District heating in Reykjavík and electrical production using geothermal energy

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Abstract

The District Heating Utility in Reykjavík is the world's largest geothermal district heating service. 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 750 MW thermal. Annually, about 60 million cubic meters of hot water flow through the Utility's distribution system. The water from low-temperature fields is used directly. In the high-temperature field the steam is used to generate electricity and cooling water is used for district heating. New high-temperature field is now being developed for power generation.

Keyworws: *Reykjavík, district heating, geothermal fields, electrical production, future plans.*

1 Introduction

Reykjavík 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, Reykjavík Water Works merged with Reykjavík Energy. In 2001 a contract was completed for the mergers of Akranes utilities and the Borgarnes Heating Utility with Reykjavík Energy.

Reykjavík 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. Geothermal heat is one of Iceland's greatest natural resources. The capital city has enjoyed this inexpensive and reliable power source for more than 70 years. This paper deals mainly with the use of geothermal energy for space heating and electrical production.

2 Geothermal activity in Iceland

Iceland lies on the Mid-Atlantic Ridge, a spreading ridge and fracture zone forming an underwater mountain range and rifts splitting the earth's crust under the Atlantic Ocean from North to South. An active volcanic belt cuts across Iceland, corresponding fairly well with the interface between the American and Eurasian plates, which are diverging at the average rate of approximately two centimetres per year.

Geothermal activity in Iceland is closely related to these plate boundaries. High-temperature areas in Iceland total just over 20 and lie all within or on the perimeter of the active volcanic zones, frequently associated with central volcanic complexes. The energy source of these systems is magma, which ascends into the upper crust within the volcanic zones, usually in magma chambers in the roots of central volcanoes. Water and steam from high-temperature fields have a temperature above 200°C at a depth of 1000 m, but the highest recorded temperature is 380°C.

Low-temperature areas in Iceland total a few hundred and all lie outside or on the perimeter of the active volcanic zones. Many are without a doubt former high-temperature geothermal fields that have drifted out of the active volcanic zones and cooled. The water from low-temperature geothermal fields contains relatively low contents of dissolved solids and the temperature is below 150°C at a depth of 1000 m.

3 Harnessing of low temperature geothermal fields

In previous centuries, the utilization of geothermal heat was primarily limited to bathing and laundering. For hundreds of years, the residents of Reykjavík used the thermal springs in Reykjavík to wash their laundry. District heating in Reykjavík began in 1930; utilizing the water from boreholes close to the thermal springs. They provided 14 litres/second of water at 87°C. The water was piped 3 kilometres to a primary school in the eastern part of Reykjavík, which thereby became the first building in Reykjavík to be supplied with natural hot water. Soon more public buildings, including swimming pools, as well as about 60 private houses were connected to the hot water supply.

It was clear from the start that more geothermal water would have to be found to fulfil the requirements of the town of Reykjavík. A large geothermal area 17 km east of Reykjavík, Mosfellssveit area, was considered to be ideal both relatively close and capable of producing great quantities of geothermal water. The first house was connected to the geothermal water distribution from Mosfellssveit in 1943. Reykjavík District Heating could then deliver 200 litres per second of water at 86°C. By the end of the following year the number of connected houses reached 2850.

Test drilling and other research resulted in more geothermal water being found within the city limits of Reykjavík. In the beginning of 1962 as many wells as possible were harnessed and pumps installed to increase their output. It was also necessary to re-drill older wells in Mosfellssveit to increase their output. Several holes were drilled between 1967 and 1970 in the geothermal area by Elliðaár River. At the end of 1972 97% of houses in Reykjavík had geothermal water. Moreover, pipelines were laid to nearby municipalities, which are now supplied with geothermal water through the Reykjavík District Heating system (Gunnlaugsson et al., 2000).

4 The Hengill geothermal area

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. 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 Ölkelduháls is connected with this volcanic site.

West of these volcanic systems lies the Hengill system, with volcanic fractures and faults stretching from southwest to northeast through Hellisheiði, Nesjavellir and Lake Þingvallavatn. The most intensive geothermal prospects are associated with this fault zone, Nesjavellir farthest to the north, and Hellisheiði on the southern side.

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 Hveragerði, and at Nesjavellir, where Orkuveita Reykjavíkur operates a geothermal power plant producing 90 MWe of electricity and 200 MWt of hot water for space heating.

Orkuveita Reykjavíkur has had 22 deep wells drilled at Nesjavellir, ranging from 1000 to 2200 metres and temperatures up to 380°C have been measured (Steingrimsson et al., 2000). The construction of the Nesjavellir power plant began in early 1987 (Ballzus et al., 2000). 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 the fall of 1998, the first steam turbine was put into operation and the second in the end of the year. Additional holes were put online, increasing the total processing power to 200 MWt, with the water production reaching more than 1100 litres 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, that is, the collection and processing of steam from boreholes, the procurement and heating of cold water and the production of electricity.

