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Reykjavik energy - District heating in Reykjavik and electrical production using geothermal energy

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Abstract

Geothermal water has been used for over 70 years in Reykjavik for heating of houses. Orkuveita Reykjavikur operates the largest municipal district heating service in the world. It started on a small scale in 1930 and now it serves more than half of the nation's population. The harnessed power of the geothermal areas is about 700 MW thermal. Annually, 60 million cubic meters of hot water flow through the Utility's distribution system. From 1998, electricity has been co-generated from geothermal steam along with hot water for heating.

1 Introduction

Geothermal water has been used for centuries for heating houses. The oldest geothermal district heating system in the world is most likely in the town Chaides-Aigues in Massif Central in France. The town is located in a narrow valley about 750 – 800 m a.s.l. Old manuscripts show that 82°C geothermal water was used to heat houses in the town in the 14th century.

The oldest geothermal heating system in the United States began delivering water in 1892. This was in Boise, Idaho where 77°C water from drillholes was used to heat houses along the avenue, which led to the hot spring area. In 1998, the geothermal water was still being used to heat 226 homes and 36 commercial buildings in downtown Boise.

In Iceland, drilling for hot water started in 1928 at the thermal springs in Reykjavik. Fourteen drillholes were drilled and the result was 14 l/s of about 87°C water. In 1930, a 3 km long pipeline was built, and the first house connected. This was the beginning of geothermal district heating in Reykjavik. Shortly thereafter, a hospital, another schoolhouse, an indoor swimming pool and about 70 private houses were connected to the district heating. This is now the largest geothermal district heating service in the world.

About 87% of all houses in Iceland are heated with geothermal water. Almost 90% of the country's inhabitants are connected to a district heating service that make use of geothermal heat. In Iceland, there are 29 district heating services, each serving an area ranging from one municipality to several adjoining municipalities. Figure 1 shows the water production for the 20 largest heating services in Iceland.

Today, geothermal energy is used for district heating in at least 9 capitals of the world, i.e. in Addis Ababa (Ethiopia), Beijing (China), Budapest (Hungary), Bucharest (Romania), Paris (France), Reykjavik (Iceland), Rome (Italy), Sophia (Bulgaria) and Tbilisi (Georgia).

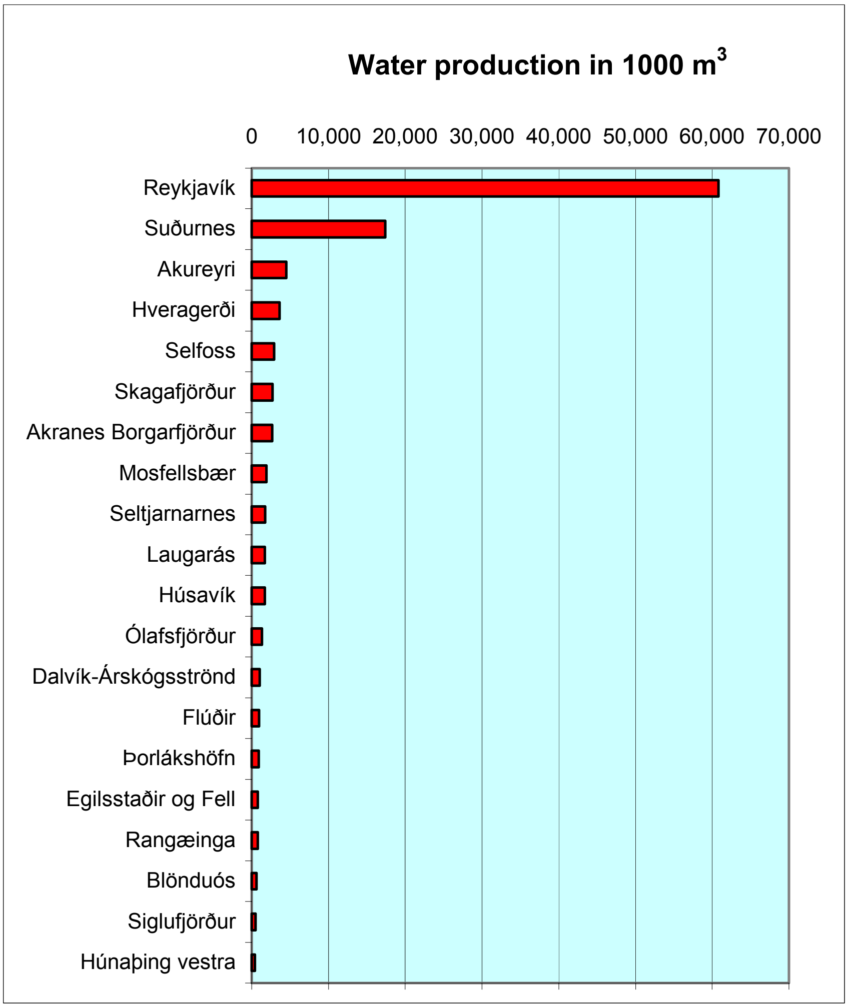

Figure 1: Water production of the largest district heating services in Iceland. Data from Samorka-home page.

