National Energy Authority
Department for Natural Heat

GEOTHERMAL ENERGY IN ICELAND

- Utilization and environmental problems -

- An article prepared for NATUROPA -

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Geothermal Energy Utilization

Until recently practically all geothermal energy utilisation in Iceland has been confined to space heating. During the last decade geothermal steam has also been used for industrial purposes and electric generation and further exploitation in these fields is in its preparation stages. Today greenhouses cover some 135.000 square meters requiring about 40 MW thermal. The present energy production of heating district services is some 400 MW thermal and will increase to about 590 MW during the next 4-5 years, when district heating services, which are definitely planned or are in the construction stages, will be in operation.

By 1980 electric power production from geothermal steam will amount to 73 MW and industrial use of geothermal water and steam will, at the same time, be in the range of 25 MW thermal.

The total population of Iceland is about 215.000. Before 1980 a little over 140.000 of the inhabitants will use geothermal water for house heating or close to 65% of the population. House heating amounts to roughly 40% of the annual energy consumption in Iceland.

In calculation of MW thermal it is assumed that the geothermal water will cool by 40°C, or from 80°C to 40°C, in the central heating systems, a value which is close to the true value for the majority of the district heating services.

Far the largest district heating service is in the capital, Reykjavík. It is also the oldest heating district service initiating a small scale operation in 1930 by exploitation of a geothermal field within the city itself. A major expansion took place in 1943 when water at about 90°C from the neighbouring geothermal field at Reykir was piped for a distance of 17 kilometers to Reykjavík. Further drilling at Reykir led to an increase in production in 1952 so at that time it amounted to 45 MW thermal. Little increase occurred until about 1960 following deep drilling (700-2200 meters) into the previously used geothermal field within the city of Reykjavík, recovering water at about 130°C. This drilling led to an increase in production by 110 MW. The discovery of a hidden geothermal field in 1966 with a temperature of about 110°C under the eastern part of the city led to a still further increase by 40 MW thermal. At that time about 80% of the inhabitants used the geothermal water for house heating. The last major expansion has occurred after 1970. This expansion can be attributed to deep drilling (1500-2000 meters) at Reykir into highly permeable rocks and hydrolic cracking of the rock in the walls of the drillholes, which still increases the permeability and therefore the yield from the holes. The thermal water from these deep drillholes provides the rest of Reykjavík with geothermal water and all the neighbouring towns and villages,which have not been using geothermal energy for house heating. Construction of distribution pipelines in the neighbouring communities is now under way and will be completed by the end of 1976. At that time the thermal energy production of the Reykjavík district heating service will be about 420 MW thermal but now it is about 340 MW. The population of Reykjavík and the surrounding communites is about 110.000.

Outside Reykjavík district heating services using geothermal water are operating in 10 major villages and towns (13.000 inhabitants) apart from numerous smaller communities and school complexes in the farming areas. Building of district heating systems are in the preparation stages for other 11 villages and towns with a total population of about 17.000 inhabitants. Plans exists for more of the major communities but they are still at the exploratory stage geologically and economically speaking.

One of the pecularities of geothermal water utilization in Iceland is reflected in the greenhouse centers and other communities which have built up around natural hot springs in the farming areas during the last 3-4 decades. Thus, it has been the prevailing policy to locate schools, and school complexes in the farming areas by natural hot springs wherever possible in order to receive low cost house heating and obtain easy facilities for swimming pools. Then there has been a distinct tendency for trading and industrial services for the neighbouring farming areas to develop in these "hot spring communities". Tens of such communities now exist, the largest with a population of about 1000.

Electric generation by geothermal steam was initiated in 1969 by the construction of a 3 MW experimental plant at the Námafjall geothermal field in northeast Iceland. Preparation steps have now been taken to build a 70 MW geothermal plant in a nearby geothermal field, Krafla. Production drilling will begin this year and the plant may be operating in 1977. At the Námafjall geothermal field, a diatomite factory has been using natural steam for drying of the diatomaceous earth which is extracted from the bottom of a nearby lake, Mývatn. A factory producing dry algae is in construction at Reykhólar in northwest Iceland, which will be using geothermal water in the drying process.

The exploitation of the geothermal fluids in Iceland has been mostly confined to water of rather low temperature (less than about 130°C) from the so called low-temperature hydrothermal areas (non-volcanic hydrothermal areas). Further exploitation in the near future will concentrate more on the high-temperature hydrothermal areas (volcanic hydrothermal areas). This refers particularly to utilization that demands steam such as electric generation and many industrial uses. Underground temperatures in the high-temperature areas may be as high as 300°C.

