HITAVEITA REYKJAVIKUR AND THE NESJAVELLIR GEOTHERMAL CO-GENERATION POWER PLANT

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BACKGROUND

When Ingólfur Arnarson sighted land on the voyage which would make him the first settler in Iceland, he threw the pillars of his high seat overboard and relied on the gods to direct him to where he should settle. His slaves found them washed ashore in a bay where "smoke" rose out of the ground. Therefore, they called it Reykjavik, "Smoky Bay." But the smoke after which Iceland's capital is named was not the result of fire, but was rather steam rising from hot springs.

Ancient records only mention the use of geothermal springs for washing and bathing. The best known examples are the Thvottalaugar (washing pools) in what is now Laugardalur in Reykjavik, and the hot pool where saga writer Snorri Sturluson bathed at his farm in Reykholt in western Iceland.

The first trial wells for hot water were sunk by two pioneers of the natural sciences in Iceland, Eggert Ólafsson and Bjarni Pálsson, at Thvottalaugar in Reykjavik and in Krísuvík on the southwest peninsula, in 1755-56. Further wells were sunk at Thvottalaugar in 1928 through 1930 in search of hot water for space heating. They yielded 14 liters per second at a temperature of 87°C, which in November 1930 was piped three kilometers to Austurbejarskóli, a school in Reykjavik which was the first building to be heated by geothermal water. Soon thereafter, more public buildings in that area of the city as well as about 60 private houses were connected to the geothermal pipeline from Thvottalaugar.

The results of this district heating project were so encouraging that other geothermal fields began to be explored in the vicinity of Reykjavik in Mosfellssveit, by Laugavegur (a main street in Reykjavik) and by Ellidaár (the salmon river) flowing at that time outside the city but now well within its eastern limits. Results of this exploration were good. A total of 52 wells in these areas are now producing 2,400 liters per second of water at a temperature of 62-132°C.

Reykjavik Energy (Orkuveita Reykjavikur) was established in 1999 by the merger of Reykjavik District Heating and Reykjavik Electricity. The company is responsible for distribution and sale of both hot water and electricity as well as the water works in the city. The total number of employees is 492 and the turnover in 2003 was 183 million US$.

District heating in Reykjavik began in 1930 when some official buildings and about 70 private houses received hot water from geothermal wells close to the old thermal springs in Reykjavik. Reykjavik District Heating (now Reykjavik Energy) was formally established in 1943 when production of hot water from the Reykir field, 17 km from the city, started. Reykjavik Energy is by far the largest of the 26 municipality-owned geothermal district heating systems in Iceland. It utilizes low-temperature areas within and in the vicinity of Reykjavik as well as the high-temperature field at Nesjavellir, about 27 km away. Today, it serves about 180,000 people or practically the whole population in Reykjavik and six neighboring communities (Table 1).

Table 1. Reykjavik Energy - District Heating 2003

Number of people served	179,085
Volume of houses served	42,607,000 m^3
Water temperature at user end	75°C
Number of wells in use	62
Installed capacity	830 MWt
Peak load 2003	593 MWt
Total pipe length	2,157 km
Water delivered	59,600,000 m^3/year

Figure 1 is a simplified flow diagram of the Reykjavik district heating system showing the Nesjavellir plant.

THE DISTRIBUTION SYSTEM

The geothermal water from Reykir in Mosefellsbær flows through a main pipeline to six reservoir tanks just outside Reykjavik that hold 54 million liters. From there, the water flows to six storage tanks on Öskjuhlíó in mid Reykjavik holding 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 freshwater 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.

Reykjavik Energy uses either single or a double distribution system (Figure 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

