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LONG DISTANCE TRANSMISSION PIPELINES FOR GEOTHERMAL WATERS IN ICELAND (20-60 KM)

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ABSTRACT

In Iceland there are about 30 geothermal district heating systems in operation in towns and villages and some 200 networks in rural areas. Many of these have invested in long transmission pipelines to obtain hot geothermal water to provide sustainable energy for the house heating. This paper describes three of these long transmission pipelines, how they started, how they were designed in the beginning and how they developed with time. The pipelines are all economical and some very economical. They serve the majority of the population in Iceland.

One of this pipelines which is 18 kilometres long has been in operation since 1970's or almost 40 years. Another pipeline which is over 60 kilometres long has been in operation for over 25 years and the largest pipeline serving the capital city of Reykjavik is 900 mm in diameter, 23 kilometres long and has been successfully in operation almost 20 years.

Also described is the geothermal heating of the rural area where typically few farmers or very small communities pool their resources and ploughs in very long plastic pipes for heating.

Using all methods in utilizing the geothermal hot water in Iceland like constructing unusually long transmission pipelines has both been economically and environmentally successful. The expansion of the geothermal heating systems has resulted in gradually increasing the share of geothermal energy used for space heating from 43% of all houses in Iceland in the 1970's to 90% today.

1. INTRODUCTION

Geothermal energy is widely used in Iceland for space heating. The energy is not readily available in all communities so the hot water in some areas has to be pumped along long transmission pipelines to villages, towns and cities. It is not unusual to pipe geothermal hot water as long distances as 20 kilometres to heat up houses. The longest single pipeline is 62 kilometres from the geothermal sources to the consumer in a town. All this is done in an economical manner and is always more economical then using oil for heating as was done previously.

In Iceland there are more then 30 geothermal district heating systems in operation in towns and villages and some 200 networks in rural areas. In most cases they serve practically the total population of the respective communities and now totally about 90% of the space heating market of the country. All of them are community-owned, except some rural ones. And they distribute and sell hot water on the bases of a monopoly.

Following the oil price hikes of the 1970s, great steps were taken to reduce the oil consumption widely used for space heating by utilizing the geothermal water available. Steps were taken to pump geothermal water economically long distances in transmission pipelines to towns and communities thus reducing or eliminating the use of oil. Three examples of transmission pipelines will be described, including the longest one and also the largest one. The pipelines described are the following;

1. Húsavik Geothermal system, a DN350 a un-insulated asbestos cement pipeline, 19 kilometres long, built 35 years ago and has expanded to a very successful multi purpose system.
2. Akranes and Borgarfjörður District heating system (ABDHS), a DN450 and DN400 partially insulated asbestos cement pipeline, 62 kilometres long built 30 years ago and still running successfully.
3. Reykjavík Energy, a DN900 mm insulated steel pipe, 23 kilometres long, feeding the capital city Reykjavík with around 2,000 m³/h in the first stage started 20 years ago, but has now the capacity of 6,000 m³/h in the final stage.
4. Small rural district heating systems with up to 10 kilometres of mains feeding typically few farms or very small communities.

2. HÚSAVÍK GEOTHERMAL SYSTEM

Húsavík is a small township in northern Iceland with around 2,500 inhabitants. The main industry is fishing and tourism, mainly whale watching tourism.

In the distance of 20 km south of the town is a hot spring at Hveravellir with 100 °C free flowing hot water on the surface. Free flow from the Hot Spring is approx. 40 l/s (150 m³/h) at a constant rate.

Around the year 1970 it was decided to utilize this hot water to heat up the houses at the town of Husavik. At that time most of the houses were heated with oil. The cheapest solution was chosen using DN350 mm asbestos pipes un-insulated but buried in soil. Total length from the Hot Spring to Húsavík was 18.6 km and the temperature drop was around 15°C.

There is around 100 m elevation difference between the Hot Spring and the town at the coast so no pumping was required.

