

Geothermal District Heating

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SUMMARY

In geothermal heating maximum effective temperature drop should be strived at across the house heating systems. This is commensurate minimum flow rate, optimal pumping requirements and minimal fluid extraction from the geothermal reservoir. This requires the adoption of:

- Large and effective radiators.
- Double pipe heating system.
- Thermostatic control on each radiator.

In certain cases modification of existing house heating systems, e.g. conversion from a single pipe to a double pipe system or installation of larger radiators, may not be feasible. In such cases cascaded flow of the geothermal fluid through a combination of heating systems of different temperature levels may be the solution.

Direct use of the geothermal water in the house heating systems is preferred where the chemical characteristics of the geothermal fluid are suitable. Otherwise heat exchangers of resistant materials are necessary to isolate the geothermal fluid from the heating fluid where corrosion or scaling of the piping and radiator system are to be expected. Such heat exchangers must be designed for maximum temperature drop of the geothermal fluid.

The paper describes the commonly used heating system configurations in Iceland and elsewhere. It outlines moreover the characteristics of geothermal heating systems, their automatic control systems and recommended geothermal field management and monitoring systems.

KEYWORDS: Geothermal, direct use, cascaded use, control.

INTRODUCTION

Icelandic homes were converted from oil and coal fired heating to geothermal heating in the forties, fifties and sixties. They have therefore undergone the necessary changes from a conventional fuel heated house system to a geothermal one. Experience shows that this was a wise decision.

The economy of a properly designed and operated geothermal district heating system is far better than that of a conventional fossil fuel system:

- Heating cost is from 20% to 80% of the cost of heating with oil.
- Cost of heating-energy to the customer in Reykjavik is 1,5 US cents/kWh.
- The most expensive district heating in Iceland charges 3 US cents/kWh.
- Reduced tariff is offered for recreation facilities such as for swimming pools and heating of football fields.

Maximum effective temperature drop in the house heating systems - hence minimum flow rate - is of fundamental importance in geothermal systems calling for:

- Large and effective radiators
- Double pipe heating system.
- Thermostatic control on each radiator.

Where modification of existing house heating systems, e.g. conversion from a single pipe to a double pipe system or the installation of larger radiators, is not deemed feasible, cascaded flow of

the geothermal fluid through a combination of heating systems of different temperature levels may be the solution.

If chemistry of the geothermal fluid permits, direct use in the house heating systems is preferred. Heat exchangers of resistant materials are necessary where corrosion or scaling of the piping system may be expected. The heat exchangers shall be designed for maximum temperature drop of the geothermal fluid.

Low cost of operation and usually high cost of initial investment is what characterises geothermal district heating systems. The high initial cost involves the exploration and the drilling of the geothermal wells, as well as the production field development. The cost of investment and operation is directly related to the quantity of the geothermal fluid in motion, i.e. the number of wells, pumping from the well, and transmission to the market area and distributing to the customer.

Therefore:

- The supply temperature to the customer is kept constant throughout the heating season and as high as legally permitted (normally 80°C in Iceland).
- The return temperature is made as low as possible (35°C or lower in Iceland).
- All hot water is metered by volume.
- The tariff system provides an incentive to the client to use the heat from the purchased water efficiently.
- Due to high initial investment the geothermal energy shall be used as base load (see the typical load duration diagram below)

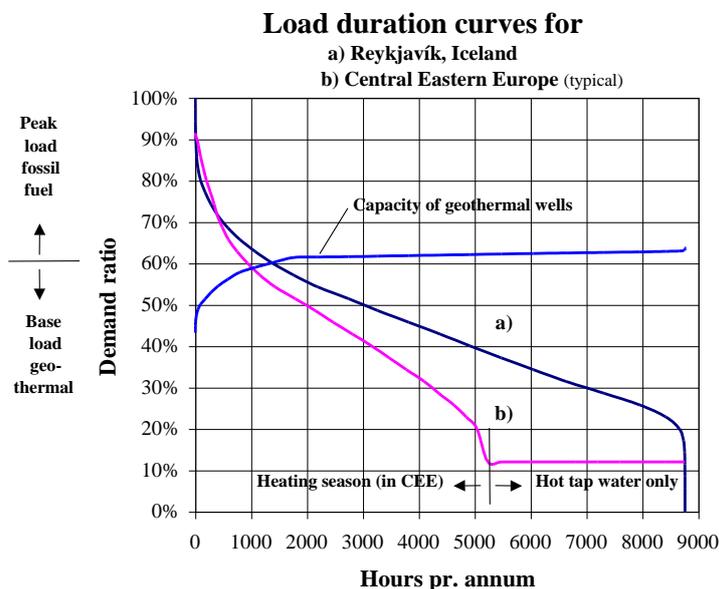


Figure 1 Typical load duration curves. Curve a) depicts a district heating system with a high load factor and b) system with a low load factor (no space heating during summer season.)

1 DISTRICT HEATING SYSTEMS

1.1 Types of district heating systems

Geothermal district heating systems may be divided into two main groups depending on whether the geothermal water is used directly in the house heating systems (secondary system) or indirectly by transferring the geothermal heat to the secondary system via heat exchangers. In the latter case the geothermal water is confined to the primary system. Figure 1 depicts a few examples of direct and indirect use of geothermal water for district heating. Temperature values shown are typical values under design conditions (e.g. -15°C outdoor temperature in Iceland.)

