

Geothermal energy and its use for district heating in Iceland

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As district heating in Iceland is a direct result of the abundance of natural heat resources, it seems logical to begin this paper with a short account of the general aspects of thermal activity in the country.

Iceland is almost exclusively built up of volcanic rocks, the oldest exposed being basaltic lava flows of tertiary age; these are confined to the west and the north west, the east and the south east parts of the country as shown in Fig. 1. These tertiary rock zones are separated by a zone of younger volcanics of quaternary and recent age, mainly basaltic tuffs, breccias and lava flows, containing a north east to south west oriented belt of active volcanism. This volcanic belt forms a continuation of the rift zone of the Mid-Atlantic Ridge.

Thermal activity is very widespread in the country, and generally two types of thermal areas are recognized, high temperature areas ($>200^{\circ}\text{C}$) and low temperature areas ($<200^{\circ}\text{C}$). The high temperature areas are all situated within the zone of active volcanism; they are characterized by large areas of hot ground, mud pools and fumaroles. The rock at the surface is intensely heated and the water issued at ground level is in most cases negligible. On the other hand, low temperature areas are more widely spread about the country and are characterized by hot water springs, often with high flow rates at temperatures between 20 and 100°C . Most of these are situated in valleys and on lowland along the coasts.

Thermal waters in Iceland have a lower content of dissolved solids than is usual in other parts of the world, e.g., New Zealand, USA and Japan; waters from low temperature areas contain less dissolved solids than waters from high temperature areas. Water tapped from boreholes in both low and high temperature areas is generally alkaline (pH 8.0 to 9.5) and reducing.

The total heat output of high and low temperature areas together has been estimated at approximately 47000MW; the present flow from surface springs and boreholes amounts to some 2700 litre/s at an

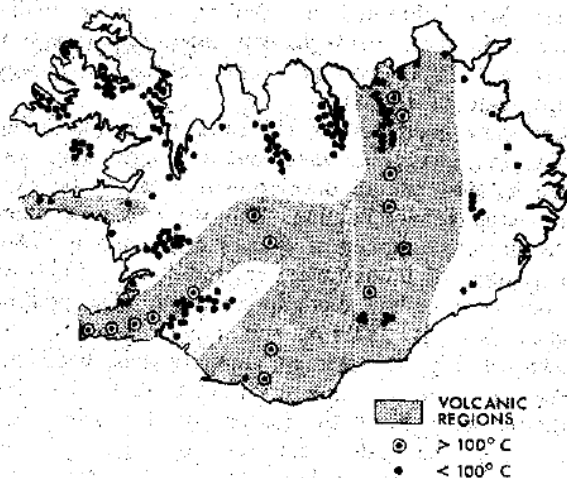
average temperature of 120°C , the useful heat above 40°C being approximately 900MW.

Utilization of hot spring water was for centuries limited to washing and bathing but in the early nineteen-twenties use was being made of it for space heating. Farmhouses situated close to hot springs were heated by primitive methods, county schoolhouses and swimming pools were built in hot spring areas and by 1930 greenhouses heated in this manner were being built to grow various kinds of vegetables.

Apart from numerous single farms and groups of farms heated by hot spring water all over the country, seven district heating systems in towns and villages with a total population of 90000 have now been built, all in the 3 to 10MW range except that of Reykjavik which has a heating load of 250MW. In addition 120000m² of greenhouses are now heated by similar means.

The total heating load met by hot spring water is nearly 300MW and the total energy used annually is approximately 5.4 million GJ (5400TJ) which represents some 20 per cent of the nation's total

Fig. 1.



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consumption of energy. The importance of geothermal resources to the national economy of Iceland will be appreciated further in the light of the fact that, today, half of the country's total energy requirements are for space heating.

THE REYKJAVIK DISTRICT HEATING SYSTEM

In the Reykjavik system, no surface springs are used, all the hot water being obtained by drilling. In 1928 the first boreholes were drilled close to hot springs in the eastern part of the city; 14 holes were drilled to a maximum depth of 400m and these yielded 14 litre/s of water at 87°C representing an energy supply rate of 2.5MW. In 1930 a small distribution system was built serving 70 houses together with a swimming hall, an open air swimming pool and a schoolhouse.

In 1933, the city authorities purchased drilling rights in a hot spring area at Reykir, 15km east of the city, and between 1939 and 1943 a distribution system was built, with a pumphouse at Reykir, a pipeline to the city, and storage tanks of 8000m³ capacity. This system was put into operation on 1 December, 1943, and served 2300 houses having a total heating load of 46MW.

In 1947 drilling was started at Reykjahlid, 3.5km east of Reykir and this area was developed in 1949-1950, extensions of the distribution system following. In all, 72 boreholes were drilled in these two areas, the maximum depth being 770m and the total yield 330 litre/s of water at 86°C.

