International Geothermal Days POLAND 2004. Zakopane, September 13-17, 2004
Imternational Course on Low Enthalpy Geothermal Resources – Exploitation and Development

INTERNATIONAL SUMMER SCHOOL
on Direct Application of Geothermal Energy
POLISH GEOTHERMAL ASSOCIATION
International Geothermal Days
POLAND 2004

3.5.
GEOTHERMAL DISTRICT HEATING IN REYKJAVÍK, ICELAND

Einar Gunnlaugsson
Orkuveita Reykjavikur, Baejarhals 1, 110 Reykjavik
einarg@or.is

ABSTRACT

Geothermal district heating started on a small scale in Reykjavík in 1930. To day it serves more than half of the nation's population with hot water for heating. Orkuveita Reykjavíkur operates the largest municipal district heating service in the world. The harnessed power of the geothermal areas is about 700 MW thermal. Annually, about 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. About 70% of the energy used for district heating comes from low-temperature geothermal fields the other from high-temperature geothermal resources.

INTRODUCTION

The twentieth century was a period in rapid development and progress in Iceland. Hitherto Reykjavík a sleepy village community became expanding town and industrial sector began to develop. During the First World War coal was rationed and the winter of 1917-1918 proved to be one of the coldest in memory. This experience drove Icelanders to search for other fuel alternatives. 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. 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 drill holes was used to heat houses.

In 1910 an Icelandic businessman wrote to the Mayor of Boise for additional information and the response was published in local newspaper. In 1908, an enterprising farmer began leading hot water from a spring in pipes into his farm for space heating purposes. The first large scale heating using geothermal water was initiated during the First World War by an owner of a woolen factory who led hot water from nearby spring in pipes into the factory and worker's housing. The practice spread througout the country and in 1930 at least 10 farmhouses in the south of Iceland were heated with geothermal water.

Drilling for hot water started in 1928 at the thermal springs in Reykjavík. Fourteen drill holes 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 Reykjavík. Shortly thereafter, a hospital, another schoolhouse, an indoor swimming pool and about 70 private houses were connected to the district heating. This is today the largest geothermal district heating service in the world.

About 87 % of all houses in Iceland are now 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 (Samorka home page).

ORKUVEITA REYKJAVÍKUR

Orkuveita Reykjavíkur 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 company. 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.

In the year 2001 the distribution systems were greatly enlarged when Orkuveita Reykjavíkur 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 Orkuveita Reykjavíkur.

The company operates 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 Orkuveita Reykjavíkur reaches from Kjalarnes northwest of the capital and all the way south to Hafnarfjördur, an area where more than half the nation's population lives.