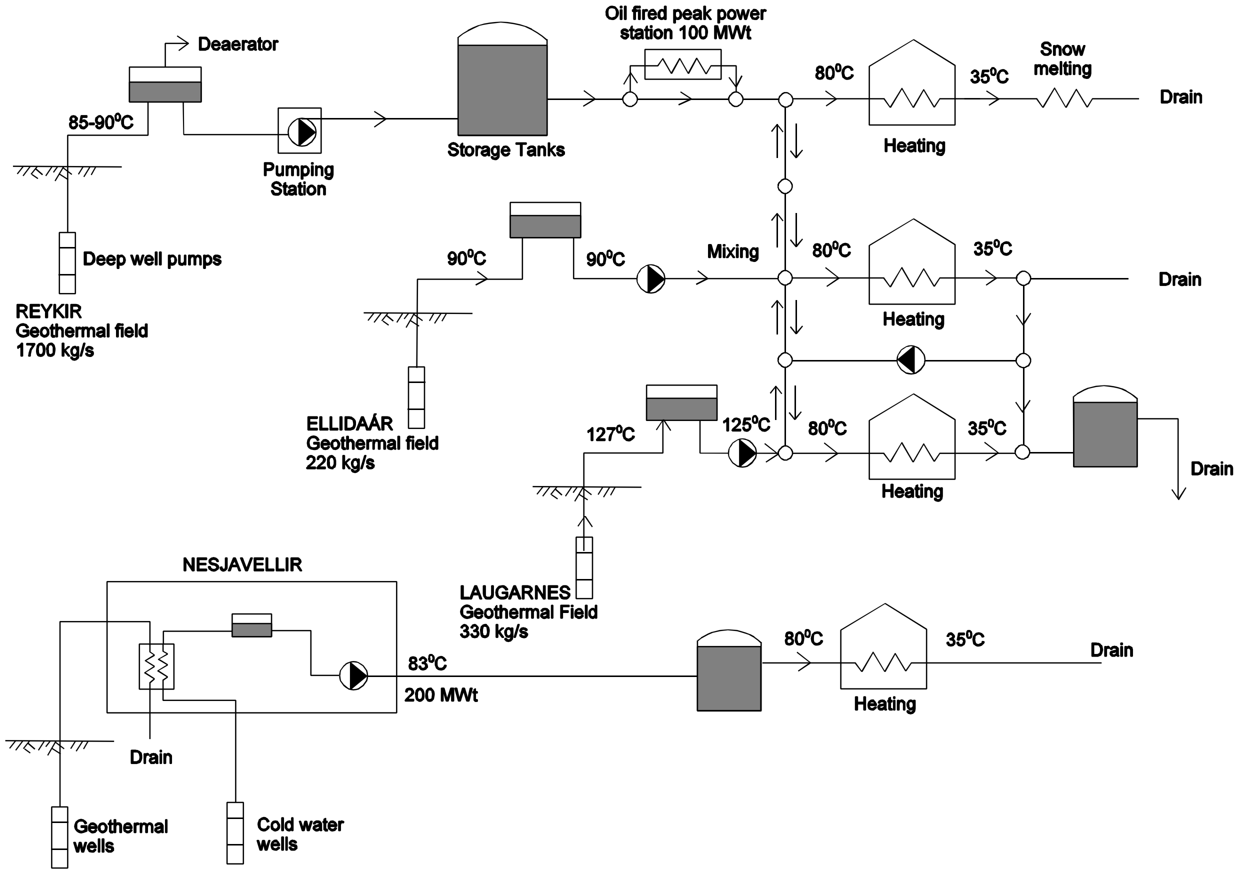

Figure 1. Simplified flow diagram for the district heating in Reykjavik.

