# DIRECT UTILIZATION OF GEOTHERMAL WATER FOR SPACE HEATING IN AKUREYRI, N-ICELAND

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**Key words: Space heating, system description, integrated energy sources**

## ABSTRACT

*In Akureyri. a town of 15000 inhabitants in N-Iceland, geothermal energy has replaced oil burning for space heating. Five geothermal fields at 2-13 km distance from Akureyri are now exploited, each yielding 15-45 l/s of 60-95°C water. In 1993 the annual energy production equalled 240 $Gwh_t$. Since the geothermal systems are fracture controlled and embedded in low permeability volcanic rocks, a 200-300 m draw-down is necessary to achive the desired flow rate. The water is pumped from the geothermal fields along insulated steel pipes to a central pumping station (CPS) in Akureyri, where it is mixed and directed to the consumers. About 30% of the supply water is collected as return water to the CPS where it enters two 1.3 MW heat pumps. In addition a 12.5 MW oil burner is stand-by for emergency use. The water is very low in chemical content. An addition of $NaSO_3$ is necessary to counteract a small oxygen contamination originating to the water in degassing tanks.*

## 1. INTRODUCTION

Akureyri is a town of 15,000 inhabitants located in Central N-Iceland (Fig.1). It has been heated by geothermal energy since the end of the seventies. Prior to that is was partly heated by electricity but mainly with oil burners, located within individual buildings. During the period 1928-1970 several attempts were made to exploite known hot spring areas in the vicinity of Akureyri. These attempts failed. Following the jump in energy price during the oil crisis of 1973 considerable effort was put into further exploration. Based on resistivity soundings, the Laugaland field was selected for deep drilling. In 1975 this resulted in the discovery of a big feed zone, which initially yielded around 100 l/s of 90°C hot water by free flow. Two years later another big feed zone was located at the Ytri-Tjarnir geothermal field initially yielding SO l/s of 80°C water. Based on short term pump tests, and simulations by the Theis model, it was estimated that these two fields together could yield 240 l/s with a water level draw-down to 190 m below the surface (Bjomsson et al. 1979). This was expected to satisfy the energy need for space heating in Akureyri. In 1977 Hitaveita Akureyrar (Akureyri District Heating) was therefore established. Construction of the district heating system was initiated in 1976 and most of the town had been connected in 1979.

Soon after pumping from the fields began, it became evident that the draw-down would be much greater than had been predicted. Since pump design limited the draw-down to 240 m at Laugaland and 330 m at Ytri-Tjamir the average annual production declined rapidly with time. After few years in operation the annual average production from these fields was reduced to 75 l/s. This unforeseen decline was answered by an almost desperate exploration for more geothennal water, mainly by drilling but, later by careful surface exploration followed by drilling. This resulted in the discovery of productive feed zones at 3 different geothermal fields; Botn in 1980, Glerardalur in 1981 and Thelamörk in 1992. These new fields together with heat pumps, electric boilers and energy saving efforts have ensured enough geothermal energy in Akureyri and will do *so* for the next decade or so. However, the over-inveshnent due to the initial over-estimate of productivity and hot water demand dong with other reasons, have led to much higher energy prices than expected. At the moment the price is close to the oil price but, it is expected drop slowly over the next decade or so.

This paper discribes the structure of the district heating system in Akureyri, both reservoir characteristics and installations for distributing the water as well as how the system is operated and monitored