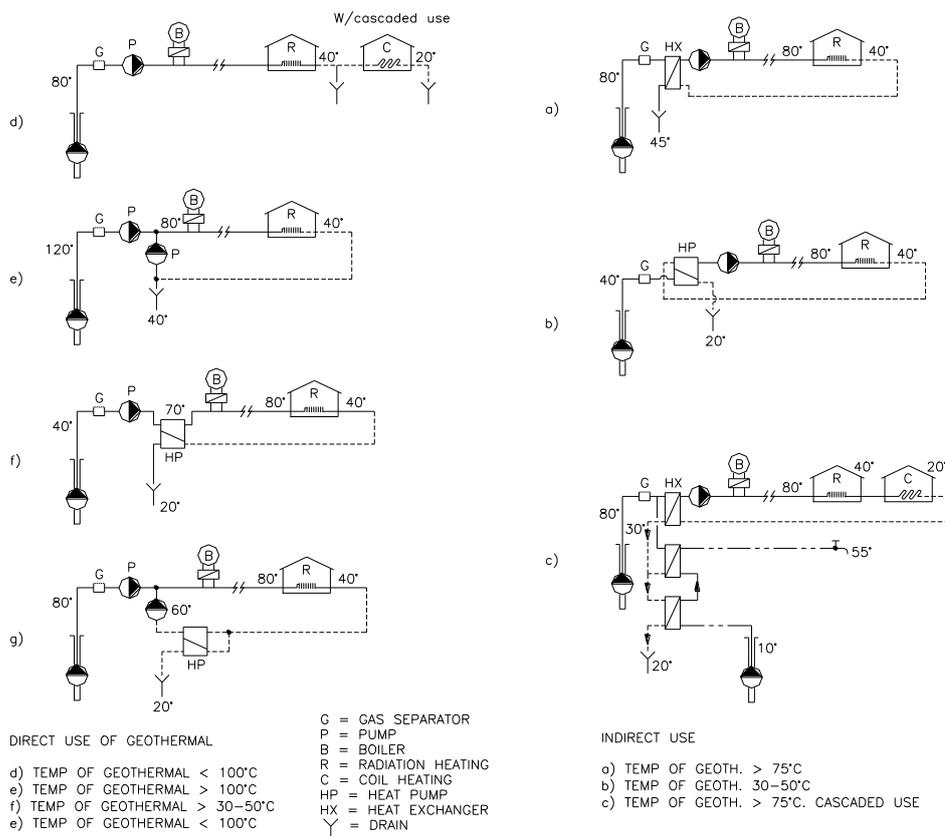


Figure 2 Examples of district heating network with geothermal water

Direct use

If the chemistry of the geothermal fluid permits the water may be used directly in the house heating systems without any fluid separation by heat exchangers (example: Reykjavik, the capital of Iceland.) In such cases the following technical solutions have been used:

- a) *Single pipe system*: This single-pass or once-through system uses the geothermal fluid (temperature below 100°C) directly for heating in radiators, floor coils etc.. The spent fluid from the radiators is discharged to waste. Due to safety limits to maximum temperature of hot tap water, usually 55 to 60°C (38°C for baths), heat exchangers or automatic mixing valves are employed. In the former case cold water is heated with geothermal water through a heat

exchanger to the required temperature and in the latter the geothermal water is mixed directly with cold water.

- b) *Dual pipe system*: A part of the spent return water from the house system (temperature 30°C to 40°C) is collected and mixed with the geothermal supply water (temperature 100°C - 130°C) to obtain a constant supply temperature (e.g. 80°C) irrespective of weather conditions. The excess return water is discharged to waste or injected back into the reservoir (re-injected.)

