GEOTHERMAL RESEARCH AND DEVELOPMENT IN ICELAND 1982

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ABSTRACT

About one third of the total energy consumed in Iceland is derived from geothermal resources. Most of the geothermal energy is used for space heating and obtained from low temperature fields in the Tertiary and Plio-Pleistocene strata outside the volcanic —. Higher permeability is encountered in the Plio-Pleistocene strata characterized by subaerial lavas intercalated by subglacial volcanics (pillow lavas and hyaloclastites) than in the Tertiary strata which consist mstly of subaerial lavas. The close association of magmatic activity with high temperature hydrothermal system within the volcanic zone has been demonstrated during the current rifting episode in the Krafla volcano. Some recent advancements in geothermal research are mtioned and a review given of recent advances in the development of both the low and the high temperature fields in Iceland.

INTRODUCTION

Geothermal energy is very important for the national economy of Iceland as over one third of the net energy consumption of the country is from geothermal resources. In 1978 44% of the total energy consumption were derived from imported fossil fuel, 36% from geotheml and 20% from hydropower (Zoega et al., 1981). Most of the geothermal energy is used for space heating. In May 1982 75% of the Icelandic population lived in houses heated by geothermal water. The district heating system are mstly owned and operated by the municipalities. The Municipal Heating Service of Reykjavík serves about 114,400 people and is the largest geothermal heating service in the world. Its operations started in 1930. Presently it supplies hot water to heat the houses of nearly half the population of Iceland.

Figure 1 shows the growth of geothermal heating during the period 1960–1980. The figure shows that already at the beginning of the oil crisis in the early 1970's over 40% of the population heated their homes with geothermal water. With the rapid increase in oil prices projects that had previously been marginal all of a sudden became economically viable. The Government supports local authorities in the various parts of the country in financing geothermal research and development.

By 1985 about 80% of houses in the country are expected to be heated by geothermal and the remaining 20% mstly by electricity generated in hydropower stations. Thus burning of oil to heat houses will be mstly eliminated.

In May 1982 the total installed capacity of geothermal energy in Iceland was as follows (MW_t= thermal, MW_e=electric) : space heating 836 MW_t, greenhouses 51 MW_t, swimming pools 21 MW_t, industrial 50 MW_t, fish culture 2 MW_t and electricity 41 MW_e. The installed thermal capacity (total 960 MW_t) is calculated with a disposal temperature of 35°C which is common in the space heating systems in Iceland. Using the average air temperature in Iceland 5°C as the reference temperature the total would be approximately 1480 MW_t. Detailed statistics of the installed capacities for the various types of utilization in the low and the high temperature fields in 1980 are reported by Gudmundsson (1982) and Gudmundsson et al. (1981) respectively.

Due to the abundant potential of hydropower in Iceland, electricity has so far been produced from geothermal energy on a small Scale. Electricity was first generated on an experimental basis in Iceland in Hveragerdi in 1944, but it was not until in 1969 that a geothermal power plant (3 MW_e) was commissioned in Namafjall for continuous operation. Large scale production of electricity from geothermal is not likely in Iceland in the near future, but co-generation of electricity in plants established for direct industrial application of geothermal steam seems favourable. Along with a natural growth of the space heating market the growth of geothermal utilization in Iceland in the next decades is likely to be mainly in the industrial sector.

Due to the importance of geothermal for the national economy much effort is put into geothermal research as well as development. Most of the geothermal exploration and research work in the country is executed by the Geothermal Division of Orkustofnun, the National Energy Authority of Iceland. The 1982 budget for the Geothermal Division is about 2.5 million US$ excluding drilling funds.