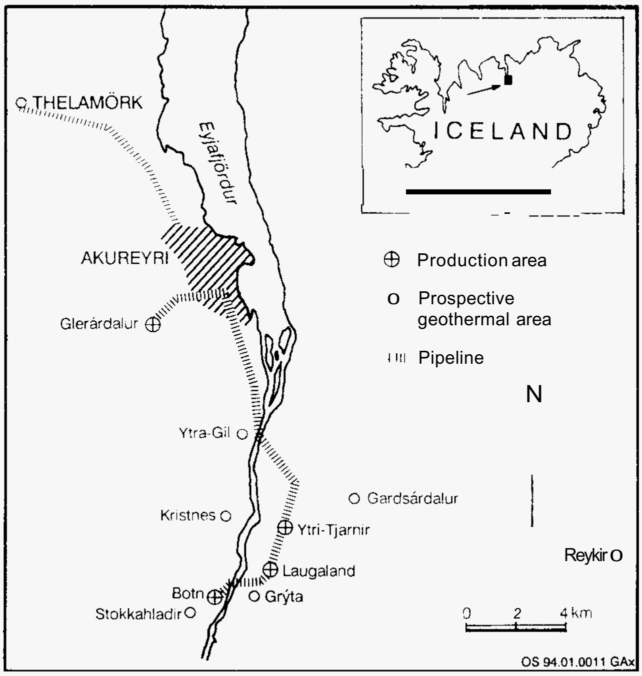

*Figure 1. A map of Akureyri and the nearby geothermal fields.*

## 2. THE HOT WATER DEMAND

Since Akureyri is located close to the Arctic Circle there is need for space heating all the year round. An indoor temperature of 20-24°C is preferred wheras only the average outside temperature of the wannest month is 10°C. The annual averge pumping from the geothermal fields equals 114 l/s, which corresponds to 231 Gwh,. In addition 14 Gwh, are produced by heat pumps and boilers. Within the year there are considerble variations in the energy demand, depending on the outdoor temperature. Fig. 2 shows the annual variations in production rate compared to the outdoor temperature. In addition to the temperature, the energy demand depends on the wind force. A plot of the daily hot water consumption as a function of the difference between indoor temperature and the wind corrected average daily temperature is shown in Fig. 3. The wind corrected temperature, $T_c$, is obtaind by:

$$T_c = T \cdot k(T) \cdot \sqrt{v}$$

where

$$k(T) = 1.22 - 0.023 \cdot T$$

where $v$ denotes the wind speed in knots and T is the outdoor temperature. There seems to be a fairly linear relationshp between the parameters in Fig. **3** but at the highest temperature it tends to level off because the hot water demand will never be less than the amount used for other purposes than heating.

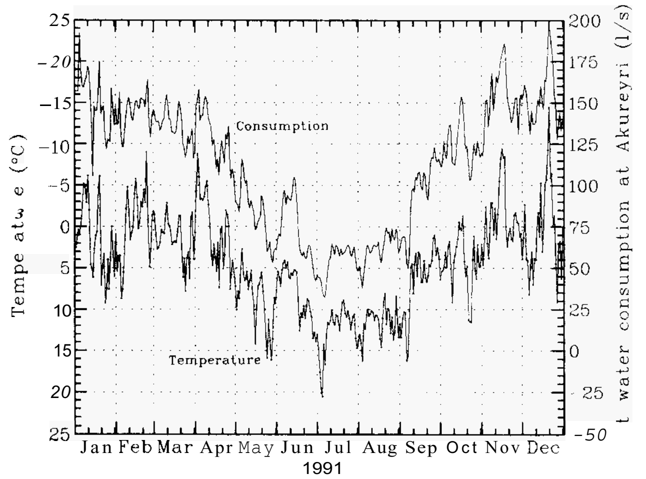

***Figure 2. Annual variation in hot water production compared to the outdoor temperature.***

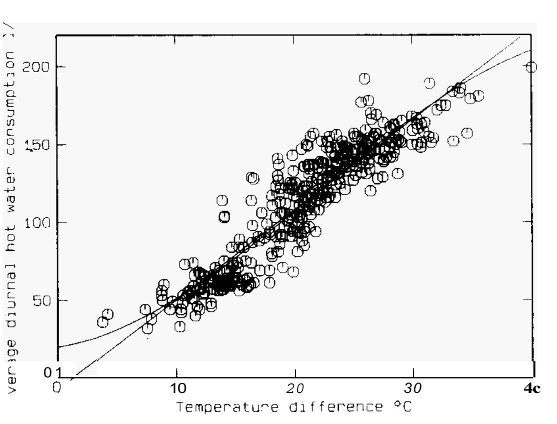

***Figure 3. The difference of the indoor temperature and the wind corrected outdoor temperature as a function of the hot water pumped from the CPS.***

## 3. THE DISTRICT HEATING SYSTEM

Fig. **4** shows a scematic picture of the district heating system. **Hot** water is pumped from three different locations towards Akureyri, from the ***Eyjafjordur geothermal fields*** **12-14 km** south of the town, from ***Glerardalur*** **2 km** west of the town and from ***Thelamork*** **10 km** north of the town. ***Eyjafjordur geothermal fields*** are a synonyme for **three** seperate geothermal fields, *Laugaland,* ***Ytri-Tjarnir*** and *Botn.* In ***Eyjafjördur*** and at ***Thelamork,*** a part of the hot water is used for local consumption but the main part is pumped to Akureyri. In ***Glerardalur*** and at ***Thelamork*** the water is pumped directly from the borholes to Akureyri. In Eyjafjordur the water from the **three** different fields is first collected at the *Laugaland* ***Pumping Station*** **(LPS)** from which it is pumped along the transmission pipe to Akureyri.

At Akureyri the **60°C** hot water from Glerardalur is heated to **73-80°C** by a **6 MW** ***electric boiler*** before it is sent to the Akureyri ***Central Pumping Station (CPS).*** There it is mixed with water from the ***Eyjafjördur fields*** and some return water that has been reheated m two **1.3 MW** ***heat pumps.*** In addition a **1 MW** ***electric boiler*** at the ***CPS*** is used together with the **27°C** return water to regulate the outlet temperature from the **CPS** to **73-80°C.**

The total length of pipelines of the distribution network in Akureyri is **215 km** and the distance from the pumping station to the most distant users is about **5.3 km**. The inlet temperature to the houses is quite variable, depending on the distance from the pumping station and the rate of consumption. It is usually in the range of **65-75°C** but m extreme cases it may fall to **45 "C** during hot summerdays.