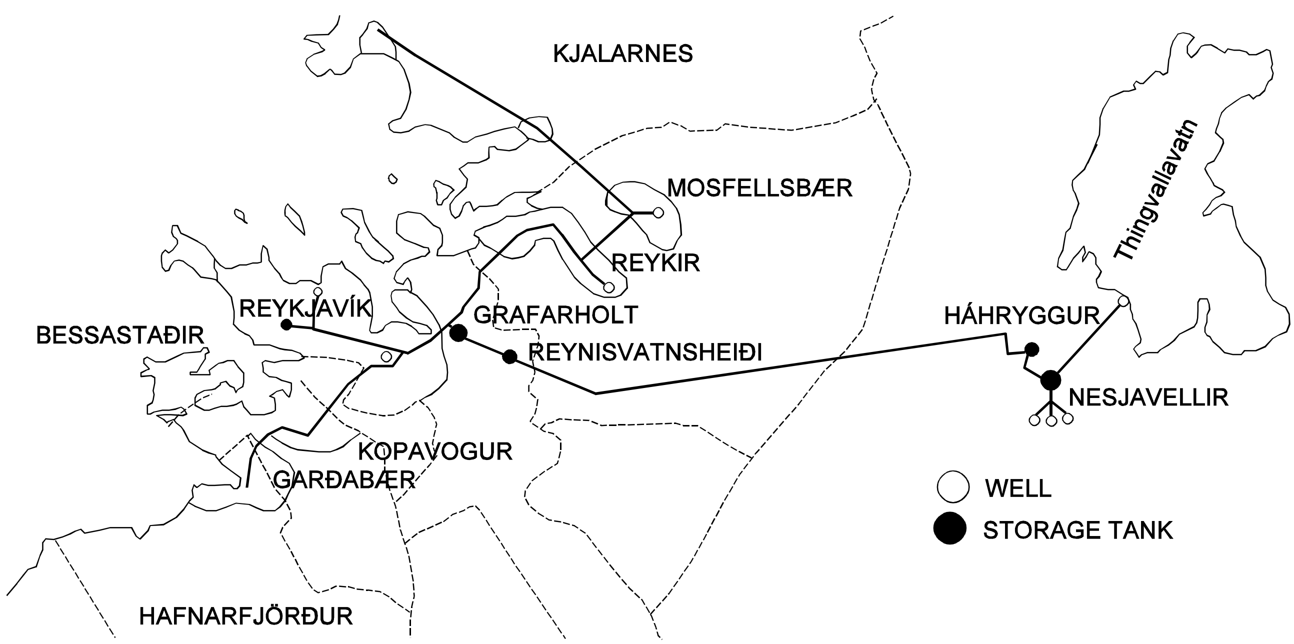

Figure 2. The hot water pipeline from Nesjavellir to Reykjavik.

geothermal water and serves to cool that water to the proper 80ºC, before being re-circulated. In the single system, the backflow drains directly into the sewer system. The utility serves about 170,000 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 liters per second are required for space heating. About 85% of the hot water from Reykjavik 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 25-40ºC. In recent years, it has become increasingly common to use this water to melt snow off 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 controls to conserve the heat. Consumers pay for the geothermal water by volume in Reykjavik. 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.

NESJAVELLIR PLANT

The Nesjavellir Geothermal Field is a high-enthalpy geothermal system within the Hengill Central Volcano in southwestern Iceland. The Nesjavellir Geothermal Power Plant was commissioned in 1990, following an intensive drilling and testing phase in the 1980s. By that time, 14 production boreholes had been drilled, and all except one were successful. Initially, the plant produced about 560 L/s of 82ºC hot water for district heating (100 MWt), using geothermal steam and water to heat cold groundwater. In 1991, the capacity was expanded to 150 MWt, and 1998 to 200 MWt. At that time, the production of electricity commenced with the installation of two 30-MWe turbines. In 2001, the third turbine was installed, increasing the capacity to 90 MWe. In 2003, the hot water production was increased to 290 MWt, and the fourth electricity turbine will be online production in 2005, bringing the capacity to 290 MWe. The stepwise increases in production are summarized in Table 2. Initially, only four geothermal wells were connected to the plant, but gradually more wells have been connected as the capacity of the power plant has been increased. Presently, 14 boreholes are connected to the Nesjavellir plant, including five new wells drilled in 1999-2003.

Table 2. Co-Generation of Electricity and Hot Water at Nesjavellir

	Hot Water		Electricity
	L/s	**MWt**	**MWe**
1990	560	100	
1991	840	150	
1998	1120	200	60
2001			90
2003	1640	290	
2005			120

The modular development of the Nesjavellir Power Plant is a good example of the development of a geothermal resource. Initially, the reservoir was tested with relatively small discharge/production, but with an intensive monitoring program and revisions of a numerical model of the resource has allowed increased production in line with the known potential of the field.

Plant Operation

A mixture of steam and geothermal brine is transported from the wells to a central-separation station at 200ºC and 14 bar. After being separated from the brine, the steam is piped through moisture separators to steam heat exchangers inside the plant building. The steam can be piped to steam turbines for co-generation of electricity. Unutilized steam is released through a steam exhaust.

In the steam heat exchangers consisting of 295 titanium plates, the 120ºC steam is cooled under pressure into condensate whose heat is then transferred to cold freshwater in condensate heat exchangers. The condensate cools down in the process to 20ºC.