By employing various methods of exploration such as systematic measurements and mapping of the temperature gradient in boreholes, gravity and magnetic field measurements and investigation of the electrical resistance of rock formations, hitherto unknown thermal fields were found inside the city, and in 1958 a large drilling rig was purchased in co-operation with state authorities and very good results were obtained by drilling in these fields. Since 1958 these fields have yielded 470 litre/s of water at 119°C average, representing an energy supply rate of 160MW.

These very good results led to a resolution being passed in the City Council and a general plan was made in 1961 for all development areas to be supplied with district heating. This work is now complete and the number of houses connected is 9280, the number of inhabitants serviced being 75 600 or 93 per cent of the city's population. The present heating load is 250MW, this having built up as shown in Fig. 2. Storage capacity has been increased to 26 000m³ and a 35MW peak load boiler plant has been built, the reason for this being that the size of the system can then be based on the maximum average 24 hour load rather than the

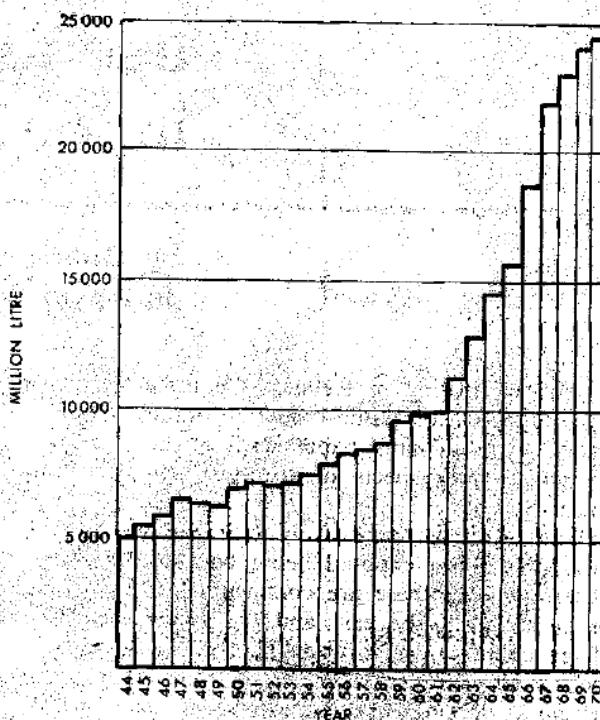


Fig. 2.

hourly maximum, thus increasing the number of houses that can be served.

Recent development in the Reykir area has shown that by deeper drilling more hot water can be obtained and strong evidence points to new hot water layers not connected to those originally exploited. This field is therefore estimated to yield a further 560 to 840 litre/s of water at 80°C increasing the available energy by 80 to 120MW in the next few years.

Development of thermal areas

As stated previously, the geothermal areas have yielded water at temperatures either below 100°C or above, and different methods are employed in utilizing these areas as illustrated in Fig. 3. Where the temperature is below 100°C (as in the Reykir area), the water comes out of the boreholes under natural pressure and is collected from the various boreholes into a cistern near the main pumphouse; it is then piped to pumps situated at a lower level which deliver it through a double 350mm pipeline to the storage tanks in the city. Pumping is regulated by air operated valves on the discharge side of the pumps, controlled by a level control in the collecting cistern.

Where the temperature of the water exceeds 100°C (as in the Reykjavik area) a certain minimum pressure must be maintained to avoid ebullition in the system and this is produced by deep well pumps