Because of elevation differences within the town the distribution system is divided into two separate parts, the upper and lower distribution systems. About **30%** of the hot water that is sent to the consumers is recollected, especially from those parts of Akureyri with the highest population density. The average temperature of the return water is 27°C. Of the total consumption, 90% is for space heating but 10% for bathing, washing and other purposes.

Within the buildings the water enters a substation which includes backpressure control valve, a no-return control valve, flowmeter, thermometer and a shut-off valve (Fig. ***5***). The water is sold to the consumers according to volumetric measurments but corrections are made if the water temperature is below certain limits at maxiumum load.

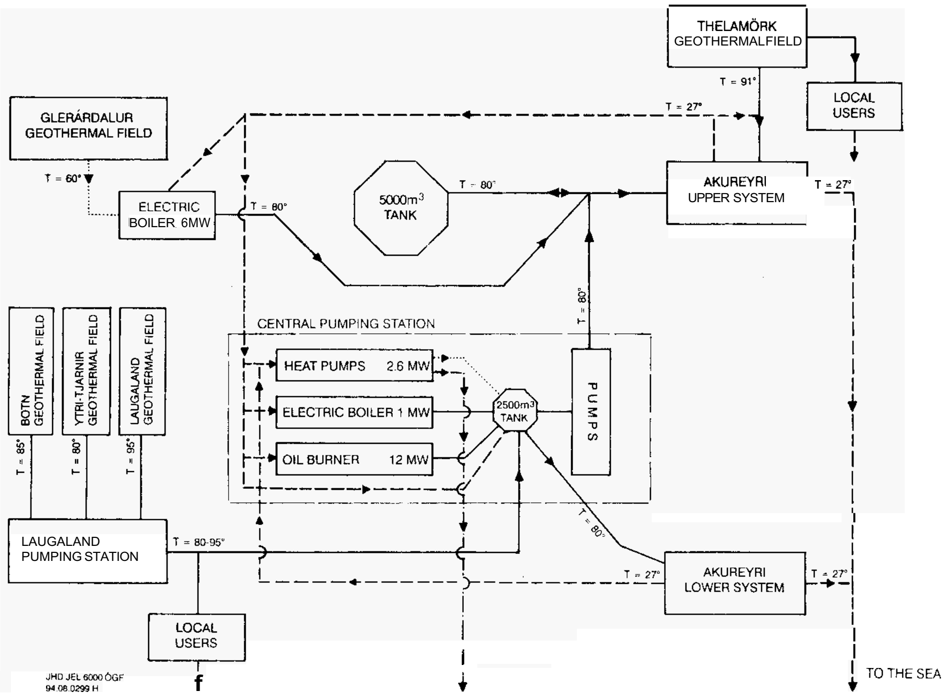

***Figure 4. A scematic picture of the Akureyri district heating system.***

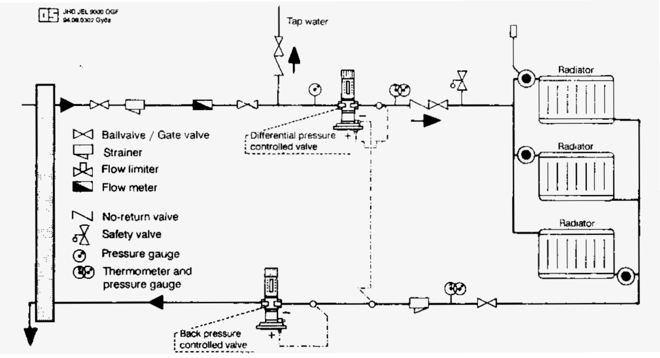

*Figure 5. A typical house substation in Akureyri.*

## 4. THE GEOTHERMAL FIELDS

### 4.1 Geological conditions

The crust around Akureyri is made of **6-10** m.y. old flood basalts interbedded with thin layers of sediments. The lava pile typically tilts a few degrees towards the active riftzone. The lava pile is intersected by numerous near vertical dykes and normal faults, which appear in swarms. The lava pile has suffered low grade alteration which together with precipitation of alteration minerals has drastically reduced the primary permeability. In recent geological times crustal movements have caused formation of tectonic fractures, which often coincide with older dykes or faults. Many of the low temperature geothermal fields in Iceland are local convection systems situated in such fracture zones. Thus the low temperature geothermal systems of Iceland are in most cases fracture dominated convection systems surrounded by almost impermeable rock. This is the case for all five geothermal system utilized by Hitaveita Akureyrar. For further details on the geology of the systems we refer to Flovenz et al. **(1995).**