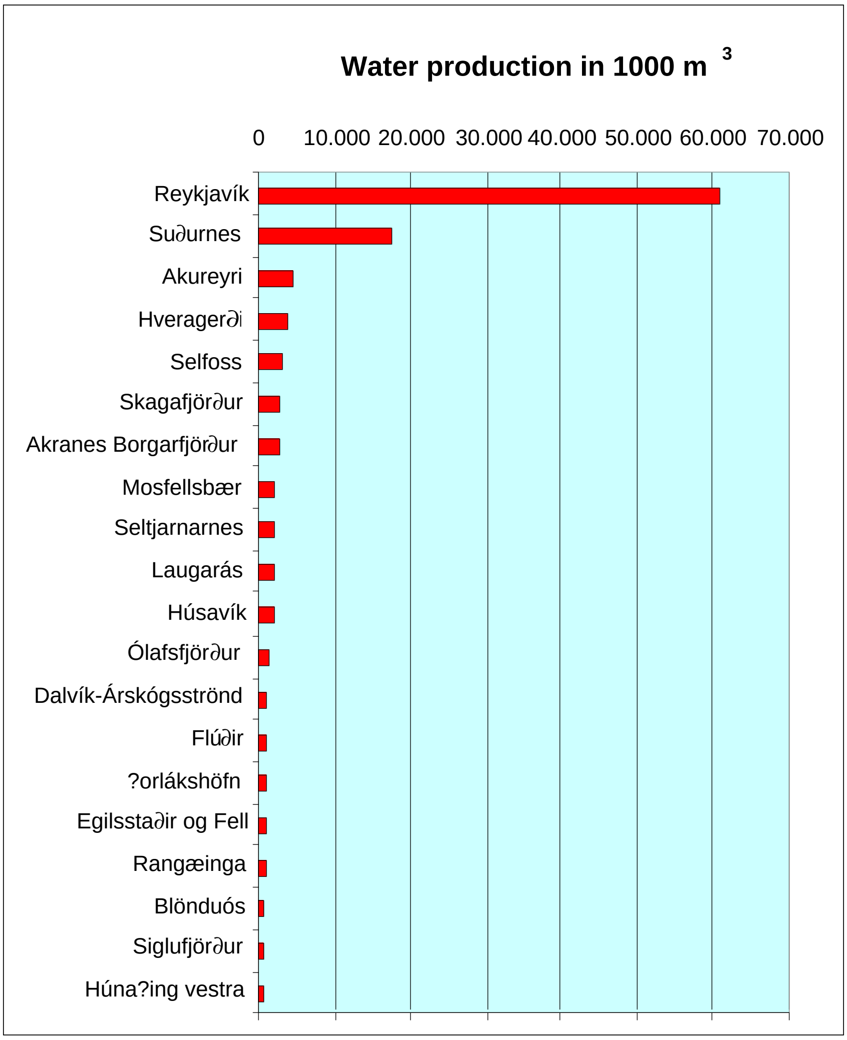


Figure 1: Water production of the largest disrict heating services in Iceland. Data from Samorka-home page.

District heating in Reykjavík started on a small scale in 1930. In 1933, about 3% of Reykjavík's population were connected to the Reykjavík District Heating. At that time, coal was mainly used for heating, and dark clouds of smoke were commonly seen over Reykjavík. Moreover, pipelines were laid to nearby municipalities, which are now supplied with geothermal water by the district heating in Reykjavík. The use of geothermal water in Reykjavík 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 Reykjavík 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.

GEOTHERMAL FIELDS

There are two types of geothermal areas, that is low-temperature areas and high-temperature areas. The division is based on temperature and geological characteristics of the areas. The general definition of the low-temperature areas is that its temperature is less than 150°C at a depth of approximately 1000 meters. These fields are characterized by warm and hot springs with little or no alteration around the springs, and vegetation often reaches up to the banks. In the high-temperature areas the water temperature is not less than 200°C at a depth of 1000 meters. The surface activity of these areas is much more divers than that of the low-temperature areas. Fumaroles are found along with boiling hot springs, mud pots and geysers. Generally the soil is very acidic making it inhospitable to vegetation. The water from the low-temperature fields can in many cases be used directly for district heating but water in the high-temperature fields contain relatively high content of dissolved solids and gases and can therefore not be used directly for district heating.

Low-temperature fields utilized for district heating in Reykjavík

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

The exploitation of geothermal water from the ***Laugarnes*** field began in 1928-1930 with the drilling of 14 shallow wells near the _vottalaugar 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, 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.

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

Table 1: Summary of the geothermal fields

Now there are 10 production wells in the field, which cover about 0.28 km^2 and is 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 ***Elli_aár*** 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 in Mosfellsveit***, 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 Reykjavík and by the end of 1943 about 200 l/s of 86°C water was available for heating houses in Reykjavík. 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 Reykjahlí_. 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.

High-temperature fields utilized for district heating in Reykjavik

The Hengill area east of Reykjavík is one of the largest high-temperature areas in Iceland. The geothermal activity is connected with three volcanic systems. 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 Reykjavíkur operates a geothermal power plant producing 90 MWe of electricity and about 200 MWt of hot water for space heating. On the southern site of the Hengill mountain Orkuveita Reykjavíkur is now preparing co-generating plant similar to the Nesjavellir plant. It is planed to be generating 120 MW$_e$ along with 400 MW$_t$.

At Nesjavellir 23 holes have been drilled. 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 drill holes to heat fresh ground water for district heating in the Reykjavík area. This stage was completed in 1990 with 100 MW$_t$ power, equivalent to about 560 l/s of 80°C water. 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).