Iceland possesses valuably hydro-power resources which have been competing with the geothermal steam for electric generation. One of the reasons for not exploiting the geothermal steam for electric generation but hydro-power lies in the fact that geothermal utilization involves much more elaborate technology and more costly research at the early phases of economic evaluation. It seems now, economically speaking, that geothermal steam is competitive with hydro-power for electric generation.

Geothermal Fluid Compositions

Most geothermal waters in Iceland are low in dissolved solids compared with the compositional range of such waters observed in geothermal fields in other parts of the world. This includes major as well as trace elements. The total dissolved solids content is typically in the range of 300 to 1500 ppm of which silica amounts to some 25% to 50%. The dominating ions are sodium, chloride, and sulphate.

Rather saline geothermal waters occur in Quaternary and Recent rocks near the coast, particularly in southwest Iceland. It is considered that the salinity of these waters has resulted from percolation of sea water into the bedrock and mixing with fresh ground water of meteoric origin in various proportions. At Reykjanes on the southwest tip of Iceland no such mixing has, however, taken place and the geothermal water presents heated sea water.

Where sea water does not enter geothermal systems, variations in the thermal fluid compositions can be related to underground temperature conditions the solubility of hydrothermal minerals or ionic exchange reactions between solution and minerals. The overall low content of dissolved solids in the geothermal waters is believed to result from reaction between the water and basaltic rock, but as is well known, Iceland is almost wholly built up of basaltic rocks.

Geothermal waters in Iceland tend to be high in hydrogen sulphide. Its concentration in the water tends to increase with temperature. Thus, waters with a temperature of 100°C contain typically about 1 ppm of H_2S but waters at 250°C contain typically some 200 ppm. The relatively high hydrogen sulphide content of the Icelandic waters is to be related with their reducing nature, and possibly juvenile source of sulphur from basaltic intrusions or their differientiated products.

Icelandic geothermal waters are very low in many trace elements. Thus, the contents of bismuth, cadmium, chromium, cobalt, copper, lead, nickel and zinc were below 2 micrograms per liter in over 100 samples of water from many of the geothermal fields, or well below acceptable limits for domestic supplies, aquatic life, irrigation, and stock and wildlife watering. In the same samples arsenic, iron, gallium, germanium, molybdenum, titanium, and vanadium were generally detected in quantities of about 1 to 100 micrograms per liter. Apart from arsenic, the data of which are not reliable, these concentration are also well below acceptable limits for the before mentioned uses. In the hottest geothermal waters arsenic may be near the acceptable limit for domestic water supplies. However, during cooling of the thermal waters, their arsenic content is apparently quickly precipitated out as hydroxide. Therefore, it seems unlikely that arsenic derived from geothermal waste water will be harmful to its environment.

The concentration of boron tends to be in the range of 0.1 to 1.0 ppm, except for a few saline high-temperature waters where it may be as high as 10 ppm. Apart from the saline waters boron from geothermal waters is not expected to influence the environment with respect to aquatic or plant life.

The homogeneous rock geology of Iceland and the observed simple relation between geothermal fluid composition and underground temperatures and geology implies that present data on the fluid compositions are sufficient to define expected environmental problems from geothermal waste water. The present data covers drillholes in 6 of the 17 high-temperature geothermal fields and the major part of the low-temperature fields.

The Waste Water

The polluting effects of geothermal waste water can be classified into 2 categories, that is thermal pollution and chemical pollution. Any chemical pollution from the low-temperature geothermal waters is at minimum because of their composition, which is not drastically different from that of cold ground waters. Waters from the high-temperature areas contain, on the other hand, a few compounds in sufficiently high concentrations to be potentially polluting chemically speaking. Those compounds in these waters, which should be particularly focused on in this respect include hydrogen sulphide, silica, and phosphate.

The rather extensive use of low-temperature geothermal water for space heating during the last 3 decades or so has practically ignored any possible environmental influence. This influence is, of course, non-existing in many of the "hot spring communities" in the farming areas where only water flowing naturally from springs is utilized. It seems also that no measurable impact upon the environment has occurred in those towns where the water is extracted from drillholes. In this respect one should bear in mind the relatively small size of all towns in Iceland.

It is evident that, apart from electric energy, geothermal energy has important advantages over other energy resources for house heating, such as coal and oil. Air pollution from coal and oil may be quite substantial but non-existing in the case of geothermal energy. This fact is evident in Reykjavík, the "smokeless city".