Separated geothermal brine has its heat transferred to cold freshwater by geothermal brine heat exchangers

Cold water at 4ºC is pumped from wells at Grámelur, near the shore of Lake Thingvallavatn, to a storage tank by the power house. From there, it is pumped to the steam heat exchangers; where, its temperature is raised to 85-90ºC.

Since the freshwater is saturated with dissolved oxygen that would cause corrosion after being heated, it is passed through deaerators; where, it is boiled at low volume pressure to remove the dissolved oxygen and other gases, cooling it to 82-85ºC as described earlier.

Finally, a small amount of geothermal steam containing acidic gases is injected into the water to rid it of any remaining oxygen and lower its pH, thereby preventing corrosion and scaling.

A flow diagram of the process is shown in Figure 3.

Distribution

The Nesjavellir power station is situated at an elevation of 177 meters above sea level (Figure 4). The water is pumped by three 900-kW (1250-hp) pumps through a main pipeline of 900 millimeters in diameter to a 2000-m^3 storage tank in the Hengill area at an elevation of 406 meters.

From there, the water flows by gravity, through a pipeline which is 800 millimeters in diameter, to storage tanks on Reynisvatnheidi and Grafarholt on the eastern outskirts of Reykjavik (Figure 2). Those tanks are at an elevation of 140 meters above sea level, and have control valves to regulate the flow of water through the pipeline and maintain a constant water level in the tank in the Hengill area.

From the storage tank, near Reykjavik, the water is fed through pipelines to the communities which are served by Orkuveita Reykjavikur.

From Nesjavellir to Grafarholt, the transmission pipe measures about 27 kilometers in length, and has fixed and expansion points every 200 m. It is designed to carry water at

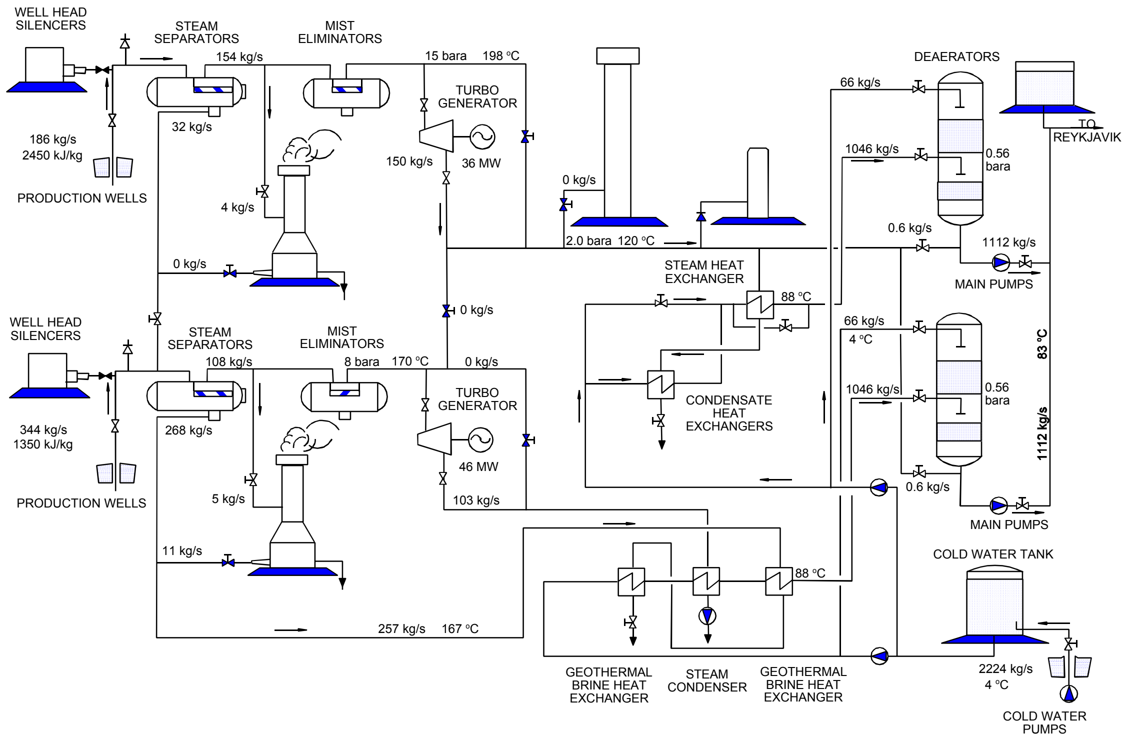

Figure 3. Flow diagram of the Nesjavellir plant.