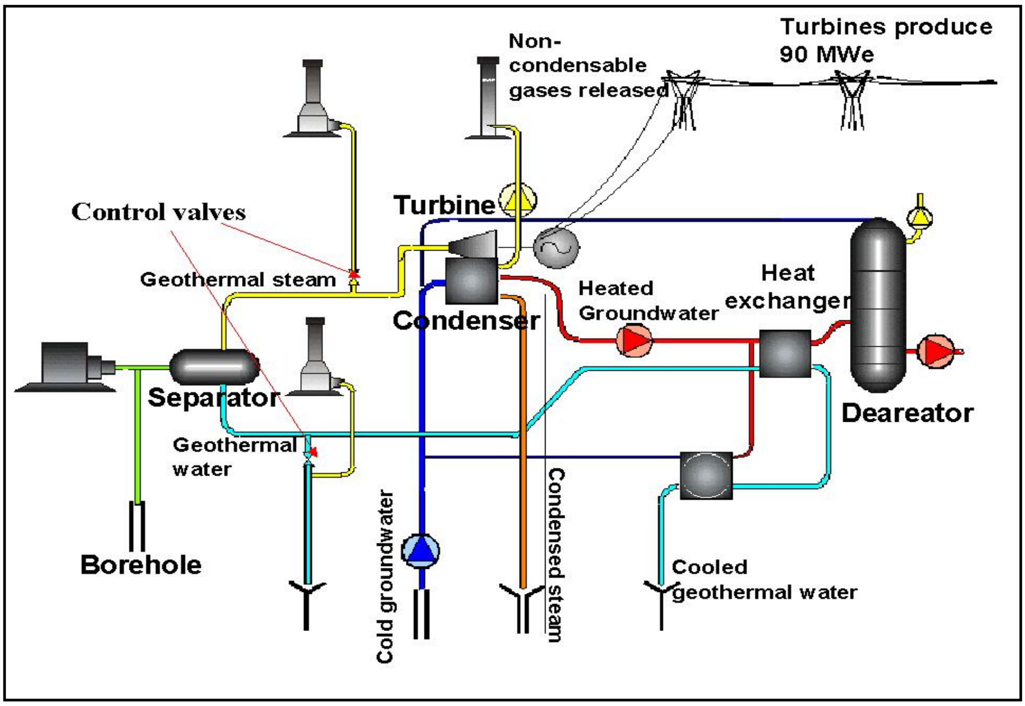


Figure 2: Simpified diagram of the Nesjavellir power plant.

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 utilized 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 utilized to 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.

The cold water is taken from drill holes 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.

CHEMISTY OF THE GEOTHERMAL WATER

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 Reykjavík 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 water from the high-temperature geothermal fields contains more dissolved solids than water from the low-temperature fields. The main component is silica, which may precipitate as the water is cooled down. Therefore cold groundwater has to be heated up in heat exchangers. But the groundwater is saturated with dissolved oxygen and it have to be removed from the water before it is used for district heating.

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

	Laugarnes	**Elli∂aár**	**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 (tot)	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	

The water from the high-temperature geothermal fields contains more dissolved solids than water from the low-temperature fields. The main component is silica, which may precipitate as the water is cooled down. Therefore cold groundwater has to be heated up in heat exchangers. But the groundwater is saturated with dissolved oxygen and it have to be removed from the water before it is used for district heating.

RESERVOIR STUDIES

Geothermal energy is generally classified as renewable resource. This is based on the fact that geothermal resources are steadily renewed, although the renewal takes place at different rate depending on the nature of the resources. Geothermal utilization involves energy extraction from geothermal reservoirs. The generating capacity of systems is often poorly known and they often respond unexpectedly to long-term utilization. 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 from one geothermal system to another. In addition, the methods of monitoring as well as monitoring frequency may differ. The basic parameters, which should be included in geothermal monitoring programs, are:

- 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.

The following chapters describe the monitoring of the low-temperature geothermal fields utilized by the Reykjavik Energy.

The Reykir in Mosfellssveit geothermal field

Aquifers can be correlated to faults and fractures. Annual variation in production is reflected in the water level (Figure 3). The water level was steadily decreasing until 1990 when it became possible to reduce pumping from the field when the new power plant at Nesjavellir 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).

The Laugarnes geothermal 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 disequilibria 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).