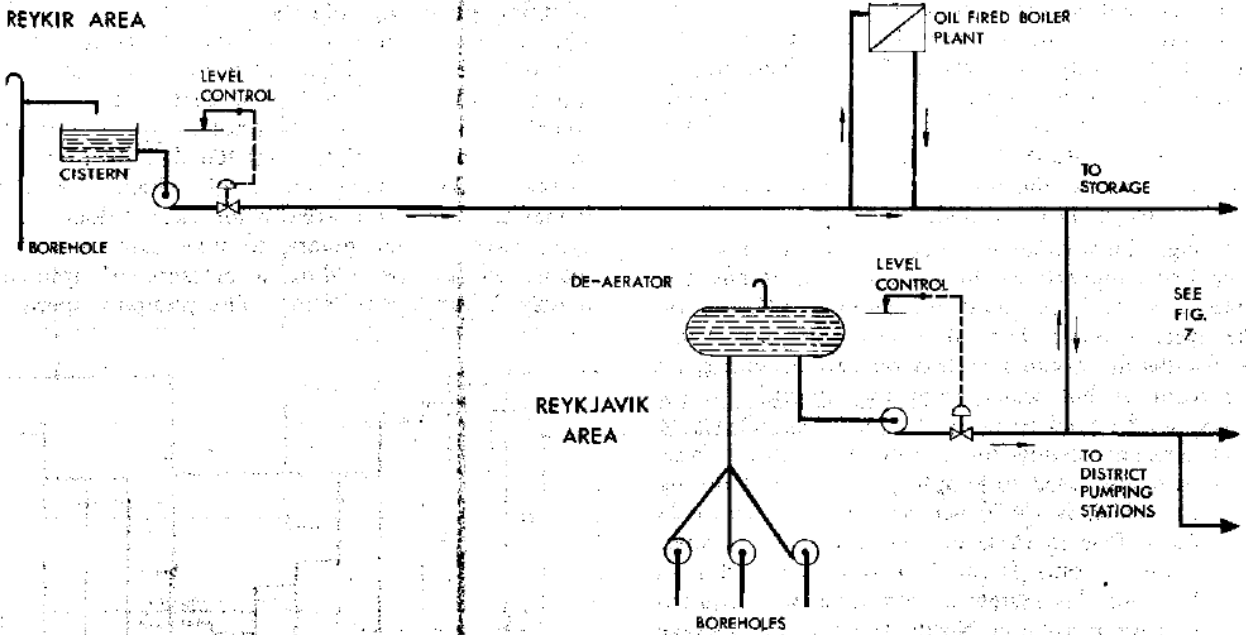


Fig 3.

inserted 110-120m down into the boreholes, connected by drive shafts to surface mounted electric motors, pumping the water through collecting mains to the main area pumphouse. The hot water in this area contains a certain amount of nitrogen in solution which has to be removed since it would otherwise collect in the radiators of the highest situated houses in the system, where pressure is lowest, and lead to vapour locking of the circulation. This nitrogen is removed by piping the water at its entry into the main pump house, through a de-aerator taking the form of one or more horizontal steel cylinders having a relatively large surface; the pressure is relieved and the water allowed to boil slightly at the surface, the gas freed by this process being led to atmosphere and the water piped to the suction side of the main circulating pumps which deliver it through high temperature mains to the nine district stations in the city. Pumping is regulated in the same manner as before by a level control in the gas separators.

These main supply pumping plants are each equipped with three pumps, any two being of sufficient capacity to pump all the water available, the third functioning as a stand-by unit. All pumps are driven by squirrel cage induction motors as speed regulation is not employed. The total pumping power in the four main plants is 2700kW and in the 16 boreholes in use in the Reykjavik area, 1100kW. Recently five deep well pumps have been installed in new boreholes at Reykir as the first step in redeveloping that area.

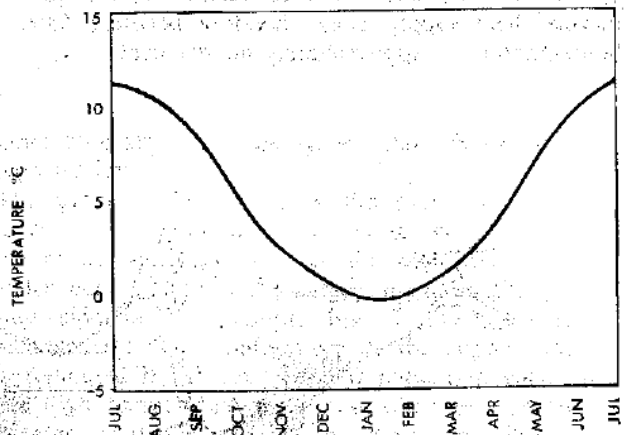


Fig 4.

DISTRIBUTION SYSTEM

Design factors

The maximum load of the system is based on an outside temperature of -10°C , and an inside temperature of $+20^{\circ}\text{C}$. For a total building volume of 11.3 million m^3 , the connected load of 250MW represents $22.5\text{W}/\text{m}^3$. The load density of the system is rather low as many of the houses in the city are single family houses in rather large grounds, the average being $19.6\text{MW}/\text{km}^2$.

The annual mean external temperature in Reykjavik is $+5^{\circ}\text{C}$, that of July being 11.2°C and of January -0.4°C . The difference between the mean temperature of the warmest and coldest months being thus only approximately 12°C , as shown in Fig. 4, the

load distribution throughout the year is therefore relatively even, the January load being only 2.3 times that of July, as shown in Fig. 5. These figures reflect the island climate of the south western coastal area of Iceland and the influence of the Gulf Stream towards balancing of the temperature. However, due to the low summer temperatures the heating season lasts throughout the year!

Although the weather in Reykjavik is very unstable, very low temperatures do not last long at any one time; days with temperatures below -5°C are on the average fewer than 10 in any one year. Thus, as the district heating system obtains its energy in the form of hot water from the ground, storage tanks can be used to carry it over short periods of cold weather lasting for a few days only. These tanks are also used to supply peak demand during daytime, which is 15-30 per cent over the mean 24 hour load. Due to these circumstances, the number of equivalent hours at full load (the load factor) is very high for this system as compared with equivalent data for Europe or North America, the average figure being about 5000 hours per annum, or 57 per cent. The capacity of the peak-load oil-fired boiler plant is approximately 15 per cent of the total system capacity and the load factor for the geothermal heat supply alone therefore becomes 5800 hours/annum or approximately 66 per cent.