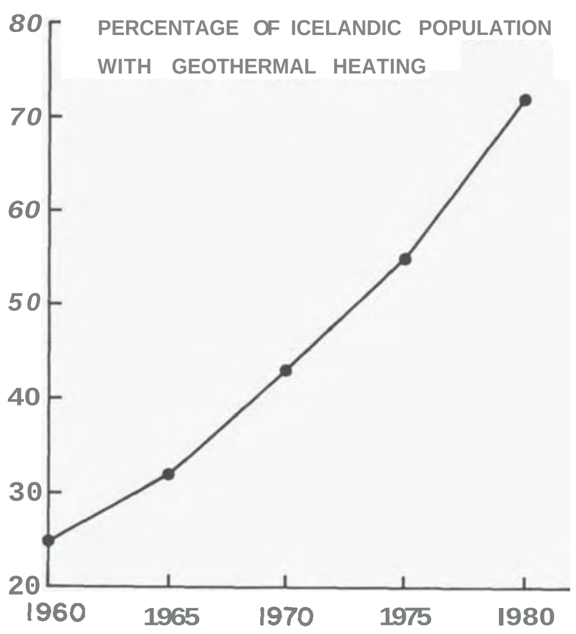

Figure 1.

This paper summarises the main geological features of the geothermal fields, some recent advancements in geothermal research are mtioned and a review is given of some recent advances in the development of both the law and the high temperature fields.

GEOLOGY OF THE GEOTHERMAL FIELDS

Iceland lies astride the Mid-Atlantic Ridge. The crustal thickness varies fran 8-15 km, and the crustal structure is known in considerable detail from geological and seismic surveys (Palmason and Saemundsson, 1974). The crust is formed almost entirely of igneous rocks. The uppermost 3-5 km are composed mostly of subaerial lavas in the Tertiary provinces, but of subaerial lavas intercalated (at intervals corresponding to glaciations) with morains and subglacial volcanics in the Plio--Pleistocene provinces and within the active volcanic zones. The lower part of the crust probably consists mstly of very low porosity impermeable intrusions and intensely altered lavas. This layer (the oceanic layer, Vp=6.5 km/s) may form the base to water circulation in the crust outside the volcanic zones (low tenperatwe areas). In the high temperature areas and other parts of the active volcanic zones the water m y circulate down into the intrusive layer during its formation.

Like other constructive plate margins the Mid-Atlantic Ridge is characterized by a high heat flaw in the crestal region, but with increasing distance symmetrically away from the ridge crest the mean heat flow falls until it reaches an average level for the *oceans.* Iceland forms a 500 km broad segment astride the ridge and falls entirely within the crestal heat flaw anomaly. The regional heat flow on the island varies from about 80 mW/m^2 furthest *away* from the active volcanic *zones* crossing the country to about 300 mW/m^2 in some regions at the margins of the Reykjanes-Langjokull axial rift zone. The geothermal gradient as measured in over 100 m deep drillholes outside known geothermal fields and outside zones of active volcanism, ranges fran 37°C/km to 165°C/km (Palmason, 1973).

Hot springs are very abundant in the country as *can* be expected fran the high heat flow. To date there have been recognized approximately 1000 geothermal localities in the country. Hot springs have also been identified in a few places on the sea floor surrounding the island. It has become customary to divide the geothermal activity into two types, low and high temperature *areas, on* basis of the subsurface temperature. The base temperature is thus <150°C in the low temperature areas, but >200°C in the high temperature *areas* (Bodvarsson, 1961). The law temperature areas *are* in Plio-Pleistocene and Tertiary volcanics. Due to the oceanic climate there is heavy precipitation in the island. Some of the precipitation percolates deep into the bedrock in *the* highland areas and flaws laterally along faults and pervious horizons for distances of tens of km before it appears on the surface along dykes or faults *on* the lowlands. The water withdraws heat from the regional heat flow *during* its passage *through* the strata (Einarsson, 1942). The high tenperatwe areas are within or on the margins of the active zones of rifting and volcanism and are thought to *draw* heat both from the regional heat flow and from local accumulations of igneous intrusions cooling at a shallow level in the crust. Deuterium isotope studies (Arnason, 1976) indicate the hydrological cycle in the high temperature system to be much more localized than in the low temperature *areas.* The thermal manifestations vary greatly from one locality to another with water temperatures ranging from a few degrees above the mean annual temperature to boiling springs, and the flow rates ranging from nil to a maximum flaw of about 180 l/s fran a single spring. The total natural flaw of springs >20°C is estimated about 1800 l/s (Saemundsson and Fridleifsson, 1980).