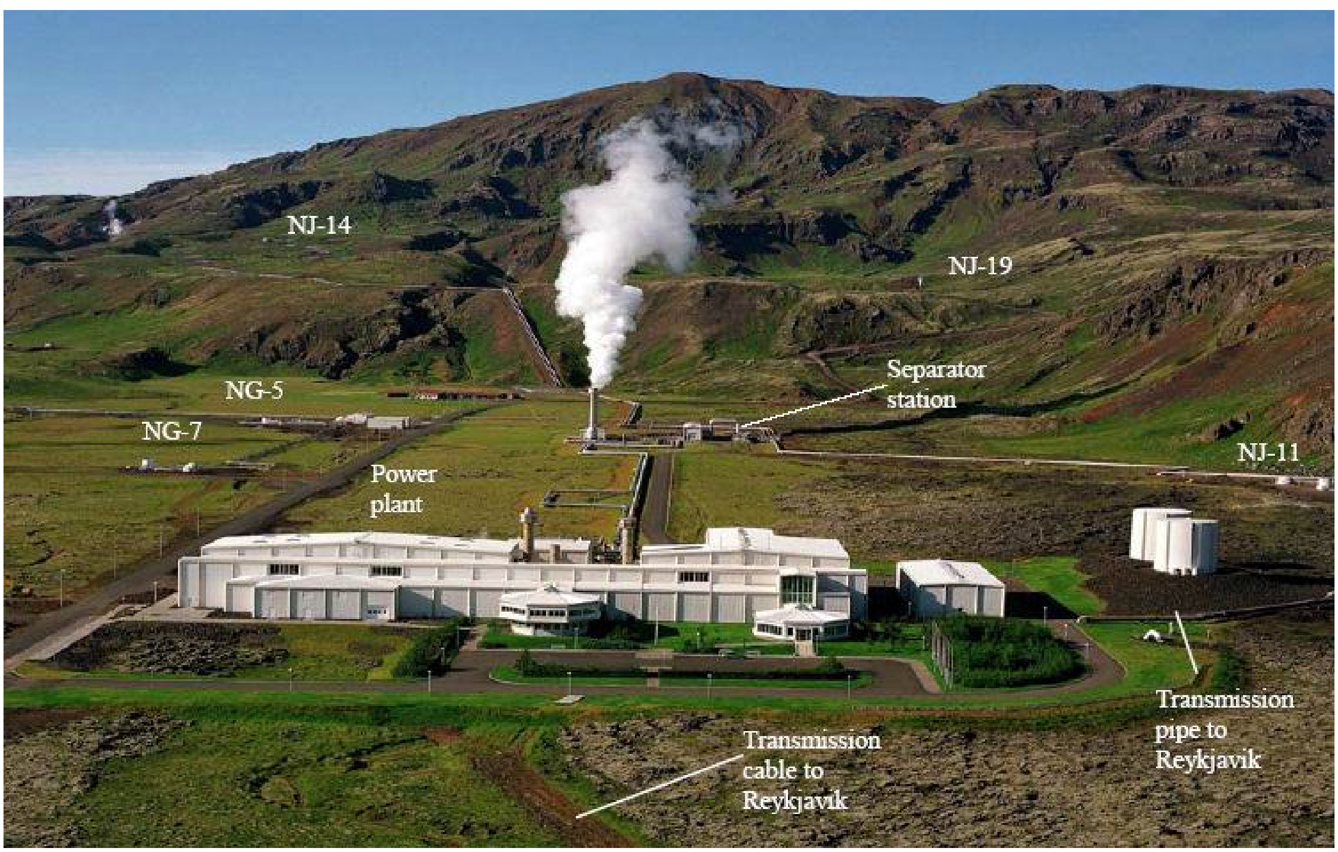

Figure 4. Overview of the Nesjavellir plant site.

up to 96ºC, with a transmission rate of 1,870 liters per second. During phase one of the project, its flow rate was around 560 liters per second; whereby, the water took seven hours to run the length of the pipe and cooled by 2ºC on the way. Good insulation and a high volume of water are the most crucial factors contributing to this low heat loss. At later construction stages at Nesjavellir, the flow rate will be tripled, reducing the heat loss to less than 1ºC.