### 4.2 Reservoir characteristics

The reservoir characteristics of the five geothermal systems utilized by Hitaveita Akureyrar have been derived by careful analysis of availible data on the production response of the systems. Long-term monitoring data have been most important, but other data, such as shorter term well-test data have also been used. The **10 - 15** year production response histories have been successfully simulated by lumped parameter models (Flovenz et al., **1993;** Axelsson, **1989)** and in addition the Botn system has been simulated by detailed three-dimensional numerical modeling (Axelsson and Bjornsson, **1993).** The production history of the Thelamork field is much shorter, however, than the histories ofthe other fields (Bjomsson et al. **1994).**

All of the systems have a low average permeability. On the basis of interference test data the permeability-thickness (kh) has been estimated at **1.3, 1.8** and **12** Dm ($10^{-12}$ $m^3$) for the Thealmörk , Botn and Laugaland systems, respectively. The permeability thickness for the other two systems, Glerárdalur and Ytri-Tjarnir, is also in this range. A permeability-thickness of the order 1 **- 2** Dm is comparable to the lowest such values estimated for geothermal systems utilized in Iceland. The geothermal systems are also small in volume. The Thelamork and Glerárdalur systems are estimated to be of the order 1 $km^3$ only, wheras the Laugaland system is estimated to be as large as a few $km^3$. The low permeability and small volumes lead to a great pressure draw-down and limited productivity for all the systems. The productivity of the five systems, estimated on the basis of lumped modeling, is presented in table 1. The Laugaland reservoir is far the most productive, because of the relatively greater volume and permeability.

The responses of the different systems to long-term production may be compared by calculating their unit responses. A unit response is simply the response to a constant production of a unit volume (or mass) per unit time. The results are presented in Fig. **6.** It shows that the greatest draw-down in the Botn and Thelamork systems and the smallest draw-down in the Laugaland system, reflecting the differences in permeability and volume discussed above. Yet, the Botn system appears to be connected to recharge systems, much larger than the production reservoir, most likely a geothermal system at greater depth as well as the surrounding groundwater system. This causes the apparent stabilization of the draw-down. This might also be the case for the Thelamork system, but the production history is still too short for that to be determined.

***Table 1. Productivity of geothermal reservoirs utilized by Hitaveita Akureyrar***

| Area | Initial pressure[1] (bars) | Maximum pump depth (m) | Productivity (l/s) | Water temperature (°C) |
|---|---|---|---|---|
| **Botn** | 17.5 | 250 | 30 | 85 |
| **Laugaland** | 19.8 | 250 | 46 | 95 |
| **Ytri-Tjarnir** | 5.7 | 400[3] | 33 | 80 |
| **Glerárdalur** | 6.3 | 250 | 15 | 60 |
| **Thelamörk** | 1.9 | 250 | 17 | 90 |

[1] Well-head [2] Until the year **2005**

[3] A submersible motor down-hole pump

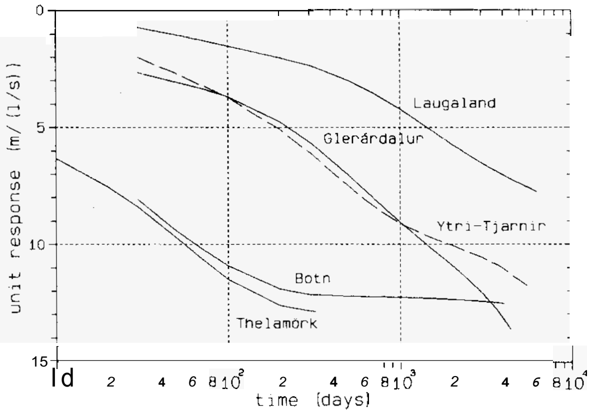

*Figure 6. Unit response of the geothermal systems utilized by Hitaveita Akureyrar,*

*Table 2. Chemical composition of the geothermal water utilized by Hitaveita Akureyrar.*

| | *Lauga-land* | *Ytri-Tjarnir* | *Botn* | *Gler r-dalur* | *Thela-mork* |
|---|---|---|---|---|---|
| **pH/°C** | 9.75/16 | 9.97116 | 9.85/19 | 10.0116 | 9.72121 |
| **$SiO_2$** | 97.5 | 88.7 | 89.6 | 74.7 | 128.0 |
| **Na** | 51.7 | 57.3 | 55.5 | 48.3 | 57.9 |
| **K** | 1.2 | 0.8 | 1.2 | 0.6 | 1.4 |
| **Ca** | 2.9 | 3.8 | 4.4 | 2.8 | 2.1 |
| **$Mg^2$** | 0.001 | 0.001 | 0.001 | 0.004 | 0.007 |
| **$CO2_2$** | 14.7 | 14.3 | 15.8 | 15.1 | 20.2 |
| **$SO_4^2$** | 38.6 | 46.5 | 53.8 | 31.8 | 31.3 |
| **$H_sS$** | 0.09 | 0.09 | 0.10 | 0.06 | 0.16 |
| **Cl** | 11.3 | 14.8 | 11.7 | 10.7 | 13.3 |
| **F** | 0.41 | 0.44 | 0.57 | 0.58 | 0.83 |
| **B** | 0.17 | 0.20 | 0.18 | 0.22 | 0.27 |
| **TDS** | 182 | 241 | 198 | 208 | 286 |
| **0 2** | 0 | 0 | 0 | 0 | 0 |
| **$dO^1$** | -13.32 | -13.94 | -13.78 | -13.85 | -14.15 |