Geothermal District Heating Direct use of low temperature water

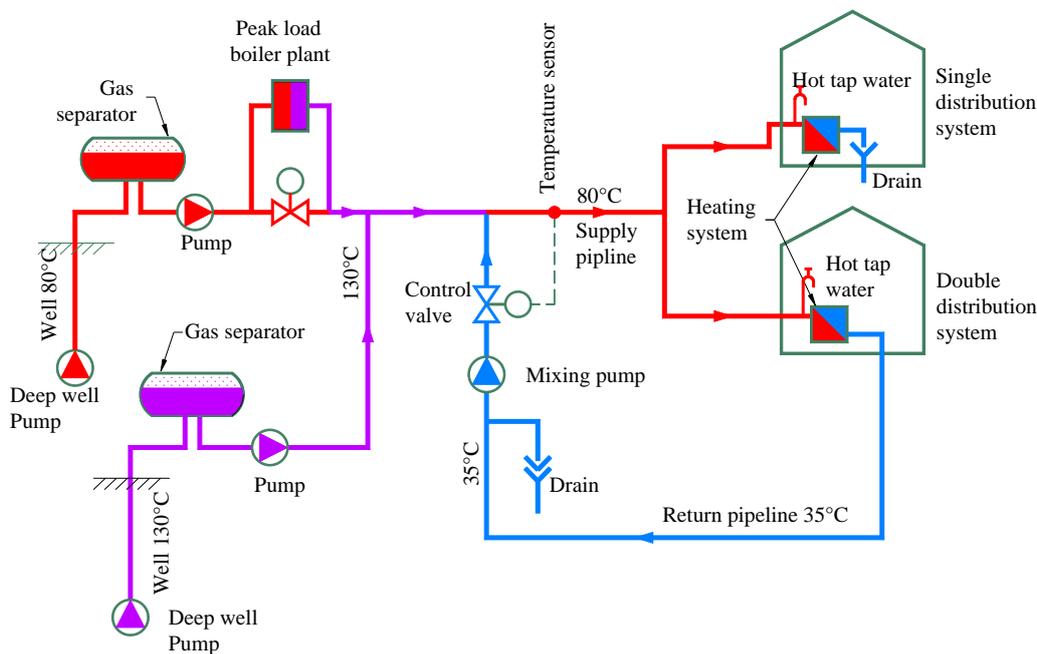


Figure 3 Process diagram for direct use of geothermal water in a single pipe network

Figure 3 shows a process diagram for direct use of geothermal water at temperatures ranging from 80°-130°C. This is in reality a simplified process diagram for Reykjavík Energy as it has been operated for over 60 years. Still today the main part of the district heating system is operated in this way. The wells are 1000 – 3000 m deep. Line shaft driven deep well pumps immersed to a depth of up to 200 m pump the water to a gas separator. The geothermal water is 80° to 130°C and the supply temperature to the consumers is 80°C. Part of the distribution network is a dual pipe system. The return water from that part is mixed together with the water from the wells to produce 80°C supply temperature. The excess return water from the double distribution system is discharged to drain. Part of the distribution network is single-pipe from which the return water is discharged from each user into the sewage system or to the rainwater discharge system. Most of the consumers receive hot tap water directly from the distribution system. The volumetric flow rate to the users is measured and the tariff is based on cubic meter of hot water. Now the charge in Reykjavík is ca. 80 UScent per m³ of hot water. The users can utilise the heat energy from the water at free will and return it to the system or discharge it to drain at as low temperature as possible. With conventional radiator system 25°C – 40°C return temperature is common, but with other heating systems such as floor heating, heated fresh air and even combined with snow melting, the return temperature can be

as low as 10°C - 20°C. This means that each m³ of hot water yields from 45 and up to 80 kWh and the corresponding energy price thus varies from 1,0 – 1,7 U Scent/kWh. There is no doubt that a district heating system of this type has the lowest energy production cost. The single pipe distribution system is less costly and has lower heat loss than a closed loop (dual pipe) system and the pumping cost is also less. It is possible to install a peak load boiler in this system, even if the well temperature is 80°C and the whole system is a single one. Then the supply temperature will be varied according to the load demand, let's say between 80°C and 130°C. In this case, the building heating systems have to be of indirect closed loop type and the charge for energy would probably be via energy meter.

The direct use process shown in Figure 3 is only possible where the chemistry of the geothermal water is such that there is no danger of mineral scaling and corrosion of ordinary carbon steel pipes and heating equipment. Also, if the geothermal water is used directly for washing and bathing, it must be free of harmful chemicals.

Indirect use (geothermal water in the primary system only)

The geothermal water is, in this case, separated from the district heating water by heat exchangers. This may be necessary due to the chemical characteristics or high temperature and pressure of the geothermal fluid used. Such an arrangement also offers more flexibility if, for instance, the geothermal sources become temporarily inoperable.

The purpose of the heat exchangers is to transfer the heat from the geothermal to the heating system medium whilst keeping the two separated.

The district heating system as well as the hot tap water system are each a separate closed-loop network in the residential unit or apartment in question. After passing through the house heating systems the secondary system heating water is collected and transmitted in pipes to the heat exchangers, where it is reheated to the required supply temperature. The secondary side of the hot tap water heat exchanger is connected to the municipal cold water supply system, which then is heated to the required temperature for the hot water taps (55-60°C.)