The supply pipeline from Nesjavellir to Reykjavík is 800-900 mm in diameter and about 25 km long. It is designed for water of up to 100°C and to convey 1870 l/s. The pipeline is made of steel, insulated with rock wool covered with plastic and aluminium on the outside where the pipelines 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 Reykjavík, with temperature decrease less than 2°C. With increasing production the flow rate increases thereby decreasing the loss of heat and shortening the transport time.

5 The geothermal areas today

Presently three low temperature fields are utilized for district heating in Reykjavík and the high temperature geothermal field at Nesjavellir. The total installed capacity is about 750 MW_t. The low-temperature geothermal areas utilized for district heating in Reykjavík contain relatively low content of dissolved solids (Table 1) and can be used directly for heating and even cooking and drinking. This water almost fulfils the requirements of drinking water standards. Only the sulphide concentration is higher and the pH value. Although the water from the high-temperature field is dilute it has too high content of dissolved solids and gases to be used directly for house heating.

Table 1. 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		

The geothermal water from the wells in Reykjavík and in Mosfellsbær comprises about two thirds of the hot water in the distribution system. One third comes from Nesjavellir.

Throughout the exploitation good record has been kept on reservoir parameters of all the geothermal fields. This includes record on production and water level. All the low-temperature geothermal fields were overexploited for few years before the Nesjavellir plant was taken into operation. This can be seen if production and water level is studied for the areas. Figure 1 shows exploitation and water level for one of the low-temperature geothermal field during 17 years period. The production is shown as coloured area and the water level is shown by line. The main production is during the winter and the summer production is only one third to one half of the winter production. The water level on the other hand is low during the winter but higher during the summer. Besides this the water level was steadily falling until 1990. This is indicating overexploitation. In 1990 the Nesjavellir power plant began operation and it was possible to reduce the production from the low-temperature fields. This resulted in rising water level, followed by balance between production and water level, which indicated sustainability of these fields.

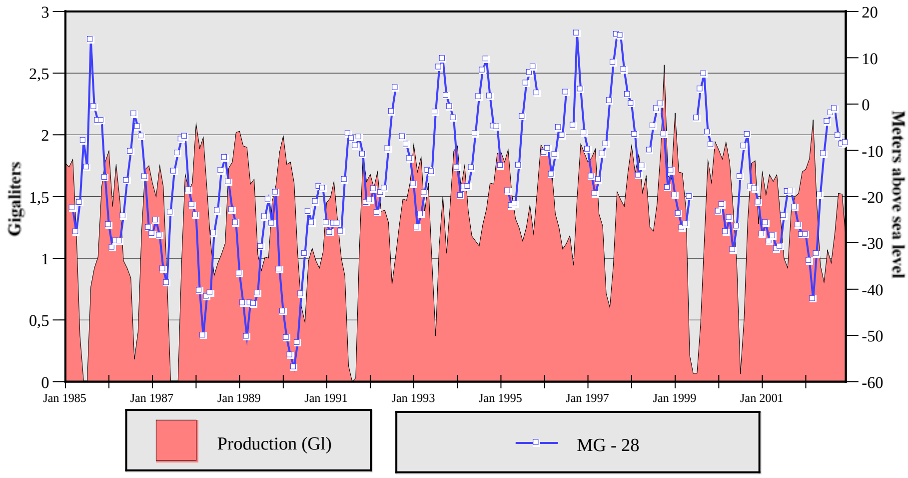

Figure 1: Production and water level for Reykjahlíð, Mosfellssveit.

6 The distribution system

The geothermal water from Reykir in Mosfellsbær flows through a main pipeline to six reservoir tanks just outside Reykjavík that hold 54 million litres. From there the water flows to six storage tanks on Öskjuhlíð in mid Reykjavík holding 24 million litres. 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 litres. 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 about 1300 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.

Reykjavík Energy uses either a single or a double distribution system (Fig. 2). In the double system the used geothermal water from radiators runs back from the consumer 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. The utility serves about 170 thousand people, and in 2002 they used about 63 million cubic meters of water, of which 7 million are recycled backflow waters. In the coldest periods about 3800 litres per second are required for space heating. About 85% of the hot water from Reykjavík Energy is used for space heating, 15% being used for bathing and washing. After the hot water has been used for space heating it is 25-40°C. In recent years it has become increasingly common to use this water to melt snow of pavements and driveways. 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 control to conserve the heat. Consumers pay for the geothermal water by volume in Reykjavík. It is therefore to their advantage to use the water wisely. The price of thermal water in Reykjavík is approximately one third of the price of heating with oil.