### 4.3 Chemical aspects

The chemical content of the water from the different geothermal fields is shown in table 2. Generally, the water is very low in chemical content and direct use should be possible without any problems. Yet, corrosion problems, especially in radiators, were encountered after a few years of operation. The corrosion was caused by oxygen contamination, mainly originating in the storage tank, but partly in degassers. A minor oxygen contamination will make the water corrosive (Kristmannsdottir, 1991). Therefore its concentration should be kept below 10 ppb. A minor oxygen contamination is usually harmless as oxygen reacts with hydrogen sulphide in geothermal water to form sulphate. But since the water utilized in Akureyri is extremely low in $H_2S$ it is necessary to mix sodium sulphide ($Na_2SO_3$) into the water to remove the oxygen. This mixing is not sufficient, however, to allow the use of the storage tank. The reaction is to slow to remove all oxygen before the water enters the houses closest to the tank.

## 5. TRANSMISSION PIPELINES AND PUMPS

### 5.1 Borehole design

Borehole design has varied with time since the late seventies, as well as drilling technology. Reservoir temperatures in Eyjafjördur are up to 100°C and the maximum observed well head pressure is 20 bar. In most cases the pressure is however much lower and the water level can be as low as 200 below the well head if the wells are connected to production wells in use.

Most of the recent wells are cased with a 14" surface casing down into the bedrock, which is typically at 10-30 m depth. Below that depth, air drilling is commonly applied with an 8 1/2" down hole hammer. The air drilling is often used down to 200-400 m depth or as deep as is possible because of water inflow and compressor limitations. Below that depth, conventional rotational drilling is used with water as circulation media. Typical drilling rates are 8-10 m/hr during air drilling, but 3-5 m/hr during rotational drilling. in case of circulation loss in underpressurized feed zones all the drill cuttings will settle into the feed zones. To avoid that, air is commonly mixed into the circulation water to lower the weight of the fluid column in the borehole.

Usually, the well is drilled to its final depth before it is cased with production casing. A cement plug is put into the well just below the desired casing depth and the well is widened to 12 1/2" by rotational or air drilling and then cased with 10 3/4" cemented steel casing. Typical depth of the production casing is 250 m and typical borehole depth is 1000-1800 m. Liners are usually not necessary, the wells are usually barefoot below 250 m depth.

### 5.2 Borehole pumps

Basically two types of downhole pumps are used by Hitaveita Akureyrar. A pump with submersible motor is used at Ytri Tjarnir, but in the other fields rotary shaft pumps are used. Five types of rotary shaft pumps manufactured by the Floway Company are used. They have 6-15 stages each, the performance is 12 - 60 Us and with motors of 50 - 300 hp, all with a rotational speed of 3000 rpm. Hot water is used as lubrication. When the pumps are not in use the shafts are kept warm by pumping down a small amount of hot water. The submergible pump is a Reda M-520 with a 216 hp motor and a rotational speed of 2915 rpm. The performance is 32 - 33 l/s. Experience shows that the life-time of the rotary shaft pumps is about 9 years with the same motors running from the beginning of operation of Hitaveita Akureyrar. The life-time of the submergible pumps has been 2-3 years.

### 5.3 Pipelines and pumping stations

At the Laugaland Pumping Station (LPS) the water from the Eyjaförður geothermal fields passes through a degasser, which is a 300 $m^3$ insulated storage tank before being pumped towards Akureyri by two Floway 14FKH pumps. They have 6 stages each, 300 hp motors and rotational speed of 1450 rpm. Their performance is 170 ***Us.*** Under normal load only one of the pumps is used, the second serving as a peak and reserve pump. During the wintertime, electrical system failure may occur, especially in bad weather when snow and ice break the electrical power lines. To account for this, a 1500 kVA power station has been installed at the LPS. Therefore the pumping from the Eyjafjordur fields towards Akureyri is not dependent on external electrical power. In addition sodium sulphite is ***mixed*** with the water at the LPS to remove the oxygen contamination..