Geothermal District Heating

Fresh water heated with geothermal fluid - Single transmission pipeline

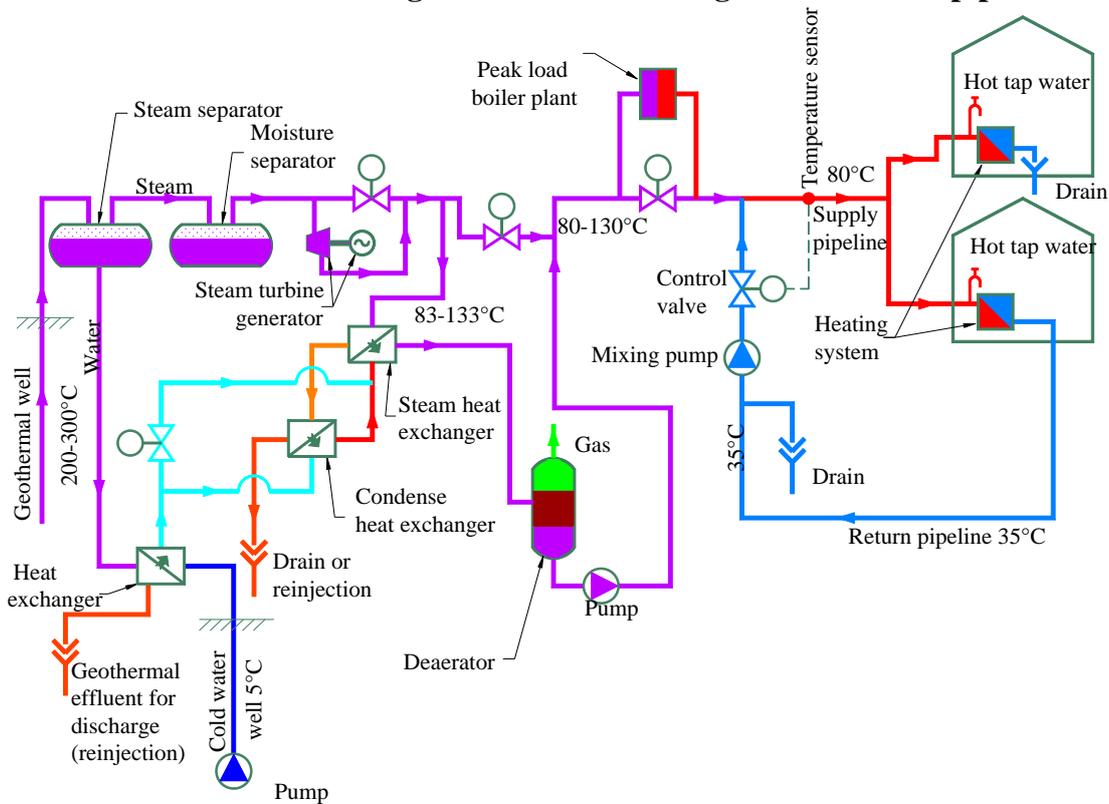


Figure 4 Process diagram for quasi-direct use of geothermal energy; fresh water heated with geothermal water and injected with geothermal steam containing sulphur for oxygen scavenging.

The second process diagram, Figure 4, depicts a system where high-temperature geothermal fluid (water and steam) is used to heat up fresh water which is then pumped to the consumers via single transmission pipeline. The distribution network and heating systems in buildings are exactly the same as on the first process diagram and the heated fresh water is used directly. The geothermal fluid from the wells flows first to a steam separator from which the steam flows to a turbine for production of electricity or to industrial application. The water from the separator flows to a heat exchanger where the fresh water is preheated. After the geothermal water has been cooled down in the heat exchanger it is discharged on the surface or reinjected into the field. The preheated fresh water runs to a steam heat exchanger and a part of it goes through a condensing heat exchanger. In the final (steam) heat exchanger the fresh water is heated up to 3°C – 4°C above the temperature in the transmission pipeline. From there the water flows to a deaerator where gas, mainly oxygen, is removed from the water by boiling, from let's say 133° to 130°C. In Iceland a small amount of geothermal steam is injected into the water before it is pumped into the transmission pipeline. The purpose is to use sulphur in the steam to remove traces of free oxygen from the water to prevent corrosion in the pipelines and heating systems.

The main advantage of this process is a relatively low cost due to the single transmission pipeline and possibility of a single distribution system. A condition for using this process is that enough inexpensive fresh water is available.

There are many alternatives to this process depending on the temperature of the geothermal fluid, for example whether electricity can be produced at a competitive price. In some cases only the water from the separator is used for heating and in other all the fluid is used for heat production.

For production of electricity three types of turbines may be considered, back pressure turbine, condensing turbine and binary cycle turbine. Which type is selected must be evaluated in each case. The selection depends on the fluid, the price of electricity versus heat energy and the energy market.

One very important factor for the economy of geothermal projects is the temperature drop of the geothermal fluid; or how much energy can be extracted pr. unit of fluid. The maximum possible temperature drop depends on the chemical composition of the fluid and the environmental conditions. There is often a limit to how much the fluid can be cooled before deposits of dissolved minerals start to form and heat exchangers and pipes may become plugged. It is often possible to delay the deposit f. ex. by use of inhibitors. However if reinjection of the geothermal fluid is required for environmental reasons or to increase the lifetime of the reservoir the fluid must under no circumstances be cooled to the extent that mineral deposit will plug the reinjection wells.