District pumping plants

The city is divided into a number of districts, each served by its own district pumping plant, as illustrated in Fig. 6. In the oldest part of the system, completed in 1943, the distribution system follows the single pipe principle. It is fed directly from the storage tanks situated on a hill which was then higher than any built area in the city; it does, however, have booster pumps to take care of higher loads, the pumps adding a pressure of approximately 2 bar ($2 \times 10^5 \text{N/m}^2$). The pumping speed is

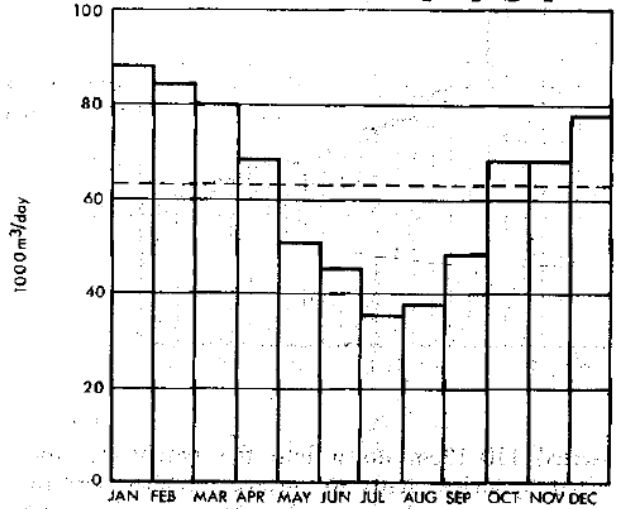
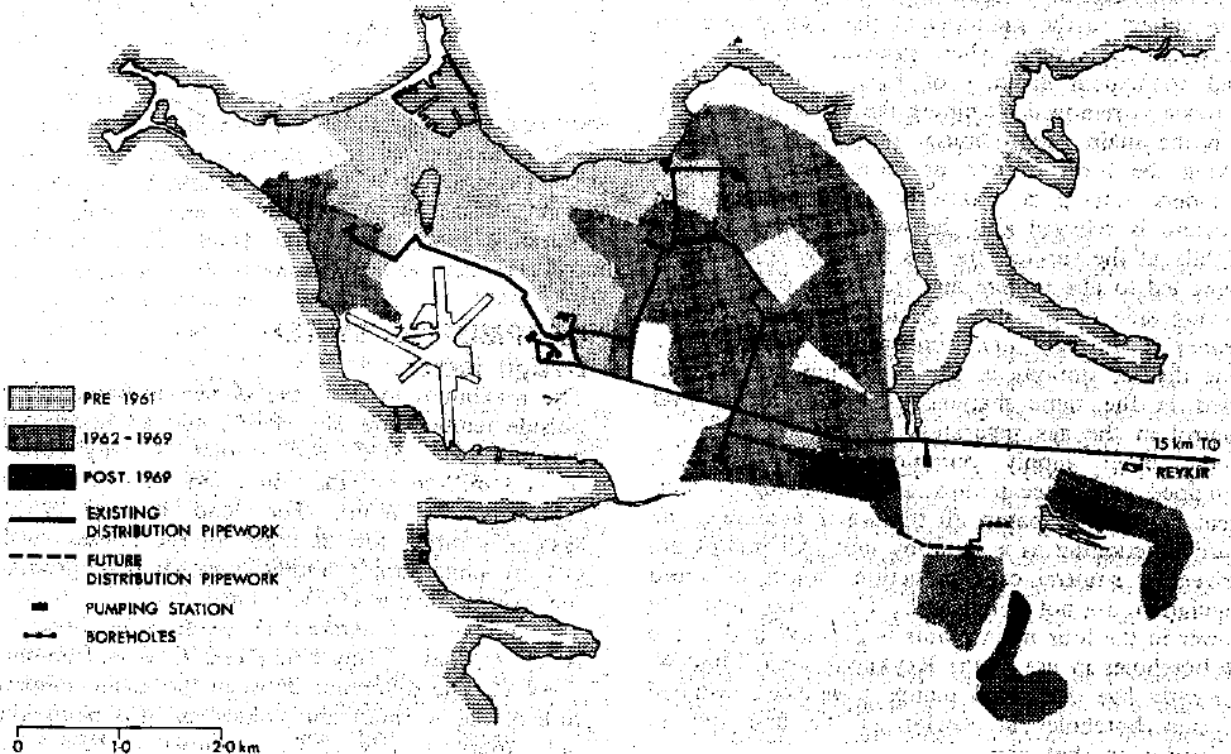


Fig 5.

Fig 6.