The transmission pipeline is a $\phi$508 mm steel pipe, insulated with water resistant rockwool and covered with a thin aluminium cover. Only about 1.3 km of the 12 km pipeline is buried in a concrete tunnel, while most of it rests on 1-2 m high concrete columns, with 9 m spacing. The pipeline can move freely on the concrete columns except at every 10th column where there is either a *fixed* point or an expansion unit to take up thermal expansion in the pipeline. The cooling in the 12 km pipeline is close to 2°C for a flow of 100 l/s.

The transmission pipelines from the fields at Glerárdalur and Thelamork are of a different construction. Since Glerardalur is located just 2 km outside Akureyri, and at an elevation of 220 m, the water is pumped directly from the borehole through a small degassing tank and to the CPS at Akureyri.

At the Thelamork field the production borehole is equipped with a frequency regulated downhole pump allowing time dependent regulation of the production without variations in the valve pressure. The water is pumped from the borehole to a 20 $m^3$ degassing tank and then by three 18 kW Grundfos pumps along the 10,1 km long pipeline to Akureyri. In the northern part of the town it is mixed with return water to adjust the temperature to the desired value.

The transmission pipeline from Thelamork to Akureyri consists of a **4.5** mm thick steel pipe, $\phi$**193.7** mm in diameter and with a 60 mm thick polyurethane insulation, covered with a polyethylene coat. The estimated temperature loss along the pipeline is 6°C. This is a subsurface pipeline without expansion units or loops, the thennal expansion is taken up by stresses in the buried pipeline.

### 5.4 The central pumping station

The Akureyri Central Pumping Station is located in the southern part of the town There the water from the Eyjafjördur and Glerardalur fields, as well as a part of the return water is blended in a 2500 $m^3$ storage tank before it is pumped to the consumers This is done by two 14DOH Floway pumps with 4 stages One of them is frequency regulated with a 150 hp, 1450 rpm, motor and a maximum performance of 120 l/s at 55 Hz The other pump has a 100 hp motor and a performance of 95 l/s The distribution system is divided into two parts due to elevation differences within the town The water from the storage tank at the CPS flows directly into the lower part of the system, while pumping from the CPS is needed to feed the upper part, either directly or through a 5000 $m^3$ storage tank located at 115 m.a.s.l

At the CPS the heat pumps, the 1 MW electrical boiler and the oil burner are located.

#### 5.4.1 Heat pumps

In 1984 two 1.3 MW heat pumps were installed at the CPS. The purpose of the installation was to extract more energy from the geothermal water instead of discarding 27°C hot return water. In the system a part of the return water is cooled down to approximately 15°C and the heat is transferred to what remains of the recollected return water. The coefficient of performance is between 3 and 4.The heat pumps have now been in operation for 11 years without any serious problems, and average operation time is 5500 hrs/year.

#### 5.4.2 Electrical boilers and oil burner

The smaller one of two electrical boilers, which have been installed at Akureyri, is located at the CPS. The bigger one (6 MW) is run in co-operation with a dairy plant, and is located at short distance from the upper storage tank. The boilers make use of cheap surplus electricity that is available in Iceland at the present, throughout most of the year. The 1 MW boiler is used to regulate the temperature of water from the CPS, while the 6 MW boiler is used to elevate the temperature of the water from Glerardalur from 60°C to the system temperature. By using surplus energy in that way the lifetime of the present geothermal fields is prolonged and an investment in new fields is delayed.

The 12 MW oil burner uses heavy fuel oil. It is primarily used in emergency cases, such as cases of major system failure. It has also occasionally been used over short and extremely cold periods in the wintertime when more power is required than can be extracted from the geothermal fields.

### 5.4.3 Storage tanks

Two storage tanks have been built at Akureyri, a *2500* m$^3$ tank at the **CPS and** a 5000 m $^3$ tank for the upper system. **The** purpose of the tanks was to filter out **short** term changes in consumption and to have **some** reserve water availible at all times in case of a system failure. To avoid oxygen contamination a blanket of steam, produced by the *6* MW boiler, is used to cover the water surface in the larger tank. Both the tanks **are made** of steel and insulated by rockwool.

## 6. ENERGY CONSUMPTION AND PREDICTIONS

The first houses were connected to Hitaveita Akureyrar in November 1977. In the three years that followed most of the town was connected to the system and the energy consumption increased rapidly to nearly 300 Gwh/year in 1982. (Fig. **7**). The long term generating capacity of the four geothermal fields that had been harnessed in 1982 was only around **250** Gwh/year. Therefore the geothermal fields were thus heavily overexploited, especially Laugaland and Ytri-Tjarnir. *An* almost desperate exploration effort, mainly by intensive deep drilling in 1978-1980 yielded relatively poor results, yet increased the total investment considerably. The overexploitation resulted in rapidly increasing draw-down in wells and in 1982 a constantly increasing energy production by the oil burner **was** foreseen. For three reasons this was not very attractive. Firstly, the distribution system was originally designed as a no-return system, i.e. the return water was not collected. It became therefore necessary to reconstruct a part of the system to recollect return water from the most densely populated parts of the town. This increased the investment cost further. Secondly, the oil price was still very high and the purpose of building the district heating service was to avoid oil as fuel. Thirdly, a lack of electricity in Iceland at that time kept the price of electricity relatively high.