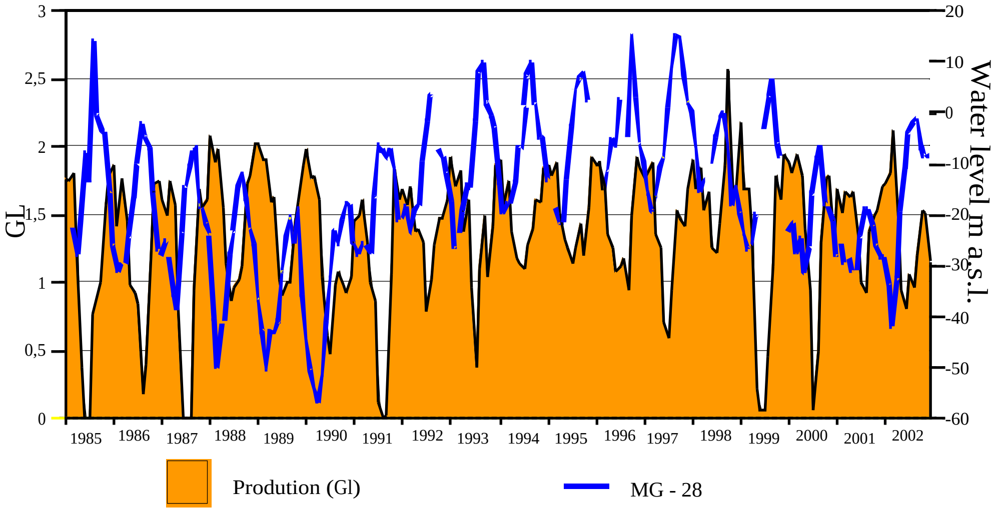


Figure 3. Production and water level at Reykir geothermal field

The Ellidaár geothermal 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).

THE DISTIBUTIN SYSTEM

Reykjavík District Heating uses either a single or a double distribution system (Figure 4). 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

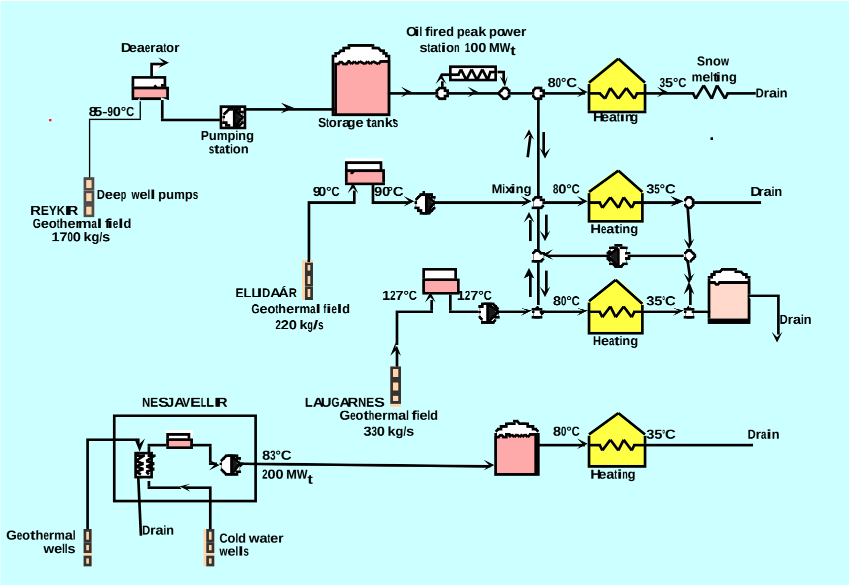
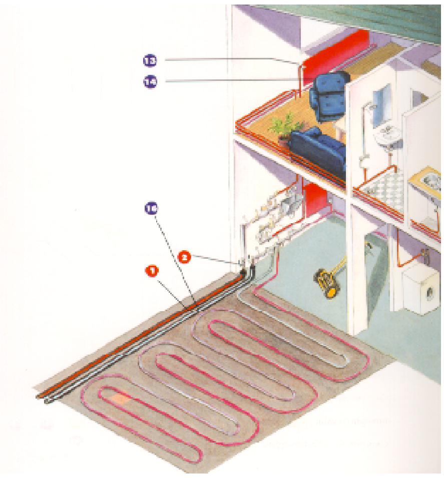


Figure 4: Simplified diagram of the district heating system in Reykjavik, Iceland

The geothermal water from Reykir in Mosfellssveit flows through a main pipeline to six tanks. The storage tanks usually meets the demand because the cold spells do not last very long. just outside Reykjavík that hold 54 million liters. From there, the water flows to six storage tanks on Öskjuhlí_ in mid-Reykjavík, 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 Reykjavík 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 annual production is about 60 million cubic meters of hot water.



About 85% of the hot water from Reykjavík 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 run-off water to melt snow of pavements and driveways (figure 5). The use of geothermal water for melting snow has been increasing during the last two decades. The total area of snow melting systems installed in Iceland is around 740,000 m^2 and the energy consumption is approximately 320 GWh annually. Half of this energy comes from used return water from space heating systems.