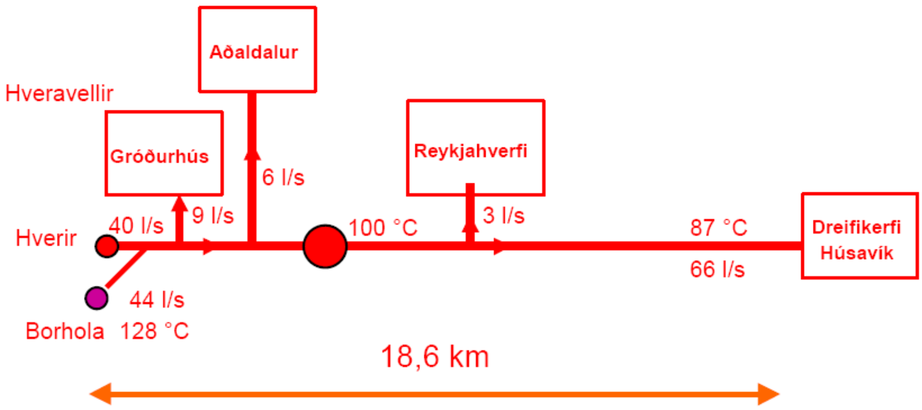

FIGURE 1: Schematical drawing showing pipes, temperature and flow
for Husavik geothermal system in the first years.

Gradually the demand increased, farms in the vicinity were connected to the system and small industry started using the hot water. The demand rose and wells had to be drilled to support the increased demand from 40 litres per second (150 m³/h) to 150 litres per second (500 m³/h).

The increased consumption of hot water in Husavik and vicinity and the long age of the pipeline led to the evident conclusions that the pipeline had to be renewed and increased in size. The main premises for this new investment were as follows:

- Have sufficient hot water available for all the consumers
- Increase the safety of the delivery.
- Attract new consumers and support different use of geothermal power.
- Utilize the available power at Hveravellir.
- Reduce the heat loss in the pipeline.
- Assure the right temperature in the hot water to the consumer.

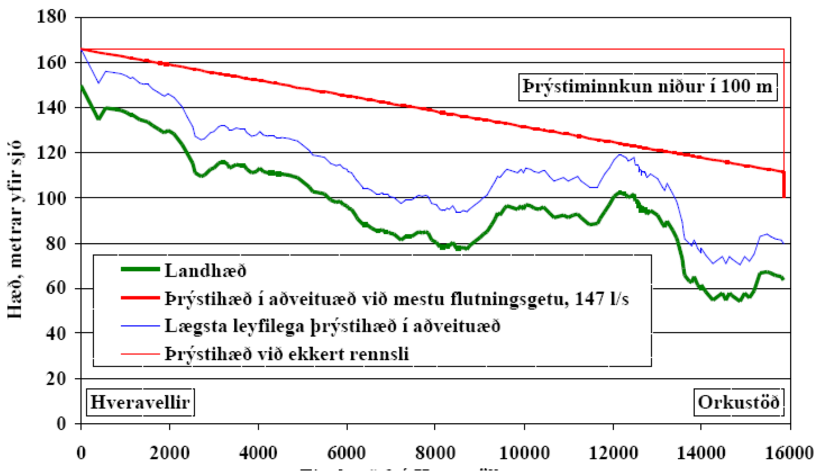

FIGURE 2: Drawing showing longitudinal section of pipeline from
Hveravellir to Husavik and pressure line.

Thirty years after the geothermal project started the decision was taken to build a new 16 km long DN400 mm steel pipe insulated with polyurethane and with a 560 mm in diameter PHE plastic coat. The pipeline was designed to carry up to 147 litres per second of 130°C hot water. The pipeline was installed at +70°C with no expansion compensators for tension or compression.