Due to the high geothermal gradient in Iceland it is never a problem to find temperatures high *enough* for utilization by drilling, but finding *good* aquifers *can* be difficult and expensive. Although the primary porosity of the volcanics is high the permeability of the strata is reduced immensely both as a result of zeolites filling vesicles and cracks and by compaction and general alteration of the rocks. Primary permeability is thus reduced in some of the volcanic rock formations to almost *zero* and secondary permeability becomes prevailent. The secondary permeability is related to fractures, faults and dykes that formed under extension within the axial rift zones during the growth of the volcanic pile or fractures and faults that formed later, sometimes under different stress conditions outside the zones of crustal growth. Thermal modelling indicates that thermal stresses are likely to play a significant role in enchancing the vertical permeability of the crust to a depth of several km (Bodvarsson and Lowell, 1972; Lister, 1980; Palmason, 1981). Secondary permeability may also be formed by dissolution of the wall rock of major aquifers in the deeper parts of geothermal systems (Bodvarsson, 1951). As an example of the potential of the last mentioned type of permeability it can be mentioned that the largest hot spring in Iceland, Deildartunguhver, with a flow rate of 180 l/s of boiling water carries about 2,000 tonnes of dissolved solids per year or about 20 million tonnes in the last 10,000 years (Saemundsson and Fridleifsson, 1980).

Low temperature areas

Most of the geothermal power utilized in Iceland is obtained from the low temperature areas. Utilization and successful prospecting for geothermal water has mstly been limited to known geothermal localities. The production wells in individual geothermal areas are, however, commonly sited by aid of geological, geochemical and geophysical exploration methods some distance from the natural hot springs. By drilling and pumping the natural flaw in the law temperature areas is commonly increased 10-20 times without signs of overexploitation.

Regional exploration studies as well as drilling data and pumping tests have been used to make reservoir models of the main geothermal fields under exploitation in Iceland. The flow channels from the recharge areas in the highlands to the hot spring areas in the lowlands apparently vary fran the Tertiary to the Plio-Pleistocene provinces (Fridleifsson, 1978). In the subaerially erupted Tertiary volcanics the flow channels appear to be mainly dykes and faults but to a less extent thin high porosity stratiform horizons. In the Plio-Pleistocene strata, which are characterized by successions of subaerial lavas intercalatedwith thick piles of subglacially erupted pillow lavas, hyaloclastites and detrital beds, potential flow channels are much more abundant. There in addition to faults and dykes, effective large scale reservoirs and flow channels are thought to be in the pillow lava cores of hyaloclastite ridges and high porosity stratiform horizons of fragmental material. There is a significant difference between the aquifers encountered by drilling in the Tertiary and the Plio-Pleistocene areas.

In the Tertiary strata the aquifers appear most often to be narrow and connected with vertical structures (dykes and faults). Data is available on the transmissivity in drillholes in three thermal areas in Tertiary rocks; the transmissivity is of the order of 10^{-3} m^2/s, an order of magnitude lower than that of the most permeable Plio-Pleistocene strata (Fridleifsson, 1979). The most intensely drilled thermal area in Tertiary strata is at Laugaland near Akureyri in N-Iceland (Björnsson 1981). The strata is of basaltic lavas with minor sedimentary interbeds. The hot springs on the surface are associated with dykes, but at depth particularly one dyke out of a whole dyke swarm acts as a main aquifer. Small aquifers have been found connected with both individual dykes and clastic interlayers, but the best aquifers have apparently been encountered at the intersection of permeable dykes and the interlayers.