Very limited experience has been gained on the environmental influence of large quantities of waste water from the high-temperature areas where only the steam is exploited. The water fraction from the wet-steam drillholes in such areas is dicharged at temperatures as high as 180°C and it may amount to as much as 80% of the total flow from the holes. Discharge of so hot waste water is to be contrasted with the effective use of geothermal energy for space heating where the waste water is discharged at a temperature of about

40°C. For example a 50 MW geothermal electric plant may produce waste water of some 500 liters per sec at 150°C whereas the Reykjavík district heating service, when producing 420 MW thermal, will discharge less than 2500 liters per second of water at about 40°C.

Environmental influence, including thermal and chemical pollution, accompanying geothermal energy exploitation is dominantly a localized problem. In respect to large scale exploitation of steam from the high-temperature areas in Iceland in the near future, views on nature preservation will play an important role. Some areas in the vicinity of these geothermal fields may have such pecularities geologically, or from the faunal and floral point of view to make an objection to any substantial geothermal energy utilization. Disposal of untreated waste water into rivers and lakes will little doubt not be accepted in many areas on the same grounds. Iceland is in a possession of many very valuable salmon rivers and trout lakes.

The harmful effect of hydrogen sulphide in the waste water lies in its toxic nature, particularly to aquatic life. For example mortal concentrations for trout are about 1 ppm for exposure of 24 hours. An exposure of the waste water to the air in ponds or dams allows most or practically all of the hydrogen sulphide to be removed from the water and into the atmosphere. Air stripping of the waste water will have the same effect. Thus, it is planned to discharge all the waste water from the planned 70 MW geothermal plant at Krafla into a depression of an explosive crater. The waste water will loose its hydrogen sulphide and cool down to 10-20°C in this discharge reservoir so thermal pollution of surface and ground waters is eliminated.

The influence of phosphate involves its role as a fertilizer. In the cold climate of Iceland chemical weathering of the basaltic bed rock is at minimum and as a result the phosphate content of the pore water in soils is extremely low. Geothermal waters may contain some 0.1 ppm of phosphate. It seems, however, very unlikely that phosphate in geothermal waste water will be troublesome, especially when other sources of phosphate, for example fertilizer, related to human activity are taken into consideration.

The problem with silica results from its precipitation from the water. If the waste water has to be discharged into the ground, this precipitation leads to the sealing of cracks and openings in the bedrock and the formation of impermeable beds instreams and lakes formed by the waste water. With time the streams and lakes become more and more extensive as has been observed at the Námafjall geothermal field where steam has been utilized for the last 6 years for industrial purposes and electric generation but the waste water emerging from silencers at 100°C has been flowing into the surrounding young lava fields, which were originally very permeable.

The concentration of silica in the high-temperature geothermal waters is determined by the solubility of quartz. The solubility of quartz increases with increasing temperatures. Thus, the silica concentrations in the geothermal waters increase with increasing temperatures. The rapid cooling of the geothermal water, which occurs as it flashes in a drillhole, leads to silica supersaturation with respect to quartz solubility. However, precipitation of quartz from a supersaturated solution is extemely sluggish and experience has shown that precipitation of silica from solution is not to expected until the geothermal fluid has cooled sufficiently to reach opal saturation. Opal, the amorphous form of silica, is much more soluble than quartz at all temperatures, and like quartz the solubility of opal increases with temperature. It is thus evident that the problem of silica precipitation from geothermal waste water is directly proportional to the temperature of the geothermal water in the underground reservoir. The relation between opal saturation and reservoir temperatures are complicated by the fact that the flashing of the high-temperature water leads to an increase in its pH. This in turn may cause some of the dissolved silica to become ionized and this ionized silica does not participate in equilibrium with the solid phase. The effect of raised pH by the flashing involves, therefore, lowering of the opal saturation temperature. If reservoir temperature is 260°C opal saturation is reached at 160°C, if pH effects are ignored, and cooling below that temperature is likely to result in some silica precipitation. If, on the other hand, the pH is raised to about 9.6 through the flashing, opal saturation is reached at about 125°C.

The rate of silica precipitation is related to factors other than reservoir temperatures. The precipitation may never be sufficiently rapid to bring all the silica from solution, which is in excess of opal saturation. External conditions that will aid precipitation include the salinity of the waste water, the extent to which silica in excess of opal saturation is polymerised the degree of supersaturation, the temperature of saturation, turbulence flow, and the material with which the water comes into contact with.

Experience has shown that the silica precipitates relatively easily out of waters with salinity similar to that of sea water. Thus, after 5-7 days storage, all silica in excess of opal saturation has been precipitated. If such saline waste water is stored in reservoir lakes all the silica may be brought out of solution and silica sealing will not be troublesome where the waste water is made to seap into the ground. This will not be so for the typical non-saline high-temperature waters in Iceland. Insufficient experimental results are available which demonstrate the rate of silica precipitation from such waters. It is conceivable that a chemical treatment of the water to precipitate silica would be regarded as economically acceptable in order to avoid sealing in the downflow zones of the waste water.