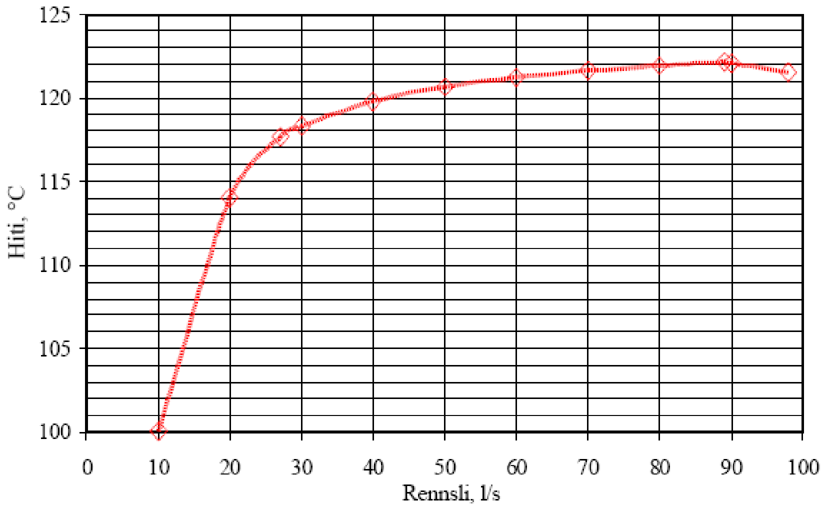

FIGURE 3: Water temperature in pipeline at the end station with regards to water flow in pipe.

The flow in the pipeline depends of the usages of hot water at different users and at different seasons (less in the summertime). Maximum flow rate without pumping is 147 litres per second (530 m³/h) and maximum pressure in the pipeline is 15 bar which occurs when the flow is suddenly stopped.

At 95 litres per second flow rate the water cools down from 124°C to 121°C or by 3°C along the 16 km long pipeline.

Since the water from the wells was around 124°C it was decided to cool the water down to an appropriate level (around 80°C) for space heating by installing a turbine and generator with so called Kalina technology to produce electricity. The generator chosen can produce up to 2.0 MW of electricity.

The Kalina technology is based on the generation of electrical power by using the geothermal heat-energy in order to vaporise a mixture of ammonia and water, which is running in a closed circuit. The geothermal water heats up the ammonia-water solution to make the vapour that drives the turbine. After the turbine the vapour goes to a condenser using 170 litres per second of 4°C cold water. The condenser water is then used for fish farming and out door swimming pool.

The mixture of ammonia-water makes this technology exceptional and the Husavik plant is the first commercial plant using this technology. The Kalina technology has been developed over two decades; however the commercial marketing of the technique started only a few years ago.

The long transmission pipeline that started back in 1970's has turned out to become one of the best examples on how the geothermal energy can be utilised at different temperatures for separate uses or as shown above in multiple purpose use for the benefit of all.