2 Reykjavik Energy

Reykjavik Energy entered its first year of operations in 1999 following the merger of the city's Electric Power Works and District Heating Utility. On January 1st 2000, Reykjavik Water Works merged with Reykjavik Energy. All these companies were leading players in the Icelandic energy sector, and merged to create a dynamic new company to handle procurement, sale and distribution of electricity, cold water and geothermal hot water for space heating.

The year 2001 was especially eventful for Reykjavik Energy. First the distribution systems were greatly enlarged when Reykjavik Energy took over Thorlákshöfn Heating Utility; preparations for a hot water distribution system were started in Grímsnes and Grafningur parish; and last, but not least, a contract was completed for the mergers of Akranes Utilities and the Borgarnes Heating Utility with Reykjavik Energy.

Reykjavik Energy operates the world's largest and most sophisticated geothermal district-heating system - an electricity distribution network and a water distribution system that meets the most demanding international standards for the quality of water and its environment. The area serviced by Reykjavik Energy reaches from Kjalarnes northwest of the capital and all the way south to Hafnarfjordur, an area where more than half the nation's population lives.

District heating in Reykjavik started on a small scale in 1930. In 1933, about 3% of Reykjavik's population were connected to Reykjavik District Heating. At that time, coal was mainly used for heating, and dark clouds of smoke were commonly seen over Reykjavik. Moreover, pipelines were laid to nearby municipalities, which are now supplied with geothermal water by the district heating in Reykjavik. The use of geothermal water in Reykjavik for space heating instead of fossil fuels reduces air pollution. Today, almost all houses in the area are connected to the district heating system. The district heating in Reykjavik serves 57% of the population of Iceland with geothermal water, and is the world's largest municipal geothermal heating service. The installed power is about 750 MW.

3 The low-temperature fields

Three low-temperature geothermal areas are utilized for district heating in Reykjavik. In the low-temperature fields, there are a total of 52 exploitation wells with a total capacity of about 2300 l/s (Table 1).

Table 1: Summary of the geothermal fields

Field	Temp °C	Capacity l/s	No. of exploitation wells
Laugarnes	125-130	330	10
Elliðaár	85-95	220	8
Mosfellssveit	85-95	1700	34

The exploitation of geothermal water from the Laugarnes field began in 1928-1930 with the drilling of 14 shallow wells near the Þvottalaugar thermal springs. The deepest well was 246 m deep and the well field delivered 14 l/s of artesian water at a temperature of 87°C. This water was used for heating schoolhouses, a hospital, swimming pools, and about 70 residential houses.

In 1958, further drilling in the Laugarnes area commenced with a new type of rotary drilling rig, which was able to drill deeper and wider wells than previously possible. Deep well pumps pumped the water from the wells, whereas the water previously extracted in the area had been free artesian flow from the wells. The yield increased to 330 l/s of 125 to 130°C water.

Now there are 10 production wells in the field, which cover about 0.28 km^2 and located at a junction of a caldera and a fault-scarp. The temperature is 110 to 125°C at 400 to 500 m depths and increases with depth. The highest measured temperature is 163°C at 2,700 m depth. The main aquifers are at 1,000 to 2,000 m depth.

The Elliðaár field had minor surface manifestations before drilling with a maximum temperature of 25°C. Drilling began in the area in 1967, finding aquifers with 85-110°C. The exploitation area covers 0.08 km^2, but the manifestations cover 8 – 10 km^2.

Prior to drilling in the Reykir area, the artesian flow of thermal springs was estimated to be about 120 l/s of 70-83°C water. After drilling, the water from this area was piped to Reykjavik and by the end of 1943 about 200 l/s of 86°C water was available for heating houses in Reykjavik. After 1970, the deep rotary drilling of large diameter wells and installation of pumps redeveloped the Reykir field. The yield from these wells then increased to 2000 l/s of 85-100°C water.

The Mosfellssveit geothermal field, which is about 5.5 km^2, is geographically divided into sub-areas, Reykir and Reykjahlíð. It is located between two calderas and the stratigraphy consists of lavas and hyaloclastite layers cut by numerous faults and fractures. Altogether, 34 exploitation wells are in the field. The temperature is in the range of 65 – 100°C.

In general, there are more dissolved solids in geothermal water than in cold water - sometimes so much that it is not considered healthy for consumption. The low-temperature geothermal areas utilized for district heating in Reykjavik are low in total dissolved solids (Table 2) and can be used directly for heating and even cooking and drinking. This water almost fulfills the requirements of drinking water codes. The sulphide concentration is higher than allowed in drinking water as well as the pH value.

The geothermal water from the wells in Reykjavik and in Mosfellssveit comprise about two-thirds of the hot water in the distribution system. One-third comes from Nesjavellir.