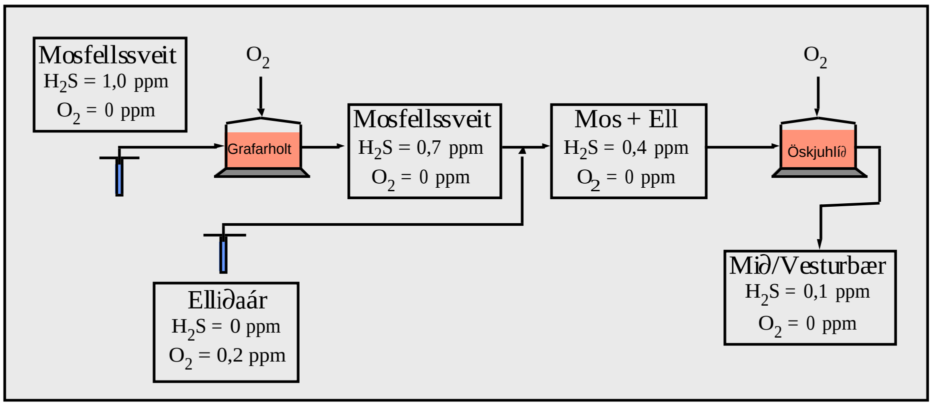
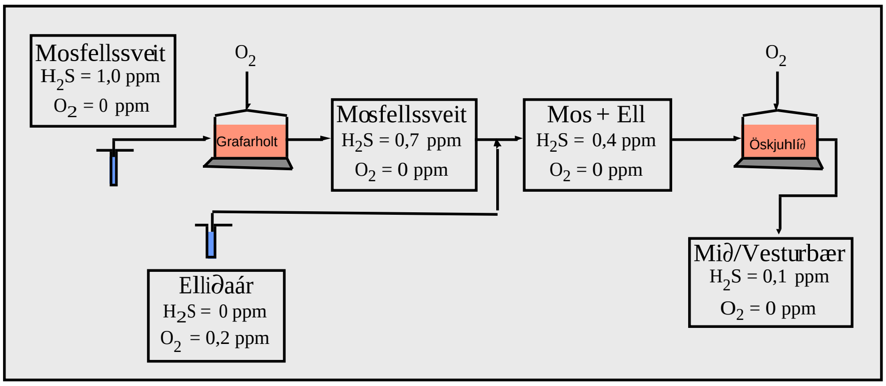


Figure 5: Run-off water used for smow melting



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 increases. 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 5). 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

BENEFITS OF GEOTHERMAL DISTRICT HEATING IN REYKJAVIK

Clean air in one of the main benefits of utilizing geothermal energy for space heating, and it has 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. Geothermal water for house heating is very compatible in price compared to other alternatives (figure 6), especially if environmental issues are taken into account. Space heating using geothermal water also allows cascading uses such as for swimming pools, green-houses, heated garden conservatories and snow melting.

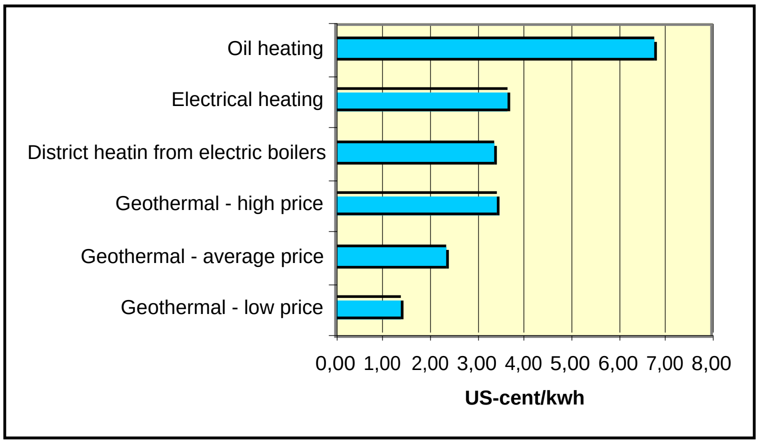


Figure 6: Comparison of prices of different heating sources for house heating in Iceland

FUTURE OF DISTRICT HEATING IN REYKJAVIK

Almost all houses in Reykjavik and surrounding communities are heated with water from geothermal fields (99.9%). The increase of inhabitants in this area is around 3-4 % per year. The low-temperature geothermal fields in Reykjavik are now fully utilized. Therefore the future energy for heating will come from the high-temperature fields in the Hengill area. Orkuveita Reykjavíkur is now developing the Hellisheidi geothermal field on the southern site of the Hengill complex. Deep research drilling was started in 2001 by drilling two wells, followed by the drilling of three wells in 2002 and two wells during the summer of 2003. Production drilling has started as well as construction of a 120 MW electrical and 400 MW thermal plant.

REFERENCES

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

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

Samorka home page – www.samorka.is