In 1981-84 Hitaveita Akureyrar increased the energy price dramatically. The price actually approached the price of oil heating. The price increase, together with energy saving efforts led to about 15% reduction in energy consumption (45 Gwh/y) from 1982 to 1985 and at the same time the generating capacity was increased by 15 Gwh/y by installing the two heat pumps. However, in late 1985 the most radical energy saving effort took place. It involved a change in the mode of selling the water. Instead of selling it through a flow limiter, where the users paid for the maximum installed power instead of energy used, the price became based on volumetric measurement of the consumption. This led to a further 15% (40 Gwh) decrease in energy consumption. At the same time, the tariff was adjusted so that the total income of Hitaveita Akureyrar was not reduced. The explanation for the dramatic effect of the sales mode on the energy consumption lies in the behaviour of the users. When they buy the water according to **a** preset flow limiter value they try to select as low a value as possible. By this they minimize their cost of heating, but often they buy less than is necessary to keep a comfortable indoor temperature during the coldest days of the year. But they don't care how much energy they use. The users pay the same regardless of they just open the windows on warmer days or wether they turn off their radiators.

The 30% reduction in energy consumption from 1982 to 1987 had a very positive effect on the energy budget of Hitaveita Akureyrar (Fig. 7). Instead of overexploitation of the geothermal fields there has been enough geothermal energy available from 1985 to 1995. It has, therefore, not been necessary to use the oil burner except in emergency cases. This has provided a reasonably long period to explore other potential geothermal fields in the vicinity of Akureyri. This resulted in the Thelamork field being harnessed since late 1994 (Flovenz et al, 1995), which together with the new *6* MW electric boiler will ensure enough energy for the next decade or so.

## 7. SYSTEM CONTROL AND MONITORING

### 7.1 Daily control

To account for changes in consumption rate the water level in the degassing tank at Laugaland is monitored and automatically kept constant. This is done by frequency regulation of the main pumps at the Laugaland Pumping Station. The water level in the smaller storage tank at Akureyri is also monitored and kept within a selected range by switching selected borehole pumps at Laugaland and Botn automatically on and off. The submersible pump at Ytri-Tjamir is, however, always kept at a constant production rate, since its life time seems to be reduced considerably by frequently turning it on and off.

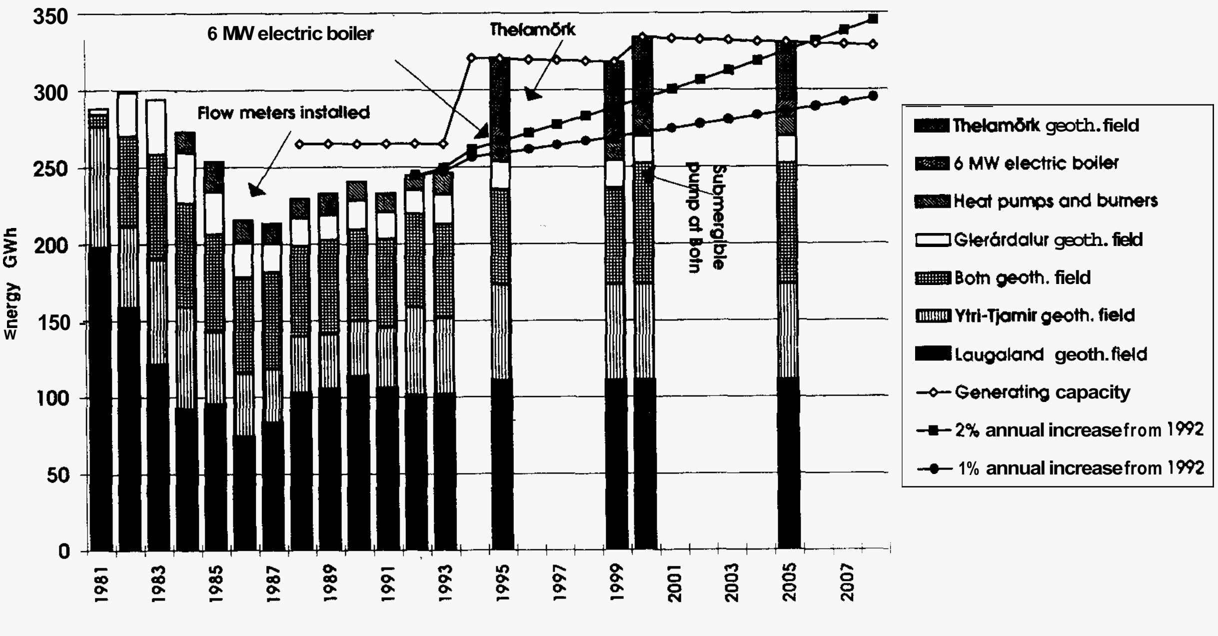

*Figure 7. Energy consumption, future demand and generating capacity of Hitaveita Akureyrar.*

The two heat pumps are in operation when enough return water is available. They have an automatic internal control. The outlet temperature from the CPS is manually controlled by selecting which boreholes are in operation (they have different reservoir temperatures), by varying the mixing of retum water and by use of the 1 MW electric boiler.