4 The Hengill geothermal area

The Hengill area east of Reykjavik is one of the largest high-temperature areas in Iceland. The geothermal activity is connected with three volcanic systems. The geothermal heat in Reykjadalur and Hveragerði belong to the oldest system, called the Grensdalur system. North of this is a volcanic system named after Hrómundartindur, which last erupted about 10,000 years ago. The geothermal heat in Öldukelsháls is connected with this volcanic site.

West of these volcanic systems lies the Hengill system, with volcanic fractures and faults stretching from the southwest through Innstidalur, Kolviðarhóll and Hveradalur (Hot Spring Valley) and to the northeast through Nesjavellir and Lake Þingvallavatn.

Several potential geothermal fields are found within the Hengill complex. Only two of these areas have been developed - one for space heating, industrial use and greenhouse farming in the town of Hveragerdi; and at Nesjavellir, where Orkuveita Reykjavikur operates a geothermal power plant producing 90 MWe of electricity and about 200 MWt of hot water for space heating. A fault zone associated with the Hengill Volcano cuts through the volcanic zone from southwest to northeast. The most intensive geothermal prospects are associated with this fault zone, Nesjavellir farthest to the north, and Hellisheidi on the southern side.

Table 2: Chemical composition of thermal and heated groundwater. Concentration in mg/kg.

	Laugarnes	Elliðaár	Mosfells-sveit	Nesjavellir geothermal water	Nesjavellir heated water
°C	130	86	93	290	83
pH/°C	9.45/23	9.53/23	9.68/20	6.2	8.59/24
SiO_2	150.2	67.6	95.0	600	21.8
Na	70.3	46.2	47.9	106	9.8
K	3.5	1.0	1.0	22.1	0.8
Ca	3.7	2.2	1.5	0.1	8.7
Mg	0.00	0.01	0.02	0.00	5.1
CO_2	17.5	26.3	23.7	204	31.4
H_2S	0.3	0	0.9	279	0.3
SO_4	28.7	13.3	20.3	13.2	8.3
Cl	55.6	25.1	12.2	118	8.5
F	0.6	0.18	0.83	0.7	0.08
CO_2 - gas			8700		
H_2S - gas			3350		

5 Nesjavellir

The district heating in Reykjavik has drilled 22 holes at Nesjavellir. The depth of these holes ranges from 1,000 to 2,200 meters, and temperatures of up to 380°C have been measured. The construction of the Nesjavellir power plant began in early 1987. At the first stage, the plant utilized geothermal steam and separated water from four drillholes to heat fresh ground water for district heating in the Reykjavik area. This stage was completed in 1990 with 100 MW_t power, equivalent to about 560 l/s of 80°C water.

The next stage of power harnessing was brought online in 1995 when the fifth hole was connected, heat exchangers and a deaerator were added, and the production capacity was increased to 840 l/s. This corresponds to 150 MW_t of thermal power.

From the beginning, the production of electricity with steam turbines had been planned. In fall 1998, the first steam turbine was put into operation, and the second toward the end of the year. Five additional holes were put online, increasing the total processing power of the power station to 200 MWt, with the water production reaching more than 1,100 liters per second. In June 2001, the third steam turbine was put into operation. The turbines are 30 MWe each, making the total production of electricity 90 MWe.

The power harnessing cycle may be divided into three phases: (1) the collection and processing of steam from boreholes; (2) the procurement and heating of cold water; and (3) the production of electricity (Figure 2).

Steam mixed with water is conveyed from boreholes through the collection pipes to the separation station where the water is separated from the steam. From the separation station, steam and water proceed by separate pipes to the power plant of about 12 bars and a temperature of 190°C. The steam is conveyed to the steam turbines where electricity is generated. In the condenser, the steam is utilised to preheat cold water, raising the temperature from 4°C to 50-60°C. In the first tube fluid heat exchanger, the separated water is utilised to

