives (for variable flow rate). The storage and degassing tank (SDT) and all the storage tanks (ST) needed are sized to compensate the daily variations in demand.

When the available geothermal water temperature is too low to heat the tap water and even to supply space heating at low partial loads, heat pumps can be used to extract heat directly from the geothermal water or from an intermediate fluid (chemically treated water) heated in a heat exchanger with geothermal water (to protect the evaporator of the heat pump). Large district heating systems working all the time with heat pumps are not common, being to economic (too high investment and also running costs), but are quite common for individual houses, at least in certain economic environments.

It is known that the coefficient of the heating performance of a heat pump decreases with the increase of the temperature difference between the condenser and evaporator. For an ideal heat pump, working on the ideal Carnot cycle, the coefficient of the heating performance is given by:

$$C_h = \frac{T_c + 273.15}{T_h - T_c} + 1$$

where:

T_h [°C] = condensation temperature of the working fluid;

T_c [°C] = evaporation temperature of the working fluid.

For a real heat pump, in order to make the heat transfer possible over the entire area of the condenser, the condensation temperature of the working fluid has to be higher than the outlet temperature of heated fluid. For the same reason, the evaporation temperature of the working fluid has to be lower than the outlet temperature of the cooled fluid. Usually the temperature difference is 4°C for both the condenser and the evaporator. Also the coefficient of performance of a real heat pump is reduced roughly by half by the irreversibility of the thermodynamic processes and the mechanic and hydro-dynamic losses. An empirical equation for the coefficient of the heating performance of a real heat pump is (Harrison, 1990):

$$C_h = \frac{0.5 \cdot (T_{co} - 4 + 273.15)}{T_{ho} - T_{co} + 8} + 1$$

In certain economic environments it is still economic to assist the geothermal district heating by heat pumps, either directly (extracting residual heat from the outflow geothermal water) or indirectly (extracting heat from the return pipe of the secondary network). In Figure 4 is given a possible layout for space and tap water heating using a source of geothermal water with a temperature of about 50°C, the consumer being equipped with cast iron radiators for space heating.

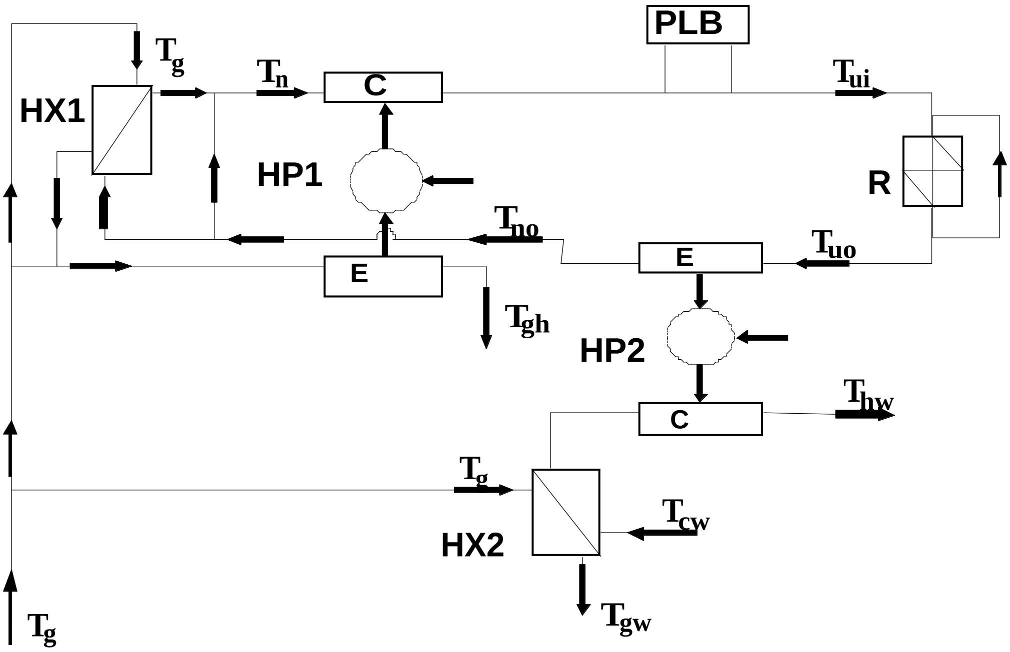

Figure 4: Heat pump assisted heating system

The system is basically a heat pump assisted with direct evaporator type. At low partial loads, as long as the radiator water inlet temperature is below 45°C, the heat demand is supplied through direct heat exchange from the geothermal water by the primary heat exchanger (HX1). The condenser of the heat pump (HP1) is by-passed in this case. As the required radiator water inlet temperature increases above 45°C, the primary heat exchanger can no longer supply the total heat demand and HP1 is turned on. The radiator water outlet temperature is increasing at the same time, causing an increase in the geothermal water outlet temperature from the primary heat exchanger. The latter is therefore passed through the evaporator of the HP1 in order to lower the temperature of the waste geothermal water as much as possible. When the network return temperature (T_{no}) reaches 40°C the direct heat exchange through HX1 is no longer efficient and it is consequently by-passed. The evaporator of the HP1 is then fed with geothermal water at well head temperature (T_g). During the periods of time when the heat pump is working at partial loads, it is not desirable to regulate its speed continuously in order to ensure all the time the required inlet temperature for the radiator water. It was considered more energy efficient to have the possibility to mix a part of the outlet radiator water with the inlet radiator water. In this way the inlet temperature can be regulated continuously by regulating the mass flow rates of the two streams, while running the heat pump at a certain constant speed. When the required inlet temperature of the radiator water increases above the maximum outlet temperature from the condenser of the HP1, the heat supply is supplemented by the peak load boiler (PLB).

The fresh water is first heated by direct heat exchange up to the intermediate temperature T_{iw} in the heat exchanger HX2. Subsequently it is heated up to the standard temperature T_{hw} = 65°C in the condenser of the second heat pump (HP2). This arrangement insures a decrease of the radiator water outlet temperature, improving the heat exchange in the HX1. During the time the space heating system is turned off (out of the heating season), geothermal water at the well head temperature T_g can be fed to the evaporator of the HP2.

The most important issue when looking for a technically and economically viable solution is that each geothermal resource has particularities which have to be well understood and take into account. The task of the thermal engineer is to find a viable technical solution which reaches the objective of the project and has acceptable economic performance indices. This is not always the one with the lowest investment cost, but usually the one with the highest energy efficiency and lowest running cost.

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