Geothermal district heating

Heat exchangers at the distribution system - Single transmission pipeline

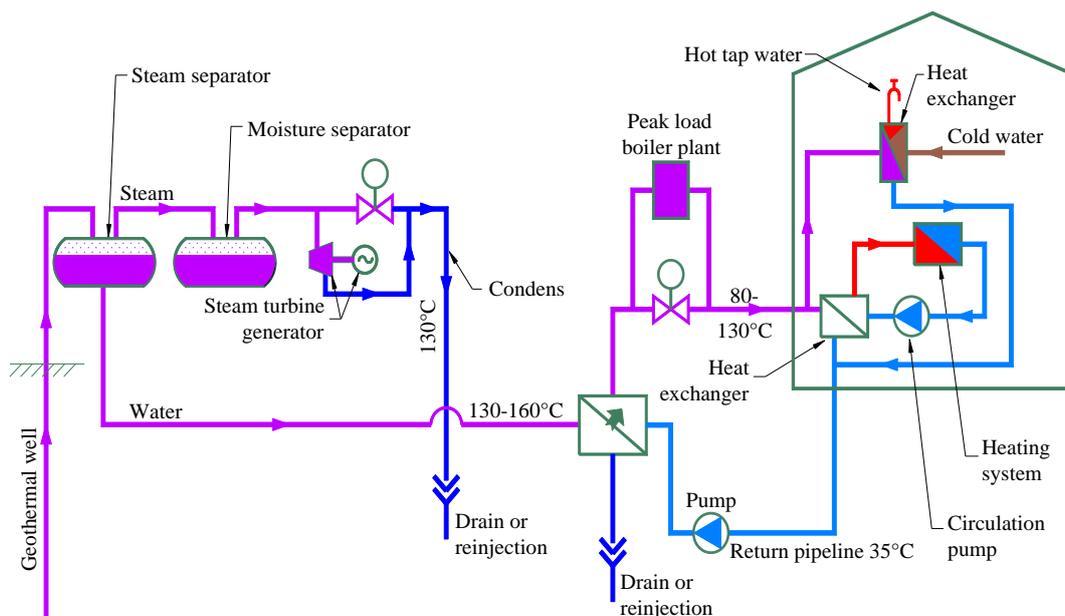


Figure 5 Indirect use of geothermal energy; heat exchangers by the distribution network

Figure 5 depicts a system where the geothermal water is piped from the geothermal field to a connection with the distribution network. There the heat energy is transferred to the district heating system via heat exchangers. (Note: Pump is missing on the picture). The distribution system itself is a conventional closed loop system. The water in the distribution system is heated with the geothermal water via heat exchanger. Conditions for this process are that the geothermal water can be transmitted through a pipe over long distances without scaling or corrosion problems - this may however require that the temperature and pressure be maintained above certain minimum limits. The second condition is that the geothermal effluent can be discharged in the vicinity of the market, either to drain or by re-injection.

There are numerous alternatives to this process diagram which usually applies to high temperature geothermal fields. No pumps are needed in the wells and the steam may be used for production of electricity. The condensate from the turbine is discharged but it can eventually be pumped into the transmission pipeline. This process can also be used for hot water applications from a low temperature field. In that case a deep well pump would be installed in the well as shown in the first process diagram and the first part of the process would be exactly the same as there.

This process should be considered when scaling and/or corrosion problems may be expected when the system pressure is released and/or the geothermal water is cooled down. The main advantage of this system is the single transmission pipeline (lower cost.) Therefore this process is especially actual where the geothermal field is distant from the market. Sometimes it will be necessary to use inhibitors in the geothermal water to prevent scaling and/or corrosion.

As for other processes the temperature utilisation (or final temperature) of the geothermal fluid depends on the chemical composition of the fluid and the environmental conditions.

Geothermal District heating

Closed Loop - Double transmission pipeline -Heat exchangers at the geothermal field

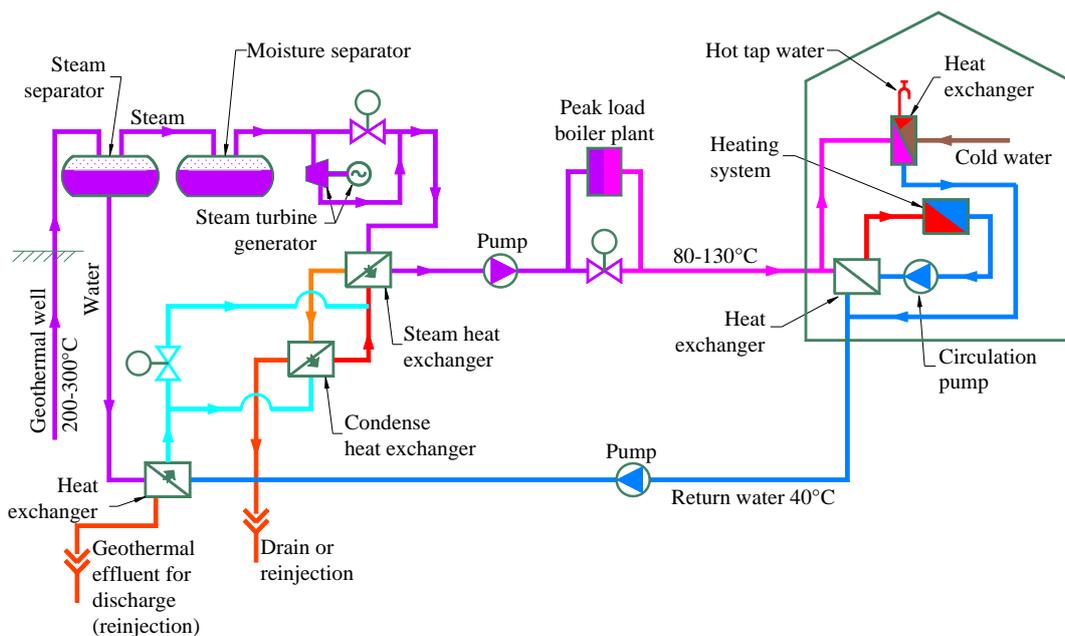


Figure 6 Process diagram for indirect use of geothermal energy with heat exchangers at the geothermal field and a double transmission pipeline.