### 7.2 Monitoring of thc geothermal systems

Careful monitoring of the geothermal field is crucial in the management of the system. It provides information used to estimate the productivity of individual fields and wells and its variations with time. Information on production rate and water level in individual production wells as well as water level in surrounding observation boreholes is used for modelling the geothermal reservoirs and to make predictions on future trends in water level for the desired production. The predictions are usually done by lumped parameter modelling of the data (Axelsson 1989). Under ordinary circumstances these parameters are measured once a week along with the water temperature and the electrical conductivity of the water. Figure 8 shows an example of several years of monitoring the pumping rate, water level and temperature for one of the boreholes at Laugaland.

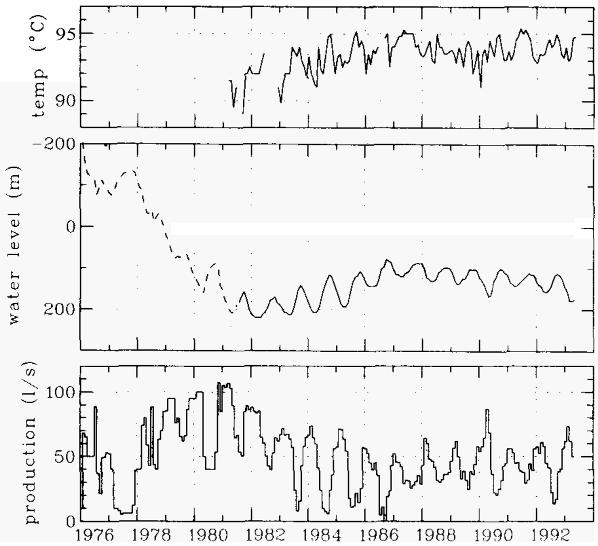

**Figure 8.** *Result of monitoring water level, production rote and temperature in a well at the Laugaland geothermal field.*

Once a year a complete chemical analysis is done for water from all the boreholes to monitor possible chemical changes. Generally, chemical changes have been very small, except for the Botn field where significant changes have been observed. These changes together with most other availible data have been used as the basis for detailed three-dimensional modelling of Botn (Axelsson and Bjomsson, 1993). To monitor possible sudden chemical changes in the geothermal water the electrical conductivity of the water is measured weekly. The sensitivity of the conductivity measurements corresponds to a change of +/- 0.5 ppm of a NaCl equivalent solution. The conductivity measurements are belived to be suitable for giving indications if sudden changes in chemical content occur. In addition the content of dissolved oxygen and $NaSO_3$ is frequently measured to ensure efficient removal of oxygen by sulphite mixing.

## 8. FUTURE ENERGY POLICY

The great investment in the district heating service at Akureyri, together with high interest rates in the eighties have led to a relatively high price for the hot water. The consumer price is now about 32 mills/kWh which is similar to the governmentally subsidised price for electricity for space heating. This can be compared to the average geothermal price of 11 mills/kWh in Iceland or 42 mills/kWh in the case of oil burning.

The generating capacity of Hitaveita Akureyrar is now estimated to satisfy the energy consumption until at least the year 2005, provided that the average annual increase will not exceed 2%. In this period no major investment is expected such that the big debts which now plague the company will be reduced considerably. This is expected to open the way for a lower energy price in the future. However, care must be taken in price reduction as it will most likely lead to an increase in consumption and therefore call for additional new investment in energy production sooner than otherwise.

During the next ten years geothermal exploration will be continued. There are still several known but unexploited geothermal resources in the vicinity of Akureyri which could give additional energy when needed. Furthermore, reinjection of retum water or possibly injection of cold water into the geothermal field is likely to prolong the lifetime of the present geothermal fields and increase their generating capacity (Axelsson et al 1995).

## ACKNOWLEDGEMENT

The authors would like to thank the Vignir Hjaltason and Ari Rognvaldsson at Hitaveita Akureyrar for providing information to this paper, Trausti Jonsson at the Icelandic Meteorological Office for providing meteorological data and Helga Sveinbjornsdottir, Gyða Guðmundsdóttir and Pall Ingólfsson at Orkustofnun for assistance in drafting and layout.

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