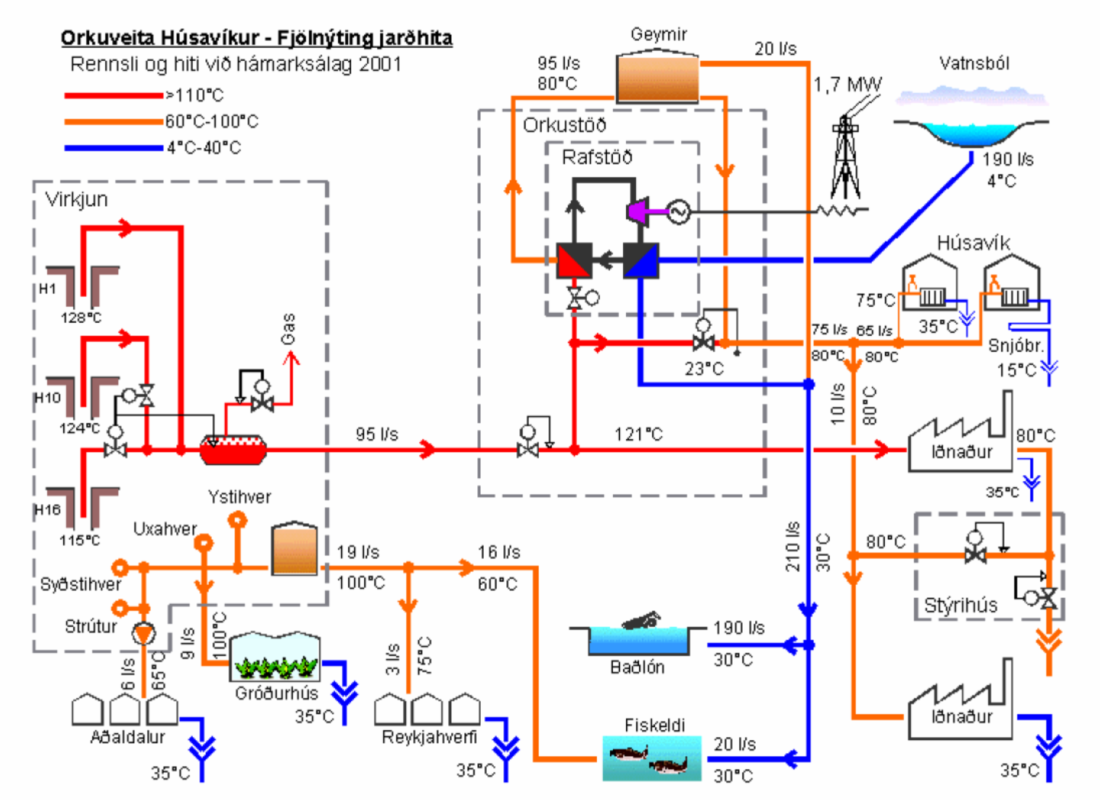

FIGURE 4: Drawing showing multiple use system at Husavik Geothermal System today

3. AKRANES AND BORGARFJÖRÐUR DISTIRCT HEATING SYSTEM

In previous centuries, the utilisation of geothermal heat was primarily limited to bathing and laundering. The Icelandic Book of Settlement, the Bishops Sagas and the Sturlunga Saga cycle mention the use of hot pools for bathing, the most famous instance of which is certainly the Pool of Snorri Sturluson in Reykholt (1179-1241).

FIGURE 5: This is the well preserved thermal pool from the middle Ages, where Snorri used to bath. There was a tunnel from the bath tub to the house, see the entrance in the back.

Close to the famous old bath is the largest natural thermal spring in Iceland, Deildartunguhver. It provides 180 litres per second (650 m³/h) of 96°C hot water and is the largest hot spring in Iceland.

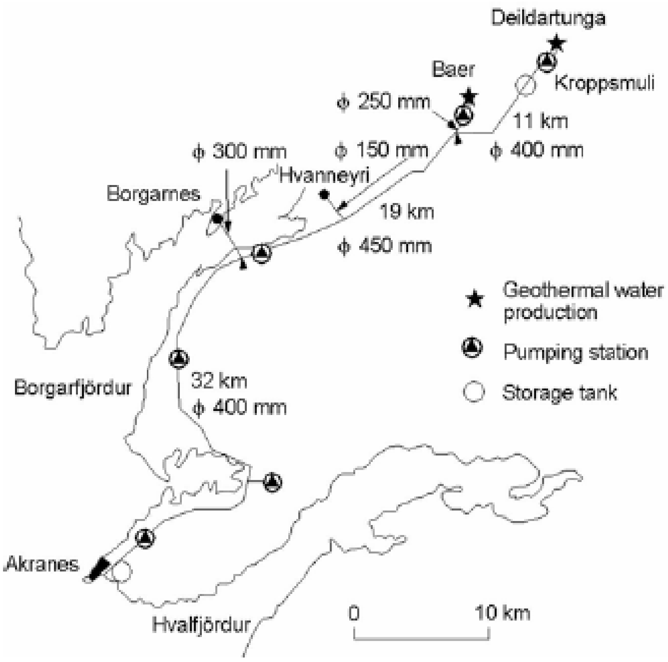

FIGURE 6: Map showing pipeline location.

Akranes and Borgarnes are two towns in the western part of Iceland with the population of 5,200 and 1,700 inhabitants respectively. These towns were heated with oil but the distance to the famous hot spring at Deildartunga is 34 kilometres and 64 kilometres respectively. The thought of pumping this water to the nearest towns, 30 and 60 kilometres, was always considered inconceivable.