The last process diagram, Figure 6, shows a double transmission pipeline and a heat exchanger station located in the geothermal field. The whole system outside the geothermal field is a traditional closed loop system with treated clean water. The geothermal fluid is never brought out of the geothermal area. It is assumed that a part of the steam is used for production of electricity. As for the other options the utilisation of the steam for production of electricity or other depends on various conditions such as the reservoir temperature, the well characteristics and the market situation. The temperature drop of the geothermal fluid depends on the chemical composition of the fluid and the environmental conditions as before.

The four process diagrams presented here are examples of utilisation of geothermal energy for district heating. All the process diagrams are simplified and there are many alternatives within each. They are not to be taken as exact solutions for geothermal district heating or other applications. On the contrary all geothermal projects are tailor made in compliance with local geological and market situations.

Peak load plant

It is generally found to be more economical to install fossil-fuelled boilers to handle the usually brief periods of peak heat demand, than to provide geothermal capacity sufficient for all load situations especially in places where the load factor is low (Figure 1 depicts typical energy duration curves for Iceland with high load factor and Central Europe with low load factor.) A boiler plant requires a comparatively low capital investment but is expensive to operate. This makes boiler plants for heat generation typically more economical for intermittent peak load applications, than would the provision of additional geothermal well(s). A geothermal well is generally found to be more expensive than a boiler plant of similar thermal capacity. Heat pumps may alternatively be employed to boost the thermal base load capacity.

Following is an example to demonstrate how a peak load boiler can lower the energy production cost for a heat market with full load utilisation of for example 2 000 hours pr. year: It is assumed that the market is large enough. The price of geothermal energy is taken as 1,9 UScent/kWh for full load utilisation of 2 000 hours pr. year and 1,1 UScent/kWh for 3 500 hours per year.

First we look at an alternative with no boiler and 10 MW available geothermal power. Thus, the maximum demand of the market that can be served is 10 MW. Annually 20 GWh of geothermal energy can be delivered to that market. That means 20 GWh of geothermal energy will annually replace another energy source, usually decentralised burning of oil or lignite coal. The total production cost will be 390 000 USD and the specific production cost of energy equal to the production cost of geothermal energy namely 1,9 US cent/kWh.

If we now install a peak load boiler that covers 60% of the maximum load demand, the market that can be served will increase from 10 MW to 25 MW maximum load demand. Referring back to the load curve, we now see that although geothermal power is only 40% of the maximum power demand it will be cover 70% of the annual energy demand. That means geothermal energy will provide 35 GWh of the 50 GWh total energy demand. Or in other words, for each 10 MW geothermal power installed 35 GWh of geothermal energy will replace another energy source instead of 20 GWh annually, if a peak load boiler is not installed. If the price of peak load energy is 2,0 US cent per kWh, the total cost will be 685.000 USD/year and the production cost of energy will be reduced to 1,4 US cent/kWh.

This is an example of how a peak load boiler can influence a geothermal district heating project, both the size of the market that can be served and the cost of energy production. In a real project it is important to optimize the size of a peak load boiler, taking into account the marginal cost of installed geothermal power, cost of peak load boiler, cost of fuel and the cost of an increased market

2 PIPE SYSTEMS

The source of geothermal fluid to be used for district heating systems is, in most cases, located some distance away from the heating market, although geothermal water may also be found within the market area. A transmission pipeline is therefore needed to transport the geothermal fluid from the geothermal field to the end users. Collection mains are required to interconnect the geothermal wells, collect the fluid from each one and transport it to a heat or distribution centre in or close to

the geothermal field. In the heat centre the fluid is transferred to the main transmission pipeline, which links the geothermal field and the distribution network at the consumer end.

2.1 Collection and main transmission pipeline

The transmission pipeline diameter is dictated by local conditions such as the grade of the land over which the pipeline is laid, available power for pumping, etc. An approximate rule of thumb is to design the diameter of the pipe so that the pressure drop in a straight section of pipe at maximum rate of flow is the order of 0,05-0,10 MPa/km.

Transmission pipelines may be of assorted makes and types. The various alternatives usually differ greatly both in cost and durability. The most common pipeline material is carbon steel, but various plastic materials (polypropylene, polybutylene, and polyethylene) may be used for smaller size pipelines. The use of plastic pipes can lead to corrosion damage in downstream metallic components due to atmospheric oxygen diffusing into the water through the pipe walls. Also, special care should be taken to select the correct pressure class for the expected temperature and pressure conditions. Asbestos-cement pipes have been used in long pipelines when there is an abundance of hot water and the cost of pumping the hot water is low. These pipes are attractive because of the low initial cost compared with carbon steel pipe, but have lost popularity in recent years due to the hazard to health associated with cutting, assembling and disassembling the asbestos cement pipes.

2.2 Distribution network.

The distribution network is a very important part of the district heating system. Care in the planning and design of the distribution network is of great importance for the successful operation and proper functioning of the heating system. Distribution systems are commonly of two types, either a single-pipe system or a system with two pipes, supply and return, i.e. a closed-loop system. The former may be employed where the chemistry of the geothermal fluid with respect to corrosion, scaling and water quality permits direct use. The fluid is discharged to waste or injected back into the reservoir (re-injected) after use. The latter type of system must be used where direct use of geothermal fluid is not possible due to the chemical composition, quality and/or temperature of the water.