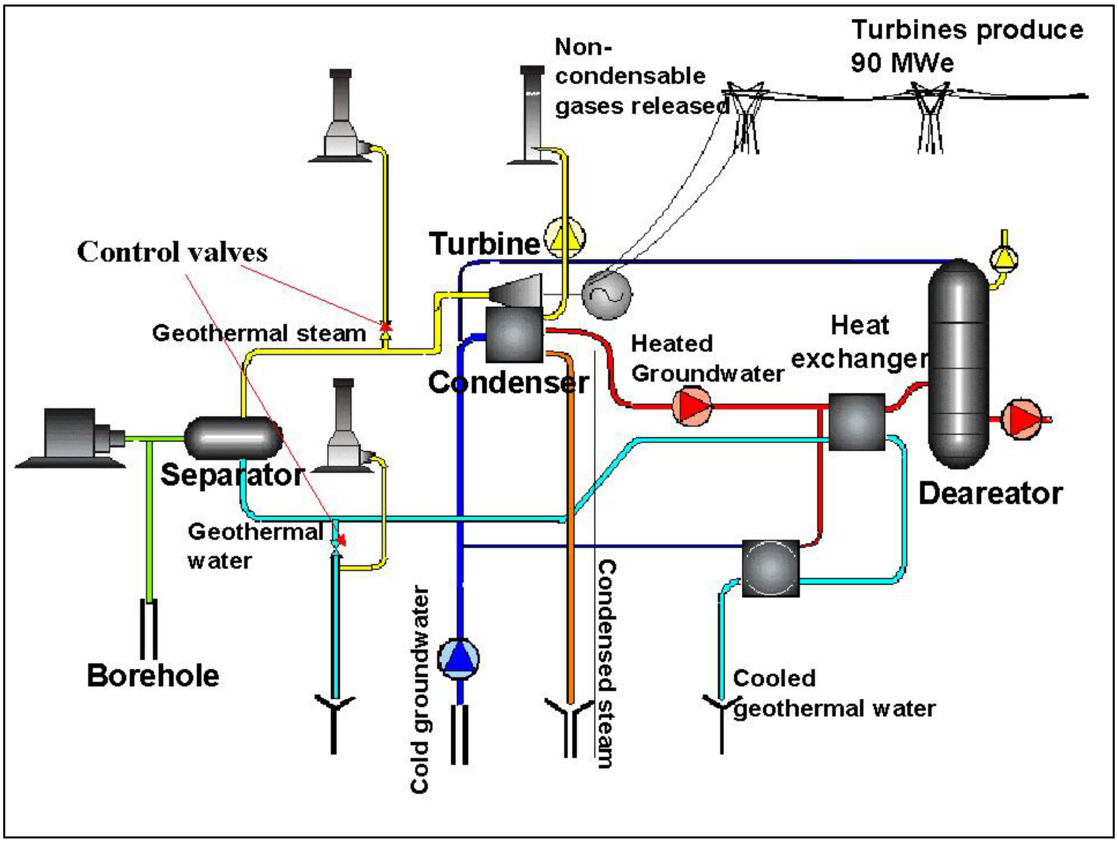

Figure 2: Simplified diagram of the Nesjavellir power plant.

heat cold water. The heated water is later mixed with the preheated water from the condensers and the final heating occurs in the second tube fluid heat exchanger (Figure 3).

The cold water is taken from drillholes from nearby Lake Thingvellir. It is pumped to water tanks next to the power plant. The water is heated up to 85-90°C. The cold water is saturated with dissolved oxygen that corrodes steel after being heated. To get rid of the oxygen, the water is sent to a deaerator where boiling under low pressure releases the dissolved oxygen and other gases from the water. During this process, the water cools to 82-85°C. Finally, a small quantity of steam containing acid gases is mixed with the water to eliminate the last traces of dissolved oxygen and lower the pH of the water in order to prevent scaling in the distribution system. A small quantity of hydrogen sulphide (H_2S) ensures that dissolved oxygen that could get into the water in storage tanks is eliminated.

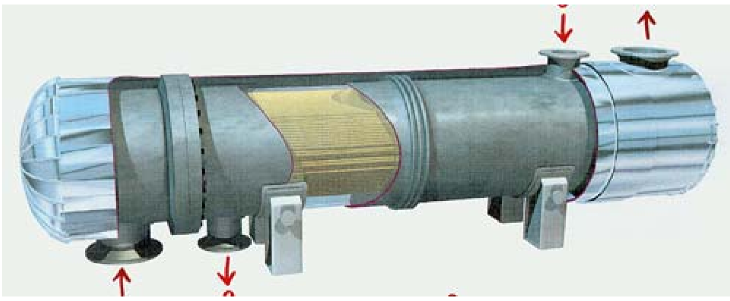

Figure 3: Tube heat exchanger at Nesjavellir

The supply pipeline from Nesjavellir to Reykjavik is 800-900 mm in diameter and about 25 km long. It is designed for water of up to 100°C and to convey 1,870 l/s. The pipeline is made of steel, insulated with rock wool covered with plastic and aluminum on the outside where the pipeline lies above ground, but with urethane insulation, covered with plastic, where it runs underground. In the first stage of the project, the pipeline conveyed 560 l/s. At this flow rate, the water took less than seven hours to flow from Nesjavellir to Reykjavik, with temperature decreasing less than 2°C. With increasing production, the flow rate increases, thereby decreasing the loss of heat and shortening the transport time.

6 Reservoir studies

Geothermal exploitation involves energy extraction from highly complex underground systems. The generating capacity of geothermal systems is often poorly known and they often respond unexpectedly to long-term energy extraction. This is because their internal structure, nature and properties are often poorly known and can only be observed indirectly. Therefore, the management of geothermal resources can be highly complicated. Successful management relies on proper understanding of the geothermal system involved, which in turn relies on adequate information on the system. This knowledge is continuously gathered throughout the exploration and exploitation history of a geothermal reservoir.

The parameters that need to be monitored to quantify a reservoir's response to production differ somewhat, of course, from one geothermal system to another. In addition, the methods of monitoring, as well as monitoring frequency may differ. Below is a list of the basic aspects included in conventional geothermal monitoring programs (Axelsson and Gunnlaugsson, 2000):

- Mass discharge history of production wells.
- Enthalpy or temperature (if liquid or dry steam) of fluid produced.
- Wellhead pressure (water level) of production wells.
- Chemical content of water and steam produced.
- Reservoir pressure (water level) in observation wells.
- Reservoir temperature through temperature logs in observation wells.