CAPTION TO FIGURES.

Figure 1:	Utilization of geothermal energy in Iceland (1975).
Figure 2:	Natural hot springs depositing silica sinter. From the Hveravellir high-temperature area, central Iceland. Photo Ævar Jóhannesson.
Figure 3:	The storage tanks for geothermal water of the Reykjavík district heating service. Photo Ævar Jóhannesson.

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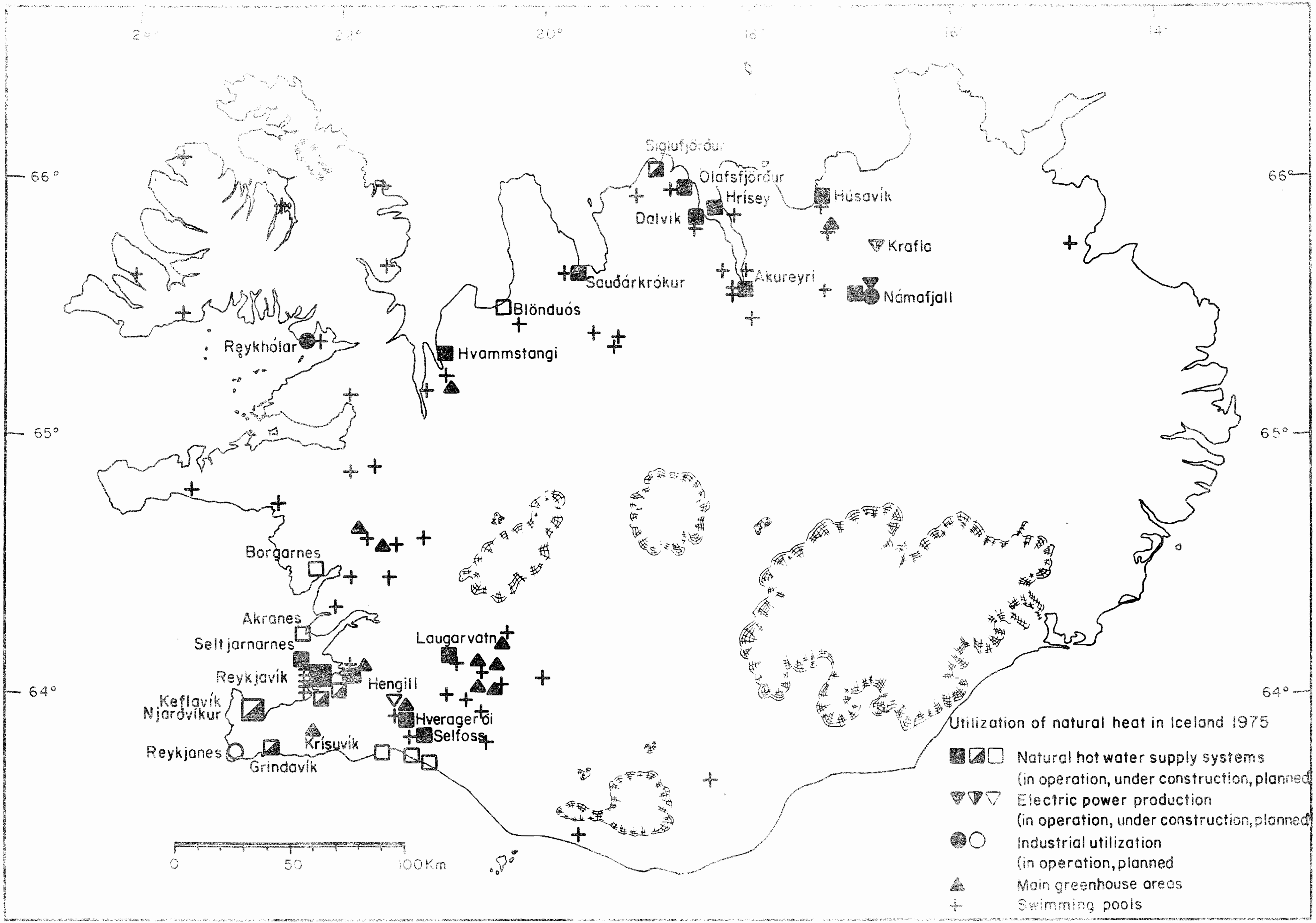

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