After the increase in oil prices in the early 1970s, a study was made on feasibility of piping the hot water at Deildartunga to Akranes and Borgarnes, in addition to farms and smaller communities in the vicinity. The study was positive using asbestos cement pipes buried in the ground and a decision was taken to build the longest transmission pipeline known of for the hot water, total of 64 kilometres. Hot water started flowing in the pipeline in 1980.

The transmission pipeline from Deildartunga to the storage tank at Akranes is 62 kilometres long and probably the longest geothermal transmission pipeline in the world. Most of the pipeline (43 km) is a DN400 mm and the rest (19 km) a DN450 mm. The majority of the transmission pipeline is made of asbestos cement due to the low cost. Steel pipe was too expensive to compete with the oil price. However, it is rather fragile and the pipeline suffers from frequent breaks. It should be pointed out that the system was build short time before asbestos was recognized as hazardous to people's health and later forbidden as a pipe material.

No foundations as such were laid under the asbestos pipe. The ground was simply levelled using volcanic ash as bedding material. The exposed surface was insulated with 50 mm thick rock wool segments. About 2/3 of the pipeline surface is insulated in this way. A trench was dug alongside the pipeline and the excavated earth used to cover the pipeline. The parallel trench serves as a drain channel.

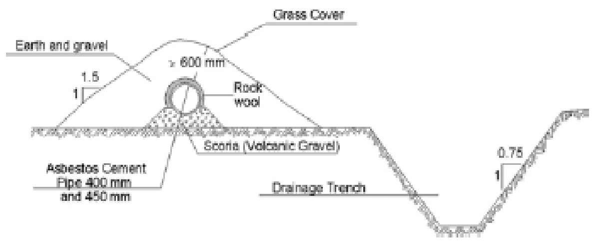

FIGURE 7: Cross section of the asbestos transmission pipline

The inlet water temperature to the transmission pipeline at Deildartunga is 96°C. The temperature drop along the pipeline depends strongly on the flow rate, resulting in considerable drop at low flow rate. It takes around 24 hours for the hot water to flow from the Hot Springs to the consumer at the end. The temperature drops on the average is 20°C on its way to the end point. The temperature in the winter time is around 82°C in Borgarnes (34 km distance) and only 77°C in Akranes (64 km distance). The flow rate is regulated to keep supply temperature almost constant.

FIGURE 8: The asbestos cement pipes on the harbour in Akranes before the construction started.

FIGURE 9: The asbestos cement pipes being laid above ground, insulated.

FIGURE 10: The asbestos cement pipes being laid into ground, un-insulated.

The total consumption of hot water was expected in the beginning 86 litres per second (310 m³/h) with the expected consumption of 113 litres per second (410 m³/h) in 20 years. Today the flow rate is 170 litres per second (600 m³/h) in winter time.

The asbestos pipeline has performed satisfactorily in spite of between 20 and 30 breaks each year. They are detected automatically and repaired quickly. In most cases the consumer does not notice these breaks.

The expected lifetime for the pipe was 20 years. The pipeline is now more then 25 years old and has shown that this project was the right decision.

Because of the high investment cost of the system the heating cost for the consumer in Akranes and Borgarnes has been among the highest of all distribution heating systems in Iceland. Despite this, the system has unquestionably proven to be a good investment in the long run, especially if factors like saving in importing of oil and environmental benefits are considered.

4. REYKJAVÍK ENERGY

The Reykjavík District Heating began operation in 1930, utilising the hot geothermal water from boreholes in Laugardalur close to Reykjavik centre. They provided 14 litres per second (50 m³/h) of water at 87°C. This was piped 3 kilometres to Austurbær Primary School in the eastern part of

Reykjavík which thereby became the first structure in Reykjavík to be supplied with hot water by the Utility.

The Reykjavík Energy now services an area housing about 183.000 inhabitants or more then half the population of Iceland. The housing heated with geothermal energy is approximately 26,000 and the harnessed power of the geothermal areas, including Nesjavellir, is about 700 MWt. Annually, about 60 million cubic meters of hot water flows through the Utility's distribution system.