Careful monitoring of a geothermal reservoir during exploitation is, therefore, an indispensable part of any successful management program. If the understanding of a geothermal system is adequate, monitoring will enable changes in the reservoir to be seen in advance. These can be undesirable changes such as decreasing generating capacity or possible operational problems such as scaling in wells and surface equipment or corrosion. Thus, the importance of a proper monitoring program for any geothermal reservoir being utilised can never be stressed too much.

6.1 Laugarnes field

Prior to exploitation, the hydrostatic pressure at the surface in this geothermal field was 6-7 bars, corresponding to a free water level of 60-70 m above the land surface. Exploitation has caused a pressure drop in the field, and the water level has fallen. Consequently, fresh and slightly saline groundwater have flowed into the pressure depression and mixed with the thermal water. A slight decrease in silica and fluoride, and in some wells also an increase in chloride concentration, were noticed but without changes in the fluid temperature. The mixing of different water types resulted in disequilibrium of calcite and formation of that mineral. Reduced pumping after 1990 has reduced the pressure drop and the mixing of groundwater (Gunnlaugsson et al., 2000).

6.2 Ellidaár field

When exploitation started in this area, the temperature was in the range of 95-110°C. Production from the field caused a pressure drop and consequent cooling of the field. Cold groundwater from the surroundings mixed with the thermal water, reduced the temperature, and affected the chemistry of the water by diluting the silica and the fluoride concentrations. Reduction of production in 1990 resulted immediately in higher water levels in the area and a decrease in the mixing with cold water (Gunnlaugsson et al., 2000).

6.3 Reykir field

Aquifers can be correlated to faults and fractures. Annual variation in production is reflected in the water level (Figure 4). The water level was steadily decreasing until 1990 when it became possible to reduce pumping from the field when a new power plant at Nesjavellir

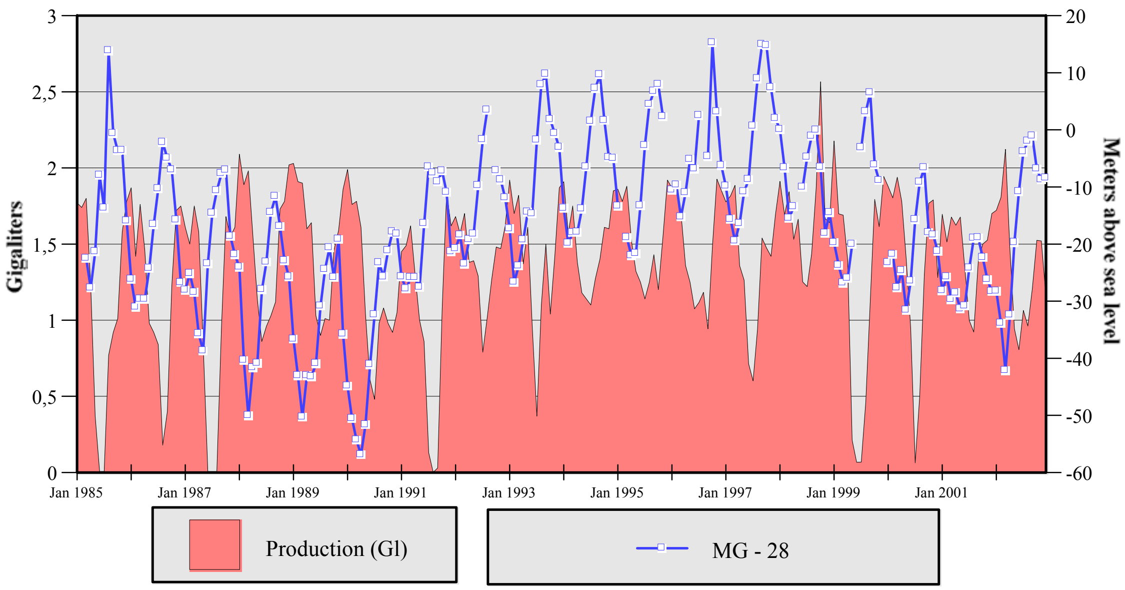

Figure 4: Production and water level at Reykir geothermal field.

started operation. Immediately after the reduction of production, the pressure built up and the water level rose again. Changes in chemistry and temperature of the fluid were only observed at the southeastern boundary of the field (Gunnlaugsson et al., 2000).

7 The distribution system

The geothermal water from Reykir in Mosfellsbær flows through a main pipeline to six tanks just outside Reykjavik that hold 54 million liters. From there, the water flows to six storage tanks on Öskjuhlíð in mid-Reykjavik, which hold 24 million liters. Nine pumping stations distributed throughout the servicing area pump the water to the consumers. The water from Nesjavellir flows to two tanks on the way to Reykjavik that hold 18 million liters. From there, the heated water flows along a main pipeline to the southern part of the servicing area.