The 8-to10-mm thick steel pipe is insulated with 100 mm of rock wool and covered with aluminum sheets; where, it lies above the ground, and insulated with polyethylene and covered with PEH plastic where it lies underground. A corrugated plastic vapor barrier is located under the aluminum skin to keep the rock wool insulation dry. Drip holes are provided at bearing plates to remove any condensation. Its high insulative properties are shown by the fact that snow does not melt on the part that lies above the surface. For environmental and traffic reasons, a 5-kilometer section of the pipe is underground. The surface section also runs under automobile crossings at several points which have been well marked. Provisions are also provided for snowmobile crossings in winter (Figure 5).

Figure 5. The 800-mm diameter pipeline with a snowmobile crossing.

ENVIRONMENTAL BENEFIT AND MONITORING

Before 1940, the main energy source for space heating in Reykjavik was the burning of fossil fuels. At that time, black clouds of smoke were common over Reykjavik, but since then, geothermal energy has gradually replaced imported fossil fuel, and today, over 98% of houses in Reykjavik and neighborhoods enjoy geothermal heating. It has been estimated that in 1960, the annual emission of greenhouse gases due to space heating in the Reykjavik area was about 270,000 tonnes. Today, this figure is about 12,000 tonnes, all natural emission from the Nesjavellir high-temperature area. 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.

A program to monitor the response of the Nesjavellir geothermal system as well as to record the influence of the utilization on the environment has evolved through the lifetime of the Nesjavellir project. A program was set up to monitor the natural runoff from the field in the early 1980s, prior to the drilling and testing of production wells. Ever since drilling commenced in the 1980s, downhole measurements and flow testing has been a part of the monitoring program as well as chemical sampling. Currently, the monitoring program is put forward in a number of written operation procedures, and since 2003, the monitoring program fulfills the requirements of ISO 9001.

The volume of discharge from the Nesjavellir geothermal reservoir is monitored and the figures are updated annually (Figure 6). The calculations are based on daily records on the operation of each well, using the setting of a control valve (if present), wellhead pressure and flow measurements. During the drilling and testing period in the 1980s, flow measurements were frequent, but after production started, these measurements are limited to short test periods, usually during the few maintenance stops of the power plant. The cumulative extraction of fluid is, therefore, evaluated from wellhead pressure using an established flow rate/wellhead pressure output curve for each well. The combined monthly discharge from all the wells is calculated and compared to the measured volume of geothermal steam and water in the separation station. Experience shows that there is a good agreement between these two independent methods; generally, the difference is less than 1%.

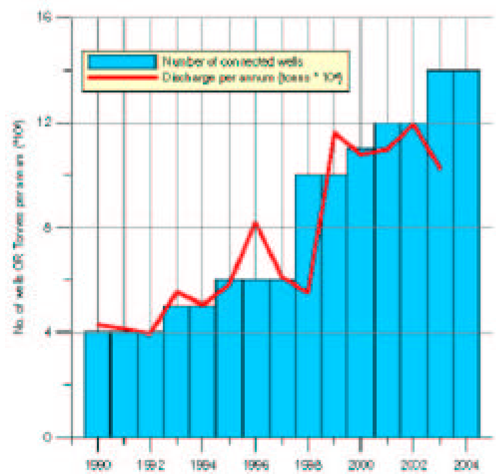

Figure 6. Annual discharge and the number of connected production wells.

Geothermal steam and water from 14 production wells are gathered in a central separator station, supplying up to 1100 kg/s of water. Electricity is generated in condensing steam turbine units. The exhaust steam from the turbines is used to preheat freshwater in the condensers. The separated geothermal water is used in heat exchangers to heat the preheated water up to the required temperature. Finally, the water is treated in deerators to suit the requirements of the distribution system. Thus, the steam and the separated geothermal water are utilized, in the most economical way possible, for co-generation of electric and thermal power, which is also good for the environment as less heat is released to the atmosphere than in conventional geothermal plants.

Comparison with alternative energy sources show that CO_2 and sulphur released to atmosphere, by using geothermal energy, is relatively small for the power production at Nesjavellir (e.g., the average amount of CO_2 released is within 1% of that of a conventional oil or coal-fired power plant of similar capacity).

ACKNOWLEDGMENTS

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