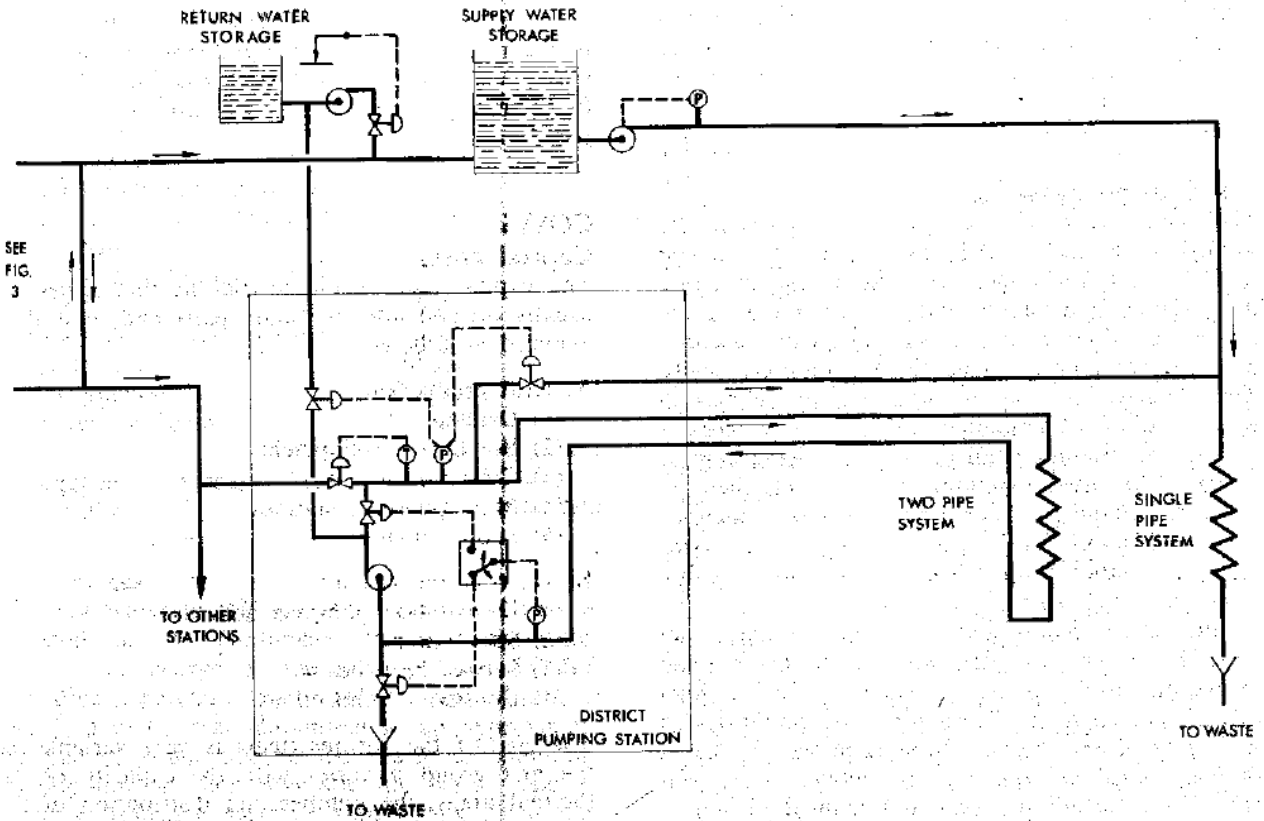


Fig 7.

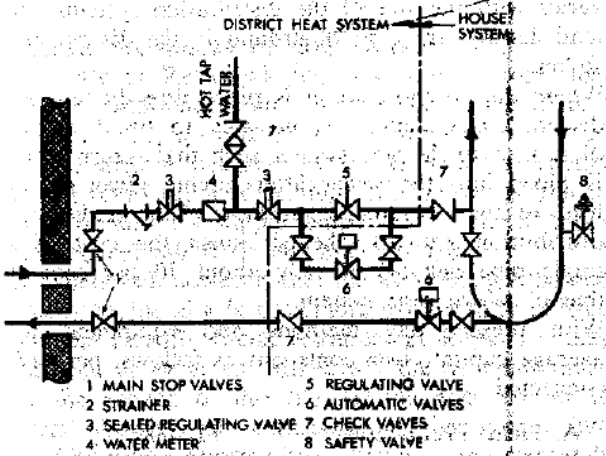


Fig 8.

regulated by a pressure controller at a selected point in the distribution system. In order to utilize water at 120°C and higher, whilst maintaining the supply to the houses at a suitable temperature for domestic use (80°C), combined single and two pipe systems have been designed such that the high temperature water is mixed with return water from the two pipe section and at the

same time supplying the system through the single pipe section.

The piping arrangement in the pumping stations serving these combined districts is such that only the return water is pumped, the high temperature water being led into the supply main on the pressure side of the pumps. Fig. 7 illustrates this arrangement. The temperature of the supply water is regulated by an air operated regulating valve in the high temperature pipe, controlled by the temperature controller (T) in the supply pipe. Pressure in the system, both in the supply and return pipes, is regulated by valves controlled by pressure regulators (P) at suitable points in the system. Each district pumping station is equipped with two pump units, one of which is sized for 100 per cent capacity and the other for 70 per cent capacity. All pumping stations, apart from those at boreholes, are fully automatic: they therefore do not require constant watching but are looked after by engineers visiting each station several times a day. During the winter season a full 24-hour watch is maintained.