The heated fresh water and the geothermal water are never mixed in the distribution system, but kept separated all the way to the consumer.

The length of the pipelines in the distribution system is over 1,300 km. This includes all pipelines from the wells to the consumer. The main pipelines are 90 cm in diameter. The pipe from the main line to the consumer is usually 2.5 cm in diameter. Some of the pipes laid in 1940 are still in use. They were originally insulated with turf and red gravel. The newer pipes are insulated with foam or rock wool.

Reykjavik District Heating uses either a single or a double distribution system (Figure 5). In the double system, the return flow from the consumer runs back to the pumping stations. There it is mixed with hotter geothermal water and serves to cool that water to the proper 80°C, before being re-circulated. In the single system, the backflow drains directly into the sewer system. In the coldest periods, the consumers use about 3,800 liters per second for space heating. When production from the fields is not quite sufficient, the water in the storage tanks usually meets the demand because the cold spells do not last very long. Geothermal water usage is measured in cubic meters. Annually, about 60 million cubic meters of water are produced.

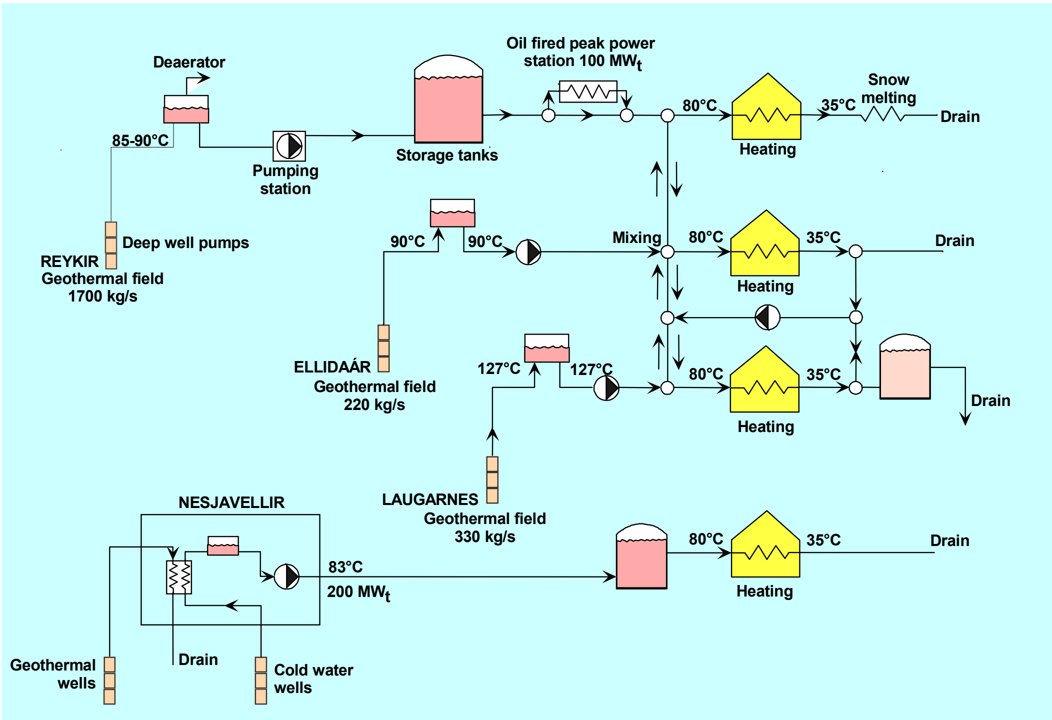

Figure 5: Simplified diagram of the district heating system in Reykjavik, Iceland.

7.1 Scaling

Troublesome scaling of calcite and silica minerals is often associated with the utilization of geothermal fluids. Knowledge of the physical and chemical conditions causing mineral deposition from geothermal water allows an evaluation of the magnitude of the scaling problems and may aid in visualizing how they could be overcome. During exploitation, cooling, heating, degassing or boiling, dissolution of materials from pipes and mixing of inflow from two or more aquifers, each with its characteristic temperature and chemistry can lead to scaling.

Calcite is the most common scaling product. It has only been found in drillholes and the distribution system where geothermal water mixes with more saline water due to lowering of the water level.

Silica. The concentration of silica increases with increasing temperature and it depends on the solubility of quartz and chalcedony. During cooling, the silica is in solution until solubility of amorphous silica is reached. At still lower temperatures, the water is supersaturated and silica depositions can be expected. Water in equilibrium with rock in low-temperature areas up to about 130°C can be cooled down to 30°C without deposition of silica. Therefore, geothermal water at up to about 130°C can be used in district heating systems without deposition of silica. Water in equilibrium with rock at 220°C reaches amorphous silica saturation if cooled down to about 90-100°C. During boiling, the concentration of silica increases due to steam loss, and the amorphous silica saturation curve is reached at higher temperatures. Due to high silica content, water from high-temperature areas cannot be used directly in district heating systems. No silica scaling has occurred in the distribution system.