In the Plio-Pleistocene strata the major aquifers tend to be horizontal and occur most commonly at the contacts of lithological units such as lavas and hyaloclastites. The transmissivity is up to the order of 10^{-2} m^2/s, and as the aquifers are more numerous the intrinsic permeability tends to be one or two orders of magnitude higher than that of Tertiary strata (Fridleifsson, 1979). The most intensely drilled thermal area in Plio-Pleistocene strata is at Reykir in Mosfellssveit, SW-Iceland (Thorsteinsson, 1976). The production area is in a heavily tilted and blockfaulted zone jus t outside a two million year old caldera. Basaltic lavas form 40-70% of the strata and these are intercalated by thick and thin beds of subglacially erupted pillow lavas and hyaloclastites as well as detrital beds. By analysing the occurrence of aquifers in the different rock types in 29 drillholes (800-2043 m deep) in the area Tomasson et al (1976) showed that large aquifers (>20 l/s) are by far more likely to occur at the contacts of lithological units than in lavas alone or in subaquatic volcanics alone. Several individual 1000-2000 m deep wells in the area can give >70 l/s with pumping and a drawdown within the wells of 10-50 m.

High temperature areas

According to the plate tectonics theory the highest heat flow on a constructive plate margin should be along the volcanic zone, which is the surface expression of the plate boundary. This is not always apparent on the surface as recent volcanic are normally highly pervious and cold groundwater percolates deep into the surface formations. In one drillhole in the volcanic zone of SW-Iceland a zero thermal gradient was encountered down to 700 m. With increasing compaction of the strata and sealing by precipitation from warm water the geothermal gradient increases. The high temperature areas are like chimneys that extend from the hot zone below to the surface. The high temperature areas are always associated with volcanotectonic features such as volcanic fissure swarms or more commonly central volcanoes with intermediate and acid volcanics, fault swarms, and sometimes calderas. At such sites there is a great abundance of dykes, sheets and other minor intrusions cooling at a shallow depth in the crust. These intrusions, in addition to the general heat flux of the volcanic zone, form the heat source for the convection systems of the high temperature areas.

To date there have been identified 28 potential high temperature areas in the country (Saemundsson and Fridleifsson, 1980). Some of these are, however, largely covered by glaciers and cannot be exploited. The surface manifestations are in the form of steam holes, boiling mudpools and highly altered ground. The high temperature areas vary greatly in size and have an aggregate coverage of about 500 km^2. One area covers approximately 140 km^2 but the bulk of the areas are 1–25 km^2.

The heat exchange between the intrusives and the meteoric water can to some extent be inspected in the deeply dissected roots of Tertiary and Plio-Pleistocene central volcanoes. These are characterized by a great abundance (locally 50–100%) of minor intrusions. Centrally inclined sheet swarms (cone sheets) have been found in the majority of dissected central volcanoes investigated to date in Iceland (Walker, 1974; Fridleifsson, 1977). The sheets are commonly 1–2 m thick. Minor dolerite, gabbro and granophyre intrusions are also common. The host rock is intensely altered and the cores of the central volcanoes are characterized by cupolas of propylitized rocks which delineates the shapes of the extinct high temperatwe convection system. The outer part of the aureoles are characterized by quartz and platy calcite, but these minerals are accompanied by laumontite and epidote and in rare cases garnet and amphilbole in the central parts (Walker, 1960; Kristmannsdottir, 1979). The heat transfer mechanism by which magma can act as a heat source for hydrothermal systems in Iceland and elsewhere has recently been reviewed by Stefansson and Bjornsson (1982).

The association of magmatic activity with a high temperature hydrothermal system has been clearly demonstrated during the current rifting episode of the Krafla volcanic system in northern Iceland. A magma chamber has been located at 3–7 km depth below the center of the 8 km broad Krafla caldera. The high temperature thermal area that presently is being exploited for power production lies right above it. Magma that flaws steadily into the magma chamber at a rate of approximately 5 m^3/s causes inflation of the caldera and during sudden deflation events magma is expelled laterally into the fissure swarm that transects the caldera (Bjornsson et al., 1979). Since 1975 small basaltic fissure eruptions have occurred eight times in or just outside the caldera. The hydrothermal activity inside the caldera has increased dramatically along the eruptive fissure and the most powerful new springs have thrown mud and rocks and formed craters that are about 15 m deep and up to 50 m in diameter. These look like explosion craters, but have been formed by steam erosion as much as by separate explosions. Surface hydrothermal activity has also increased significantly in two other geothermal areas on the fissure swarm, one about 7 km north of the caldera and the other (Namafjall) about 7 km south of the caldera. In a deflation event in 1977 a small volcanic eruption occurred on a fissure near the northern rim of the caldera. Seismometers indicated that magma was also moving southwards and nearly five hours later about 3 tonnes of basaltic scoria were erupted up through a 1138 m drillhole in the Namafjall steam field, about 12 km south of the active crater in the north.