An electronic system provides for remote supervision of all the pumping plants and borehole pumps from a central control room, and a number of functions can be controlled there also, such as starting and stopping the pumps. Automatic data-

logging is included for all stations, recording temperatures, pressures and the amount of water pumped by each station, etc. The total number of district distribution stations is nine with a gross pumping power of 2000kW.

Distribution network

The piping used in the system is longitudinally welded black steel to DIN 2440 up to 150mm and to DIN 2458 for larger sizes. Street mains larger than 75mm, and supply and collecting mains, are laid in buried concrete channels and insulated either with rockwool or urethane foam cylindrical shells. The channels are placed on a bed of pebbles in which a drain of unjointed concrete sewer pipes is buried, the minimum fall of channels being kept at 5:1000. At street junctions, the channels meet in concrete chambers, containing valves, anchors, expansion joints, etc. These chambers are ventilated, and either drained from the bottom or if that is not possible, from a pump pit.

Smaller street mains and house connections from street mains are insulated with polyurethane foam insulation protected by a water jacket of high density polyethylene. These pipes are prefabricated in lengths of 6m, the jackets being joined by sleeves of pvc, sealed at both ends by rubber rings, heat shrunk for further tightness and foamed in situ.

The total pipeline lengths included in the system are as follows:

Collecting mains	17.0km
Supply mains	32.0km
Street mains	129.0km
House connection	131.0km

Consumer connections

Central heating has been a general rule for all housing in the city for the past 40-50 years, the vast majority having radiator heating systems, and in consequence direct connection is nearly always employed as shown in Fig. 8. Domestic hot water is also supplied directly and water meters are therefore included in the supply pipe.

Inferential water meters are used, with a magnetic coupling between the water-wheel and the register mechanism. The district heating system provides water to each consumer at a certain minimum pressure in a single pipe-system or, in a double pipe system, maintains a certain minimum pressure difference to keep the return main pressure within reasonable limits to supply sufficient back pressure without overloading the house systems.

A minimum of automatic control equipment is mandatory to ensure proper utilization of the water, and supply is limited, according to the heat requirements of each consumer, by sealed maximum regulators. Generally the control equipment consists of a solenoid valve connected to a room thermo-

stat and a high limit temperature switch mounted in the return pipe from the radiators, in series. In the last few years individual thermostatic valves in the return pipe from each radiator have become popular.

COSTS

Capital costs

The capital cost of the district heating system is usually divided into two main parts and these then itemized as follows:

- A. Heat production:
 - (1) Drilling
 - (2) Borehole development
 - (3) Collecting mains
 - (4) Main pumping stations
 - (5) Supply mains
- B. Distribution system:
 - (1) Distribution pumping stations
 - (2) Street mains
 - (3) Service branches
 - (4) Consumer connections.

The cost of the various items is very variable: in the first group it varies with the capacity of the thermal areas, the number and distribution of the boreholes in the area and its distance from the distribution stations. In the second group, the cost varies with the size of the distribution systems, the load density, the type of ground in the district and so on.

Where the borehole water is piped directly into the distribution system it is possible to build a part of it as a single pipe system such that return water is piped into the sewer after having given up its heat to the consumer's radiators. This makes the distribution network cheaper since the cost of a single pipe network is only about 70 per cent of that of a two pipe system.

With present day methods and equipment the average capital costs come out as follows, per MW connected:

A. Heat Production	£12 000
B. Distribution System	£23 500
Total	£35 500

The total replacement value of the district heating system today would amount to approximately £9 million without allowing for depreciation.

Operational costs

The costs of operation for the year 1968 were as follows (at an exchange rate of 210 kronur/£ sterling):

	£	£
Revenue:		
Hot water sales and meter rent charges		1 530 000
Expenditure:		
Pumping plants	129 000	
Peak power plants network	32 000	
Maintenance of distribution network	169 000	
Office costs, billing, collecting	67 000	
Research, social expenditure, etc.	18 000	
Depreciation	410 000	
Interest on loans	139 000	
		964 000
Consequent income from operation		£565 000

Unit prices

The hot water is sold on a unit volume basis, as metered in the consumers' premises by water meters, the charge at the present being 7.7p/m³ including a purchase tax of 114 per cent. Added to this is a meter rent amounting to an approximate average of 7 per cent of the yearly consumption. Taking into account domestic hot water supplied directly from the system's supply pipes, the unit heat price is 44p/GJ. The unit heat price for fuel oil today in Iceland is 78p/GJ.

Future prospects of the system

The city of Reykjavik has now rather more than 81 500 inhabitants and, as has been stated previously, 93 per cent of its houses are connected to the district heating system. Geothermal energy is still very little used for industrial purposes, principally because the supply temperature of the distribution system (80°C) is not high enough.

It is believed, however, that the available geothermal energy in the city is now more or less fully utilized and the recently found resources at Reykir, if they turn out as expected, will satisfy the demands made by the growth of the city for the next five to 10 years allowing for expansion of the system into neighbouring communities having approximately 30 000 inhabitants.