The distribution network may in general be divided into mains or trunk lines, branch lines and house lines. The trunk lines or mains constitute, as implied by the name, the main pipelines going out from a pumping station. One or more trunk lines may be needed, depending on local conditions and size of network.

The usual arrangement is to lay the trunk line in such a fashion that the branch lines jut out from the trunk lines as branches on a tree and the line keeps decreasing in diameter towards the end farthest away from the reservoir. Lines forming closed loops are also employed because they are considered to have certain advantage over the branched type. The advantages of the closed-loop type are, for example less danger of complete sections of town having to be closed off during repair work and reduced likelihood of low water pressure for consumers who are located farthest away from the pumping station.

The closed-loop system is clearly more expensive to construct than the simple branch system, which is probably the reason why they are not more frequently used. Also, a higher temperature drop may be experienced.

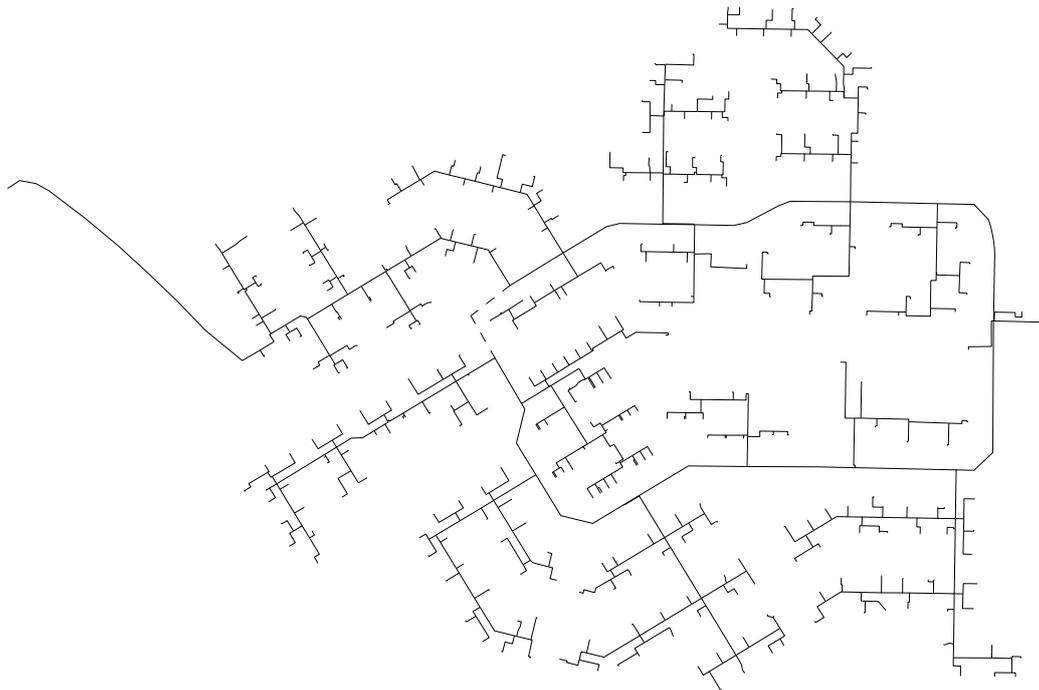


Figure 7 Example of a distribution network, Hamrahverfi in Reykjavik, Iceland

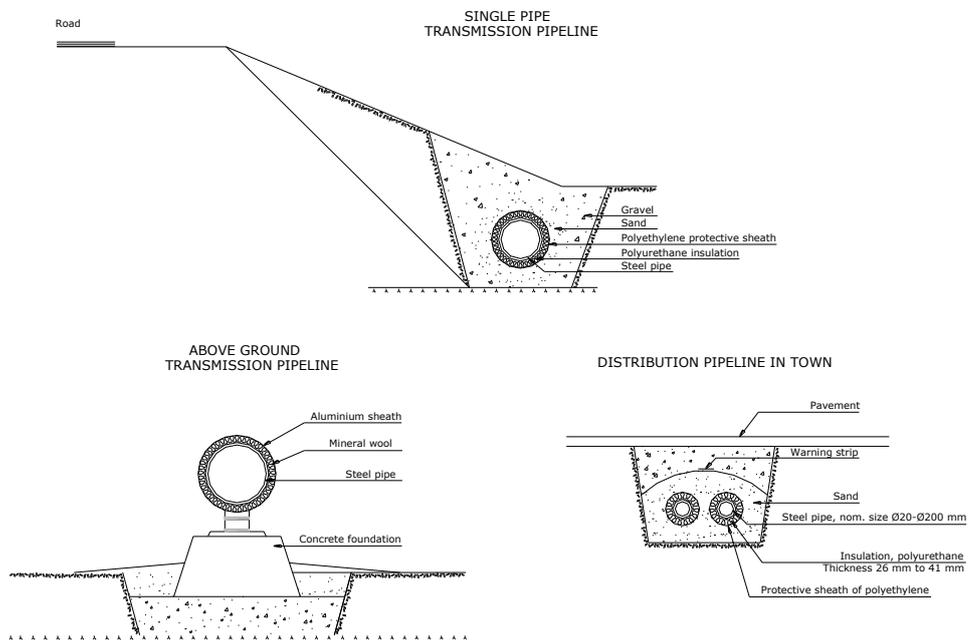


Figure 8 Examples of transmission and distribution pipelines

Service wells, typically of reinforced concrete, are located at major branch points for easy service and repair access. The wells contain valves, expansion compensators, flexible expansion hose connections and most often pipe anchor points. The wells are fitted with manholes on top to provide entrance for maintenance and inspection crews.