The rifting events and the magmatic activity have caused pressure impulses in the water-dominated part of the Krafla geothermal field (Stefansson, 1981). Magmatic gases haw similarly had pronounced effects on the chemistry of the thermal fluid (Armansson et al., 1982) and caused serious deposition. The concentration of CO_2 increased abruptly 100 times, followed by an increase in SO_4 which seemed to be caused by the release of magmatic SO_2 into the hydrothermal system. Cl_2 ? has similarly been found in unusual quantities in one well with dry steam. In one of the magmatic pulses the pH of the discharge from a well changed from about 9 to about 2 for a short while. Examples of such injections of volcanic gases into geothermal fluids can be seen in the secondary mineral assemblages of some of the most deeply dissected cores of extinct central volcanoes.

The strata of the active high temperature areas are like the Plio- Pleistocene strata composed of layers of subaerial lavas intercalated by thick piles of subglacially erupted pillow lavas and hyaloclastites. The proportion of intrusives normally increases with depth. Most of the intrusives are relatively fine grained basaltic dykes and sheets but dolerites and granophyres have also been encountered in some areas. The strata are generally highly faulted. Deep drilling has been conducted in seven high temperature fields in Iceland (Hveragerdi, Krafla, Krisuvik, Namafjall, Nesjavellir, Reykjanes, Svartsengi). Although largely water-dominated, parts of several of the high temperature system in Iceland are apparently boiling (two phase) with the pressure gradient close to the hydrostatic gradient (Stefansson, pers. comm., 1982). Measurements show the transmissivity to be highly variable between areas and within individual fields, the highest values recorded are of the order of 10^{-2} m^2/s in Svartsengi (Kjaran et al., 1979). No statistical analysis is available on the occurrence of acquifers in high temperature wells in Iceland. The maximum flaw rate (total flow) from a single well is approximately 180 kg/s.

RECENT ADVANCEMENTS IN GEOTHERMAL RESEARCH

The applications of geological, geochemical and geophysical exploration methods in Iceland have been summarised by Fridleifsson (1978), Arnorsson (1979) and Palmason (1976) respectively. Along with detailed geological mapping the most useful surface exploration methods in the last few years have been Schlumberger soundings and detailed ground magnetic surveys (Bjornsson, 1981; Bjornsson and Hersir, 1981; Georgsson, 1981; Georgsson et al., 1981). The interpretation of the resistivity soundings is done with the aid of one- and two-dimensional resistivity computer models (Dey, 1976; Johansen, 1977). The head-on resistivity profiling (Cheng, 1980) has recently been successfully applied to detect nearly vertical permeable structures (Flovenz and Georgsson,

1982) in low temperature areas.

Significant advancements have been made in the logging of geothermal wells in recent years with the acquisition of logging equipment for nuclear logs (natural gamma, gamma-gamma, neutron-neutron), electrical logs (resistivity and self potential) in addition to the more classical temperature and pressure logs. Caliper, cement bond and casing collar locator logs have further been of great value during drilling and cementing operations. Valuable comparison of geophysical logs with measurements on core were obtained in a 1900 m continuously cored well in eastern Iceland in 1978 (Jonsson and Stefansson, 1982). A new interpretation method for natural gamma ray logs in the volcanic strata of Iceland has been demonstrated (Stefansson et al., 1982).