Magnesium silicate. Depositions of magnesium silicate can form where fresh groundwater is mixed with geothermal water (Hauksson et al., 1995). In 1990, when production of hot groundwater started at Nesjavellir, the water was mixed with the geothermal water in Reykjavik. This caused scaling of magnesium silicate, where magnesium originated from the groundwater, and the silica from the low-temperature geothermal water. Since then, these two water types are kept separated in the distribution system.

7.2 Corrosion

Corrosion of carbon steel has been experienced in association with water containing dissolved oxygen at low temperatures (< 80°C), carbon dioxide waters (pH<8.5) below 100°C, and water with rather high chloride content. Corrosion is one of the parameters that often follow mixing of fresh water and geothermal water where dissolved oxygen is increased. A very slight increase in salinity will catalyze oxygen corrosion considerably. If dissolved oxygen is detected, it will result in increased corrosion.

To avoid corrosion, the dissolved oxygen has to be removed. This can by done by boiling or adding chemicals, which react with the oxygen. Addition of sodium sulphite to the water is widely used.

Dissolved oxygen and hydrogen sulphide cannot exist together in solution (or only to a certain extent). Sulphide is therefore a good natural eliminator of dissolve oxygen if it enters the system from the atmosphere, for example in storage tanks (Figure 6). The empirical results from Reykjavik Energy show that 1.6 ppm of hydrogen sulphide is needed to remove 1 ppm of dissolved oxygen. This indicates that the reaction is not only sulphate production as shown in the reaction $S^{--} + 2O_2 = SO_4^{--}$, where 0.5 ppm of sulphide is needed for each 1 ppm of dissolved oxygen.

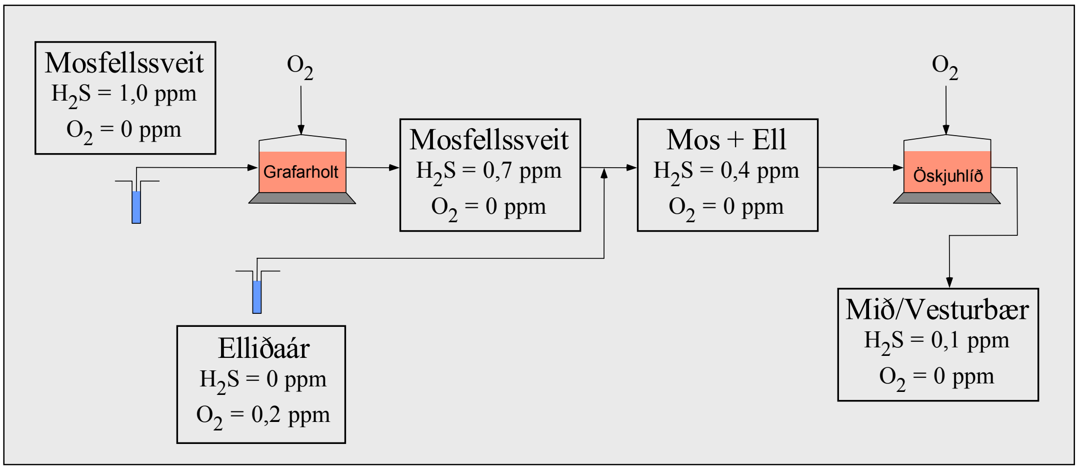

Figure 6: Elimination of dissolved oxygen using H_2S in geothermal water

Copper and copper alloys are widely used in district heating systems, e.g. in pipes, valves flow meters, heat exchangers and pumps. It has long been recognized that copper corrodes in sulphide-containing environments. The sulphide corrosion problem is sometimes related to sulphate-reducing bacteria in the literature, but in geothermal systems, especially those with sulphides of magmatic origin, the corrosion is believed to be of a chemical nature. In sulphide-containing environments, the copper become coated, almost at once with a thin black coating of copper sulphide, which is easily removed with the flowing water resulting in further corrosion of the metal. Copper pipes should therefore be avoided if the water contains hydrogen sulphide.

8 Best utilization of the hot water

Although geothermal energy is sustainable, it is necessary to make sensible use of it. It is most important to insulate buildings and to install thermostatic controls to conserve the heat. In Reykjavik, consumers pay for the water by volume. It is therefore to their advantage to use the water wisely. The price of thermal water in Reykjavik is approximately one-third of the price of heating with oil.

Consumers themselves can tell if the amount of hot water they use is within normal limits. In small houses and flats, a normal year's consumption may be up to two cubic meters for each cubic meter of space. In large buildings, normal consumption can be up to 1.5 cubic meters for each cubic meter of space.

About 85% of the hot water from Reykjavik District Heating is used for space heating, 15% being used for bathing and washing. The greatest savings come from good insulation and careful attention to radiator temperatures.

After the hot water has been used in a building, it is 25- 40°C. In recent years, it has become increasingly common to use this to melt snow of pavements and driveways.