One of the main sources of geothermal energy comes from Nesjavellir which is located about 30 kilometres from Reykjavík. Nesjavellir geothermal power plant is situated in the Hengill area, which is a high-temperature area. The plant itself generates 120 MWe of electricity and delivers 300 MWth as heat to the Icelandic capital of Reykjavik, 27 km away.

It was not until 1965 that test drilling began at Nesjavellir. This continued, with several pauses, until 1986. The construction of the Nesjavellir Power Plant began in 1987 and was formally started in 1990. Today it is a part of the largest and most modern geothermal district heating system in the world and Iceland's largest geothermal combined heat and power plant (CHP). A total of 25 boreholes (wells) have been drilled in the Nesjavellir area at depth ranging from 1000 - 2200 m and temperatures as high as 380°C have been measured.

Construction of the Nesjavallir transmission pipeline began in 1987, with the first stage being completed in 1990, pumping 560 litres per second (2,000 m³/h) of hot water to Reykjavík along the 23 kilometres long pipeline.

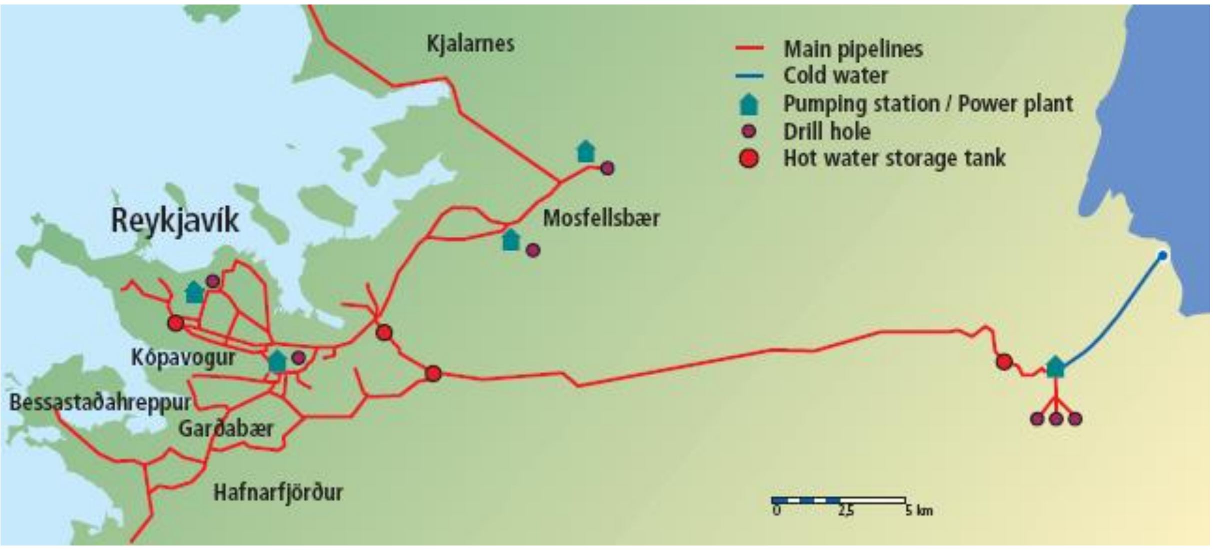

FIGURE 11: Main Pipelines from Nesjavellir and in and around Reykjavik

The power station at Nesjavellir is at 177 meters above sea level. The hot water is pumped from there through a steel pipe into a tank on Háhryggur near Hengill. The ridge is at 406 meters above sea level. The first stage of the pipeline to Reykjavík is 900 mm in diameter; it then becomes 800 mm and feeds into tanks on the Reynisvatn. These tanks are at 140 meters above sea level. There is gravity flow between Háhryggur and Reynisvatn, where control valves manage the flow through the supply line and keep the water level in the Háhryggur tanks constant.

From the tanks at Reynisvatn, the pipeline runs south, supplying water from Nesjavellir to the towns around Reykjavík such as Kópavogur, Garðabær, Bessastaðahreppur and Hafnarfjörður.