Chemical geothermometers have recently been recalibrated with data from deep wells in Iceland; the CO_2 gas thermometer appears to be very promising for the detection of upflow zones in high temperature system (Arnorsson et al., 1982; Armannsson et al., 1982).

Much effort has been put lately into reservoir engineering studies of the high temperature geothermal fields (Kjaran et al., 1979; Stefansson and Steingrimsson, 1980; Bodvarsson et al., 1981).

An international training programme in advanced geothermal research and technology has been operated in Iceland since 1979 (Fridleifsson, 1982).

RECENT DEVELOPMENTS IN GEOTHERMAL UTILIZATION

Low temperature utilization

The geothermal water used for space heating is mstly from low temperature areas (<150°C); the mineral content is low (200-400 ppm) and the water can in mst cases be used directly. Corrosion problems have been encountered where the hot water has been contaminated by oxygen. High chlorine content can also cause corrosion, such as in the Seltjarnarnes Municipal Heating Service where water with Cl-content above 500 ppm had been used directly for several years but heat exchangers have lately had to be installed at the intake of houses because of corrosion in the radiators. Production wells are commonly 1000-2000 m deep the deepest well being 3085 m in Reykjavik.

The thermal water is in most cases pumped to the surface with shaft driven pumps placed at 100-200 m depth. Such pumps have been used in Reykjavik since 1960 at temperatures of up to 130°C. Due to the lower transmissivity of the geological formations in the Tertiary provinces larger drawdown is commonly experienced than in wells in the thermal areas of the Plio-Pleistocene provinces such as near Reykjavik. The largest municipal heating service obtaining water from a *Tertiary* lava formation is in Akureyri (Bjornsson, 1981). A submergible pump with the motor at 360 m depth has been operated successfully there for about years at a water temperature of 81°C.

Long carrier pipelines in Iceland are *either* of mild steel or asbestos cement, the latter being cheaper but allowing much less effective insulation. Steel pipelines larger than 10" *are* commonly insulated with rock wool and either placed inside concrete tunnels or above surface covered with an aluminium jacket. Slimmer steel pipes are insulated *by* polyurethane insulation with a high density polyethylene plastic jacket. Asbestos cement pipes are most commonly covered directly by soil for insulation. For transporting 100 l/s the temperature *drop* will typically be 0.7°C/km for an asbestos cement pipe covered with soil, but 0.2°C/km for a steel pipe in rock wool and aluminium jacket. The longest steel pipeline in the country is 30 km. A 64 km long asbestos cement pipeline was taken into operation in W-Iceland in late 1981. It is the longest geothermal pipeline in the world and a worthy challenge to the common opinion of geothermal being a site specific type of energy. It is mstly of asbestos cement but a steel pipe is used where the pipeline *crosses* rivers or rocky hills where the pipe lies on bare bedrock. The pipe (400-450 mm in diameter) is placed on a bed of volcanic scoria and covered *by* approximately 70 an of soil. The top of the pipe is insulated by hard pressed rock wool that covers 2/3 of the circumference of the pipe. The maximum capacity of the pipeline all the way to Akranes is 205 l/s. During the first winter of operation the average flaw was 115 l/s. The water temperature was 97°C where it entered the pipe and the temperature *drop* was normally about 20°C but as much as 25°C during wet spells when the soil mvering the pipe was saturated with water (Hrolfsson, pers. comm. 1982). The temperature drop was thus 0.3-0.4°C/km. This is the first time rock wool has been used to insulate an asbestos cement transmission pipeline in Iceland. In Siglufjordur in N-Iceland polyurethane is used to insulate asbestos cement pipes; an aluminium jacket with a slot at the base is placed between the pipe and the polyurethane insulation to form a vapour barrier against the water seeping through the asbestos. The diameter of this pipe is 200 mn, the flow is 26 l/s, the distance 4.7 km and the temperature *drop* only 1°C or about 0.2°C/km. The choice of material for both pipe and insulation is based on the economics involved. In m y of the municipal heating services in the country future increase in the energy demand can be met by replacing poorly insulated pipelines with well insulated pipes rather than by more drilling and pumping from the geothermal fields under exploitation.