At a distance of 30km from the city, however, there is a thermal area where temperatures of above 260°C have been encountered. This heat can be transported to the city in the form of water at a temperature of 150°C which is sufficiently high for most industrial uses, such as in the fish and other food industries. In addition more of the greenhouse industry could be brought to the city, which is its main market.

When developing high temperature thermal areas, it is feasible to utilize part of the heat available

for the production of electricity by the use of steam turbines. That energy could among other things be used for pumping water from the field to the city.

DISTRICT HEATING IN HUSAVIK

Husavik, a town of 2000 people on the northern coast of Iceland, built a district heating system last year which is typical of the small town district heating development in this country today. A thermal area with almost boiling water is situated 19km outside the town and studies had been made for district heating from time to time during the past 40 years, but they always showed the project to be uneconomical, due to the long supply pipeline needed to bring the hot water into the town. This problem was solved in 1969 in a very simple manner. Since the hot water at the springs is at nearly 100°C and 75 to 80°C is a sufficient temperature to heat the houses, the pipeline did not require very much insulation. Further, the difference in level between the town and the springs was enough to eliminate the need for pumps if a reasonable size of pipe were used. Thus, a 250mm diameter asbestos cement pipe was laid, connected by slightly flexible couplings (Reka). Thermal expansion is almost negligible, what little there is being taken up in the couplings thus eliminating the need for expansion compensators.

The main supply pipe was laid on the surface and an abandoned road was used as a bed for nearly half the distance. A trench was dug on one side of the pipeline to drain the site and the spoil was used to cover the pipe.

The temperature drop, at the present load of 33 litre/s, is 17°C and the maximum load which can be carried by the pipe without pumping is 47 litre/s which will most likely be sufficient for another 10 to 15 years. This represents some 11MW and an annual heat use of 0.213 million GJ (213TJ). The cost of the project was £300 000 of which half was for the pipeline.

The distribution system in the town is on the single pipe principle, the main line through the town being laid in a buried concrete channel, branch pipes being of the urethane and polyethylene insulated type. Hot water is sold through sealed regulators at a fixed price per annum, no water meters being used. The total income is estimated at £38 000/annum which gives the users a saving of 20 per cent for heat service as compared with fuel oil.

References

1. Arnorsson, S., Jónsson, J., and Tomasson, J., *General aspects of thermal activity in Iceland.*
2. Kristinsson, G. H., and Zoëga, J., *The Reykjavik District Heating System.* D.H.A. 1st International District Heating Convention 1970.

Discussion

In answer to the numerous questions about his paper Mr. Kristinsson made the following points.

The asbestos pipe referred to in the latter part of the paper had no insulation other than the earth cover. No anchoring was provided, the weight of the earth cover alone holding the pipe in place. The only expansion precaution taken was the avoidance of small-radius bends (all expansion was taken up by the couplings). The pipe in this system was laid on the ground partly for simplicity, partly to save on insulation, partly because of the high water table in the area, and partly because spoil from the drainage trench automatically provided a degree of insulation. The scheme was embarked upon on the decision of the local authority, who then required householders within their area to be connected to it as a public service. On smaller schemes of this kind capital was borrowed from banks and local funds; for larger schemes it was necessary to float an international loan. For the smaller schemes the loan repayment period would be five to 10 years, whereas 20 years would be commoner for large scale extensions to such a scheme as that in Reykjavik. Connection charges helped towards speedy repayment. In the scheme at Husavik these charges amounted to 15 per cent of the project cost. Design of the scheme took about a year and installation about six months. The pumping plants throughout the city controlled the temperature by mixing a proportion of the return water with the supply water. Used heating water was run to the drains, the temperature drop on the system being approximately 35°C. A high limit control on the return pipe from each consumer prevented the wastage of water at a useful temperature. Most of the larger buildings in Reykjavik were also connected to the scheme, except a few recent buildings such as the Saga hotel which were beyond the limits of the scheme at the time of building.

The heating service itself did not check the systems used by customers. A degree of control was exercised by the local authority whose prime concern was that the heat should be used efficiently. One speaker noticed that the low insulation density of 22½ W/m²

was similar to that in Great Britain, but the temperature difference between flow and return was much less in Iceland. Mr. Kristinsson said that there was a mandatory minimum insulation standard which was significantly more rigorous than that obtaining in Britain and this would explain the difference. One speaker wondered whether there was not a case in Icelandic circumstances for providing heat at a fixed rate, thus dispensing with the use of meters. Mr. Kristinsson agreed, and said this was the coming tendency, but the existing scheme was equipped with 16 000 meters which could not easily be jettisoned.

There were few corrosion problems—the water was comparatively inert—and there were few problems with erosion due to particles in the water. External corrosion needed to be prevented, but the principal mineral content of the water was calcium silicate which was harmless.

It was wondered whether air in radiators was a problem, but Mr. Kristinsson thought this was only so in an ill-designed system. Steel radiators were quite feasible.