The supply line from Nesjavellir to Reynisvatn is 23 kilometres long. It is designed for water of up to 100°C in temperature and can convey 1870 litres per second (6,700 m³/h). In the first stage of the project, the pipeline conveyed 560 litres per second (2,000 m³/h). At this flow rate, the water took less then seven hours to flow from Nesjavellir to Reynisvatnsheiði, with the temperature decrease less then two degrees. Good insulation and a large quantity of water are the main factors in how little loss of heat there is. In the second stage of the project, the maximum flow increased to 840 litres per second (3,000 m³/h), and in the third stage to about 1100 litres per second (4,000 m³/h). As more water is produced the flow rate increases thereby decreasing the loss of heat and shortening the transport time. The maximum flow today is around 1680 litres per second (6,000 m³/h).

FIGURE 12: Pipeline made of steel, insulated with rock wool covered with plastic and aluminium on the outside where the pipeline lies above ground, but with urethane insulation, covered with plastic, where it runs underground.

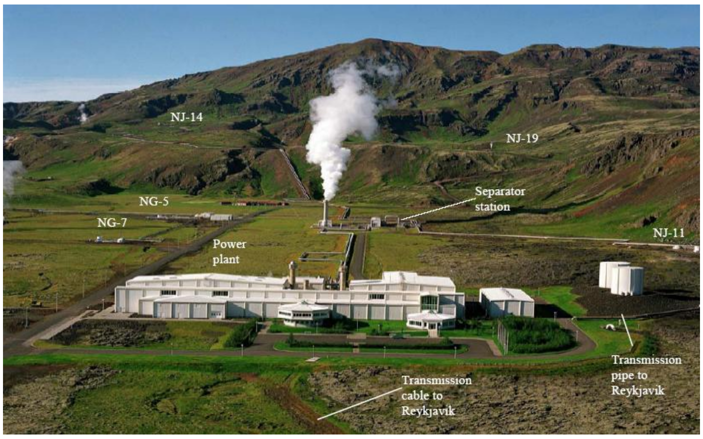

FIGURE 13: Nesjavellir power plant

The pipeline is made of steel, insulated with rock wool covered with plastic and aluminium on the outside where the pipeline lies above ground, but with urethane insulation, covered with plastic, where it runs underground. As an indication of the pipelines insulation value, it can be mentioned that where the pipeline lies above ground, snow does not melt off it. In order to facilitate traffic and for environmental reasons, above five kilometres of the pipeline are laid underground. In addition, at twelve sites where it lies above ground, it is possible to drive over the pipeline. These sites are well marked. Because of temperature changes, the steel in the pipeline can either expand or contract. When hot water was run for the first time through the pipeline, the expansion was about 24 meters from Nesjavellir to Grafarholt (on the outskirt of Reykjavik). To accommodate these changes, the pipeline rests on special supports and apparatuses with wheels. At regular intervals, there are stainless steel expansion bellows that allow the pipe to expand.

Nesjavellir Power Plant with its 120 MWe electrical production and 1,800 litres per second (6,500 m³/h) hot water production is probably one of the best examples on how geothermal power can be utilized successfully. Both the electricity and hot water coming from the plant is very competitive price wise.