The monthly average energy demand is different from one place to another. In colder climates heating is needed all the year around where in other places heating is limited to the winter months and can be turned off entirely during the summer months. On the other hand, need for domestic hot tap water is all the time. In Iceland, houses have to be heated all the year around. During summer, the heating demand is low but the system has to be able to supply sufficient water for hot domestic tap water.

Figure 7 shows average energy use for the district heating in Reykjavik.

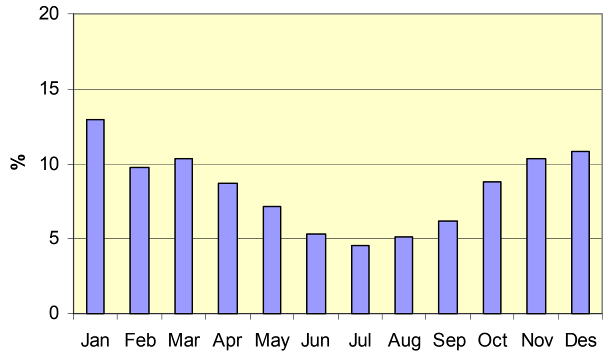

Figure 7: Heating demand in Reykjavik, Iceland

8.1 Composition of hot water used as tap water

Although water can be used directly for space heating, it is not necessarily suitable for use as domestic hot water. The water composition has then to be compared to the values recommended in drinking water codes. Some elements require special attention. The concentration of fluoride is often higher than recommended in drinking water. Too high concentrations cause teeth and bone diseases. If the concentration of iron is too high, the water may become brownish due to oxidation when it comes in contact with air. Hydrogen sulphide is not allowed in drinking water. Its presence in cold water is usually due to decomposition of some organics in the system. In the case of geothermal water, its source is often magmatic. Although hydrogen sulphide is a harmful compound, low concentrations in geothermal water should not affect humans.

9 Benefits of geothermal district heating

Clean air is one of the main benefits of utilizing geothermal energy for space heating, and it can also influence the health of the inhabitants. Clean air and reduction of coal-soot and other particles are undoubtedly the main reason. Other benefits of the use of geothermal energy for district heating is that the energy is in all cases domestic, and fossil fuels do not have to be transported. In most cases, this energy source is compatible in price to other alternatives, especially if environmental issues are taken into account. Space heating using geothermal water also allows cascading uses such as for swimming pools, greenhouses, heated garden conservatories and snow melting.

10 Future plans

Numerical simulation models, which use 20 years of exploitation history for the Nesjavellir field, indicate that the power plant can still be increased. The decision has been made to install there the fourth 30 MW_e turbine, and increase the thermal output to 300 MW_t. This increase will be commissioned in 2005.

In recent years, the Hellisheidi prospect on the southern side of the Hengill complex has been the subject of an intensive geothermal reconnaissance survey by Orkuveita Reykjavikur. In June 2001, the survey had generated positive results and the company board agreed to start the preparation for the construction of a 120 MWe power plant in the Hellisheidi field. Deep drilling was started in 2001 by drilling two wells, followed by the drilling of three wells in 2002. Two wells are being drilled during the summer of 2003. The length of the boreholes is in the range of 1,800 – 2,300 m; four of the drillholes were deviated, and intercept the faults at 1,000 – 1,300 m depth, where the main aquifers have been found with total loss of circulation fluid. Up to 1,000 m have been drilled without any return of drilling fluid and rock cuttings. Downhole measurements show that the temperature range in the aquifer zone is 255 – 275°C, but below lower temperatures are found (Gunnlaugsson and Gíslason, 2003).

Preliminary results indicate that the geothermal fluid is relatively dilute, as is common in high-temperature fields in Iceland, and the gas content is relatively low. So far, the study indicates no technical difficulties. The present survey, including the deep drilling, is carried out under a research permit, but preparation for acquiring a utilization permit is underway, including an Environmental Impact Assessment. Concurrent with the geothermal reconnaissance, an extensive study on groundwater flow is being carried out, which includes the drilling of 23 research wells, 60 - 200 m deep. The first phase of a power plant on the southern side of the Hengill mountain could be on line in 2006.

11 References

Axelsson, G., and Gunnlaugsson, E. (2000). Backgroud: Geothermal utilisation, management and monitoring. In course on: Long-term monitoring of high- and low-enthalpy fields under exploitation. *WGC 2000 Short Courses*, Kokonoe, Kyushu District, Japan, 28-30 May 2000.

Gunnlaugsson, E. and Gíslason, G. (2003). District heating in Reykjavik and electrical production using geothermal energy. Paper submitted to: *International Geothermal Conference on Multiple Integrated Use of Geothermal Energy*, Reykjavik 14-17, September 2003.

Gunnlaugsson, E., Gíslason, G., Ívarsson, G., Kjaran, S.P. (2000). Low–temperature geothermal fields utilized for district heating in Reykjavik. *Proceedings of the World Geothermal Congress 2000*, Japan, pp 831-835.

Hauksson, T., Thorhallsson, S., Gunnlaugsson, E. and Albertsson, A. (1995). Control of magnesium silicate scaling in district heating systems. *World Geothermal Congress 1995*, Florence.

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