Despite a drawdown commonly of 100-200 min pumped wells it is noteworthy that influx of cold water has only been noticed in two thermal systems under exploitation in Iceland. This is in Selfoss in S-Iceland where cold groundwater seeps into the geothermal reservoir both through natural cracks and through old drillholes with faulty casing (Tomasson and Halldorsson, 1981), and in Egilsstadir in E-Iceland where the natural hot springs are at the bottom of a lake and the drawduwn in production wells leads to cold ground water seeping into the geothermal system.

High temperature utilization

In 1976 a plant started operating in the Svartsengi high temperature field where a 240°C brine (2/3 seawater) is used for district heating by the use of heat exchangers (Thorhallsson, 1979). The installed capacity of this plant is 125 MW_t. The high pressure steam is also used for co-generation of electricity (installed capacity 8 MW_e). Ten production wells and one reinjection well have been drilled. Reinjection experiments are planned to start in Svartsengi in the autumn of 1982. This will be the first time reinjection is applied in Iceland.

The Krafla geothermal field is still seriously affected by the volcanic activity that started in 1975 and does not show any signs of abating. The geothermal system has been found to consist of a shallow liquid dominated zone with temperatures of about 210°C and a boiling zone (two phase) with temperatures ranging from 300°C at the top at 1000 m depth to 340°C at about 2000 m depth (Stefansson and Steingrimsson, 1980; Stefansson, 1981). A 30 MW turbine installed in the Krafla power station (Eliasson et al., 1980) was commissioned in 1978 and has been limited to an output 10-15 MW due to a meagre steam supply. The chemical composition of the geothermal fluid has been very seriously affected by volcanic gases associated with the magmatic activity in the area as mtioned previously. This has caused a rapid precipitation of mainly iron silicates within the rock formation surrounding the producing aquifers. This is considered to be a significant factor in the rapid decline in the productivity of the wells. At the end of 1981 altogether 16 production wells had been drilled. The accumulated steam productivity of the wells (value for each well taken after a flow test of one month or more ; interference between individual wells has been observed minimal probably because of the two-phase conditions in the reservoir) is equivalent to 50 MW production, but the steam supply is only sufficient for about 15 MW (Stefansson, 1982). Attempts are made to site wells outside the area most affected by the volcanic gases. A production field has already been identified where the fluid is not markedly contaminated by the magmatic gases. The extension of this new field is, however, rather limited and will most probably not sustain more than about 30 MW production (Stefansson, 1982). Three wells will be drilled in 1982. Directional drilling techniques were used for the first time in Iceland in one of the wells in Krafla in 1982. The planned capacity of the Krafla power station is 60 MW.

A 3 MW turbine commissioned in 1969 in the Namafjall field was removed in 1978 due to the volcanic/tectonic activity mtioned previously. The turbine was reinstalled in 1981. The steam in Namafjall is primarily used for a diatomite plant that started operating in 1967 (Ragnars et al., 1970). The present production in the plant is about 24,000 tonnes/year of diatomite. The thermal energy used in the plant is about 35 MW_t (Gudmundsson et al., 1981).

A 0.3 MW turbine was installed in the Nesjavellir field in SW-Iceland in 1980; it provides power for a pilot plant where heat exchanging processes are being tested by the Reykjavik Municipal Heating Service.

A pilot plant for the production of salt from a geothermal brine was operated in the Reykjanes high temperature area in 1979-1981 (Lindal et al. 1982). A demonstration plant with a capacity of 4,000 tonnes/year is under construction, and there are plans t~ increase the size of the demonstration plant to 8,000-12,000 tonnes/year. Depending on the success of the demonstration plant a salt factory with a capacity of 40,000-60,000 tonnes /year may be built which would satisfy the demand for salt in Iceland.

A remarkable experiment has been in operation for five years in the Westmann Islands where heat is extracted from a thick, partly molten lava flow (erupted in 1973) for space heating of a town of 5,000 people. It is estimated that the heat source will last at least 15 years.

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