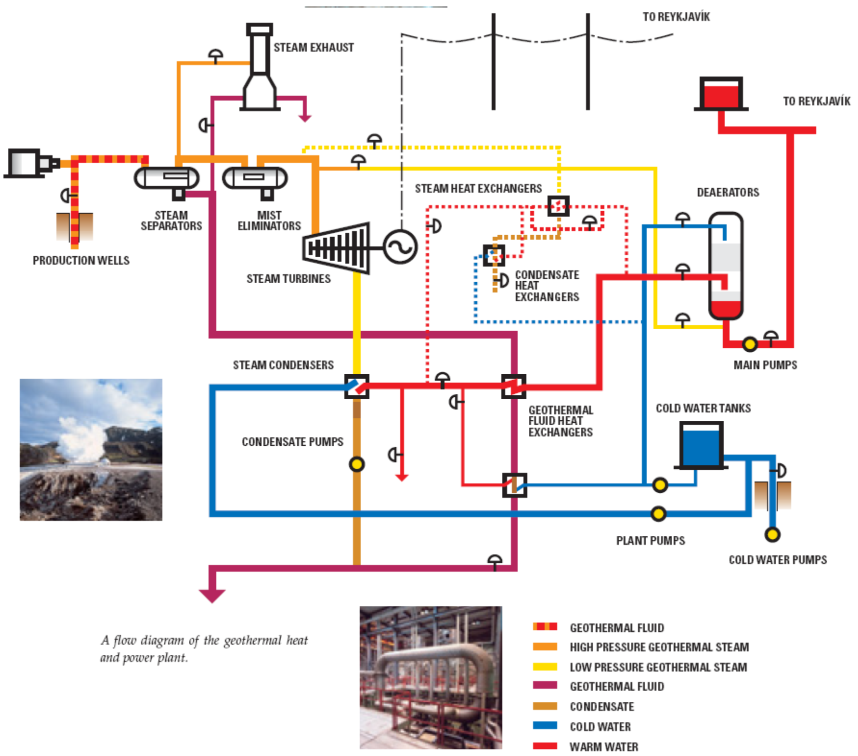

FIGURE 14: Flow chart for Nesjavellir Power Plant

5. RURAL DISTRICT HEATING SYSTEMS

There are some 200 rural district heating systems that were established outside built up areas. Typically a few farms would pool their resources and drill a well and later install the distribution system. Long mains of up to 10 km have been laid in this way and branches of up to 1 km for individual users. There have been government incentives and the economics have been favourable. In Iceland the geothermal rights belong to the land owner, with some restrictions, so they are taking advantage of their local resource. Costs are kept to a minimum by drilling relatively shallow wells with truck mounted drilling rigs, say 1000 m deep wells, and novel designs have evolved to lay the pipelines. District heating mains greater than 75 mm in diameter are mostly from pre-insulated steel pipes like in the cities, but smaller ones and most branches are now from pre-insulated PEX (cross linked polypropylene) plastic pipes. The plastic pipes come on coils, up to 500 m long, and are laid on the ground before being ploughed into the soil by a bulldozer, as is customary for laying cables in soft soil. No expansion compensators are required. Fibre optic cables or electrical cables are sometimes ploughed under in the same operation as was the case for Skagafjarðarveitur in the north of Iceland where over 60 km of mains have lately been installed in very sparsely inhabited farm region, (Figure 15).

Plastic pipes are finding increased use in geothermal district heating systems and house installations. There are temperature and pressure limitations that have to be respected and they require an oxygen barrier of plastic film or aluminium (Alupex). To sort out which materials fit the particular conditions of temperature and water composition, the Technological Institute and National Energy Authority and Ásbjörn Einarsson a corrosion consultant produced a webpage (www.lagnaval.is – in Icelandic). It informs, based on an input, whether the main metals: steel, galvanized steel, copper, stainless steel 304 or 316 or the plastics: PEX, Alupex, polybutylene, polyetylene are suitable.

FIGURE 15: Black pipe on the grass is the plastic district heating pipe and the bulldozer carry reels of electrical cables and orange reel is for the fibre optic cable. The bulldozer in the back has the plough that installs all of the pipes simultaneously.

FIGURE 16: Installing the district heating pipe and fibre optic in winter.

6. CONCLUSIONS AND RECOMMENDATIONS

The long experience in Iceland building and operating long transmission pipelines for geothermal hot water, both made from asbestos cement as well as pipelines made of steel is good and proven economical.

In spite of high investment cost all the district heating systems have been able to deliver hot water at reasonable price in the worst case (Hitaveita Akraness og Borgarfjarðar) and at a very low price in the best case (Hitaveita Húsavíkur and Reykjavík Energy). Even the very small rural district heating systems with long mains have proven very economical and supportive for the communities.

Following the oil price hikes of the 1970s, the government of Iceland took the initiative by promoting the expansion of district heating utilities, and as a result the share of geothermal energy use for space heating increased from 43% in 1970 to 83% in 1984 and 90% by 2007. The remaining 9% is heated using electricity and only 1% heated with oil, thus eliminating the use of oil for space heating and reducing the CO_2 emission.

ACKNOWLEDGEMENT

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