The authority's contract did not have a penalty clause to allow for the supply breaking down, but they had once or twice been forced to pay damages. During the excessively cold winter of 1967–68 there was insufficient hot water for a couple of days, the pressure was insufficient to maintain supply to the higher buildings and in one or two cases the systems froze.

Supply pipes in Reykjavik were currently insulated with polyurethane, waterproofed with polythene, but in the very early days of the scheme peat had been used. Its insulation properties were quite reasonable but it was not durable; it had begun to disintegrate and was being replaced.

One speaker wondered whether any assessment had been made of how long the geothermal hot water would last. No survey had been made, but Mr. Kristinsson was confident that a source of supply that had been in existence throughout recorded history was likely to prove reliable. Another speaker,

recalling the inexhaustible escape of steam at Krysuvik, wondered how much power was available there. Mr. Kristinsson thought that steam at 130°C was available at a rate of between 2.8–5.6 kg/s.

Asked about pipe sizing for domestic hot water Mr. Kristinsson said that they had adopted a very simple solution: the piping was sized for the heating load only. Experience had demonstrated that about 13 per cent of the water was used for domestic hot water purposes as an annual average.

The heating authority's jurisdiction ended at the water meter. The system was owned by the city authority who had minimum requirements for heating installations connected to the system. Proposed installations were checked by a qualified engineer in the City Engineer's department. The consumer paid a varying initial connection charge—currently 40 000kr (about £200) for a small house. The average small house would pay about 7p/m³ per year for the service—about £60 per annum for a house of about 90m².

Another speaker referred to deep bore holes for a high temperature scheme in New Zealand. This source was very little exploited in Iceland. Temperatures up to 260°C and pressures up to 40 bar were available, but the steam was very wet.

Returning to the nature of the heating authority Mr. Kristinsson said that it was a division of the City Engineer's office, as were the electricity and water authorities. When making borings outside the city it was necessary to buy the land. There was no state control for the development of hot springs—this was left to local authorities—but research on the subject was undertaken by the state. Private individuals could, if they wished, exploit geothermal resources but they would be obliged to buy the land in question. Few private individuals had availed themselves of this except for an extension of greenhouse farming. No private individuals used geothermal resources for the generation of electricity, but there was a small pilot plant in the north of the country which might be a foretaste of things to come. A speaker wondered whether the Government had considered the possibilities of thermal electric power. Mr. Kristinsson replied that less than 5 per cent of hydro-electric power was so far exploited and geothermal steam was hardly used at all. Exploitation decisions in the future might well be based on environmental and ecological considerations.

One speaker having raised the very basic problem of why the water was hot in the first place, Mr. Kristinsson said that two theories had been advanced. The first suggested that in thermal areas the earth's crust was comparatively thin, a mass of molten lava near the surface acting as a heating source to the ground water. Another school of thought observed that high temperatures were encountered at sufficient depths at all points on the

earth's surface, if one bored sufficiently deep. The highly porous volcanic rocks underlying Iceland allowed, they thought, heated water to rise to the surface rapidly.

Another speaker referred to the very high level of owner-occupied premises in Iceland and wondered, since connection to the district heating network was obligatory, what provision was made for those who could not afford the connection charge. Mr. Kristinsson thought that anyone unable to afford this charge would be unlikely to own his house, but the installation charge could be paid over five years if the consumer wished it. The connection charge was based on the size of the house only, not on the length of the connecting pipe. If the position of the house required very long connections the authority was obliged to connect, and did not pass on the additional cost to the individual consumer. The rate charged for heat was common, and no special rates were negotiated for industrial or commercial premises.

One speaker was dismayed by the thought of large quantities of warm water being discharged into the drains. Why could not this energy be conserved? Mr. Kristinsson replied that some of it was used for greenhouses, garages, etc., but it was difficult to know what could be done with this relatively low temperature water.

Another speaker wondered what provision was made for peak demands. Mr. Kristinsson said that an oil-fired boiler which stepped up the temperature of the water from Reykir to 110°C was used for this purpose. Provision had also been made for connection to a peak electric plant to add to the system's capacity but in fact the peaks coincided and this had never been used.

The pipe from Reykir was duplicated so that one pipe could act as a standby in case of the failure of the other. It had to be remembered that houses in the city were totally dependent on the district heating. The temperature at the pumping station was controlled to 80°C ± 1°. Transmission losses of up to 6 or 7°C occurred, but there were no measures taken to guarantee a specified temperature at the customer's premises.

A speaker wondered whether problems had been found with mixing taps since the pressures from the hot and cold water systems were presumably unequal. Mr. Kristinsson confirmed this; the hot water was supplied at 5 to 7 bar and cold at 2 to 4 bar, which necessitated the use of pressure regulators. There had been occasional cases of hot water being fed back into the cold mains where these regulators had not been fitted.

A vote of thanks was proposed by the immediate Past President, Mr. N. S. Billington, and was passed with acclamation.