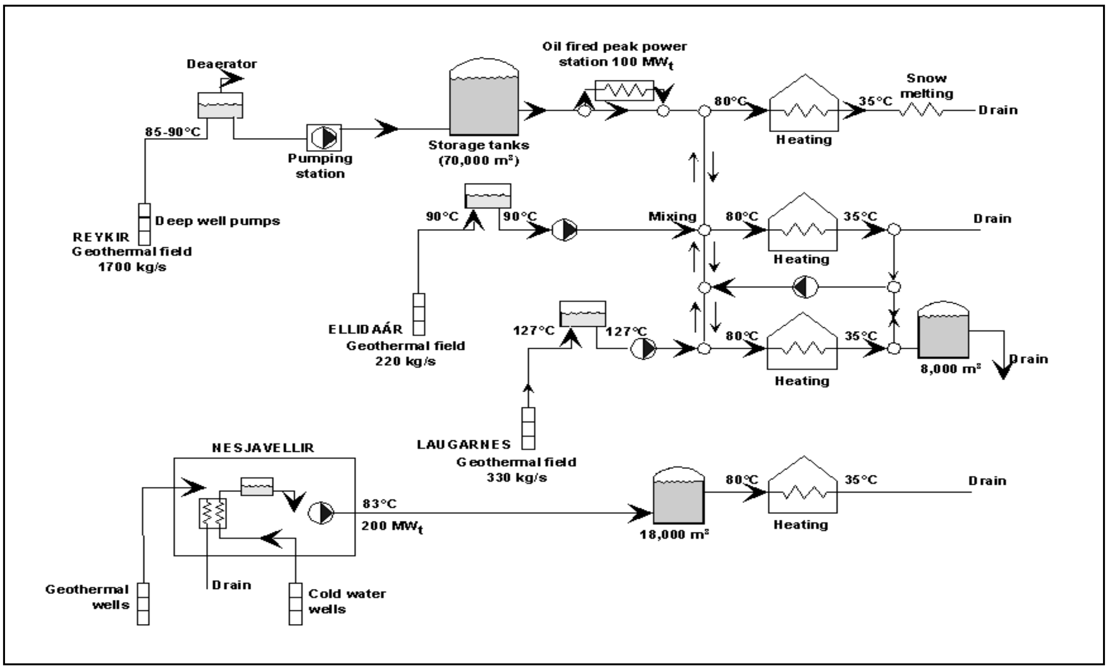

Figure 2: Simplified flow diagram for the district heating in Reykjavík.

7 Environmental benefit of district heating

Before 1940 the main energy source for space heating in Reykjavík was the burning of fossil fuels. At that time black clouds of smoke were common over Reykjavík, but since then geothermal energy has gradually replaced imported fossil fuel, and today over 98% of houses in Reykjavík and neighbourhood enjoy geothermal heating. It has been estimated that in 1960 the annual emission of greenhouse gases due to space heating in the Reykjavík area was about 270,000 tonnes. To day this figure is about 12,000 tonnes, all natural emission from the Nesjavellir high-temperature area (Gíslason, 2000). This is one of the main benefits of utilization of geothermal energy for space heating. Other benefits of the use of geothermal energy for district heating is that the energy is indigenous energy, it is relatively cheap and promotes cascading uses such as swimming pools, greenhouses, heated garden conservatories and snow melting.

8 Future plans at Nesjavellir and Hellisheiði

Numerical simulation model for the Nesjavellir field, taking into account 20 years exploitation history, indicates that the power production can still be increased. Decision has been taken to install the forth 30 MW_e-turbine and increase the thermal output to 300 MW_t. This expansion will be commissioned in 2005.

In recent years the Hellisheiði prospect on the southern side of the Hengill complex has been the subject of an intensive geothermal reconnaissance survey by Reykjavík Energy. 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 Hellisheiði field. Deep drilling was started in 2001 by drilling two wells, followed by the drilling of three wells in 2002. Two wells will be drilled in 2003. The location of the deep research wells is based on the results from the surface reconnaissance, and the drilling targets have been the young faults traversing the field, especially those that acted as magma feeders during the last eruption in the area 2000 years ago. The length of the boreholes is in the range of 1800-2300 m; four of the drillholes were deviated, and intercept the faults at 1000-1300 m depth, where the main aquifers have been found with total loss of circulation fluid. Up to 1000 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.

A flow test has been completed for three of the wells and two others are presently being tested. The steam already proven is sufficient for the production of 20-25 MW_e. 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 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 online in 2006.

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