A distribution network pipe is commonly designed to withstand 10 to 25 bar internal pressure (1,0 – 2,5 MPa). The network is so designed that the lowest pressure at the intake to houses at maximum load is never less than 0,15-0,2 MPa. Another criterion is that the radiator system in connected buildings may not be able to withstand pressures in excess of 7-8 bars (0,7-0,8 MPa). This means that in districts where there is a large difference between the elevation of the highest and lowest buildings, the distribution system must be divided into a number of separate sections, each one serving buildings within a given range of elevation. In open systems, where the geothermal return water is discharged directly to drain, the water pressure in the house system is lower. Typically, pressure sustaining valves in the discharge pipe, are used to maintain house system pressure of 1 to 4 bars (0,1 to 0,4 MPa), while the supply pressure upstream of a differential pressure regulating valve in the house intake is 2 to 7 bars (0,2 to 0,7 MPa). Normally, about 1 bar (0,1 MPa) differential pressure is sufficient for the house heating system.

Districts, extensive in area and thus having large associated pressure losses, require more than one pumping station to keep the maximum pressure within the acceptable pressure limits given above. During construction, the distribution network is typically tested at 12 bar (1,2 MPa) pressure.

2.3 House lines and house heating systems

The parts of the distribution system that connect the consumer with the distribution system are the so-called house lines. House lines differ in size depending on the size of the building and heating loads. The most common sizes are 20 and 25 mm nominal diameter, usually carbon steel pipes insulated with polyurethane foam and covered by a protective polyethylene pipe.

Larger buildings need larger pipes – anywhere from 32 to 100 mm in nominal diameter.

The design of a house heating system is aimed at maximum utilisation of the geothermal energy. Geothermal heating systems are, therefore, so-called once-through systems, i.e. the hot water passes through the heating system only once and is returned to the district heating network, discharged to waste or re-injected. The typical house heating arrangement adopted for boiler plant powered district heating systems, where a large quantity of heating water is circulated through the system and the temperature difference between the supply and return is kept low, is not economically viable for geothermal heating.

In order to maximise the utilisation of the geothermal energy, the temperature of the heating water leaving the house (return) must be made as low as possible. A prerequisite for this maxim is that the heating equipment, most popularly radiators, has sufficient heating surface to ensure the maximum practicable temperature drop across the house (see Figure 4.2.2). Alternatively, the heating water may be passed through radiators and heating panels (floor or ceiling) in sequence, a type of cascaded use.

Table 2 Common types of pipelines (1)

<i>Type of pipe</i>	<i>Application</i>	<i>Advantages</i>	<i>Disadvantages</i>	<i>Cost ratio</i>
1. Buried non-insulated polypropylene or polybutylene pipes	<ul style="list-style-type: none"> ▪ Transmission pipeline ▪ Water temp. <90°C ▪ Size range 20-200 mm ▪ Abundance of hot water ▪ Low water production cost 	<ul style="list-style-type: none"> ▪ Low investment cost ▪ Installation ease 	<ul style="list-style-type: none"> ▪ Permits diffusion of oxygen through pipe walls ▪ High heat loss 	Single pipe 30-40%
2. Carbon steel pipe mounted above ground and insulated using mineral/glass wool sheathed in sheet metal jacket	<ul style="list-style-type: none"> ▪ Collection and transmission pipelines ▪ In locations allowing surface pipelines ▪ Size range >200 mm 	<ul style="list-style-type: none"> ▪ High durability ▪ Maintenance cost low ▪ No temp. limitation 	<ul style="list-style-type: none"> ▪ Investment cost high in sizes below 200 mm relative to pipe alternative 4. 	Single pipe 80-130%
3. Carbon steel pipe mounted above ground and insulated using mineral/glass wool sheathed in spirally wound sheet metal jacket	<ul style="list-style-type: none"> ▪ Collection and transmission pipelines ▪ In urban locations allowing surface pipelines ▪ Size range >200 mm 	<ul style="list-style-type: none"> ▪ High durability ▪ Maintenance cost low ▪ Upper limit of water temperature 120°C 	<ul style="list-style-type: none"> ▪ Investment cost high in sizes below 200 mm relative to pipe alternative 4. ▪ Max. water temp. 120°C 	Single pipe 80-130%
4. Buried carbon steel pipe pre-insulated using polyurethane foam encased in a protective sheath of polyethylene	<ul style="list-style-type: none"> ▪ Distribution pipelines for size range 20 to 150 mm ▪ Transmission pipelines in range of sizes below 900 mm 	<ul style="list-style-type: none"> ▪ High durability ▪ Maintenance cost low ▪ Protective sheath is watertight ▪ Installation ease 	<ul style="list-style-type: none"> ▪ Investment cost high in sizes above 200 mm ▪ Max. water temp. 120°C ▪ More vulnerable to external damage than alternative 5. 	Single pipe 100% Double-pipe 100%
5. Insulated carbon steel pipe carried in a concrete conduit	<ul style="list-style-type: none"> ▪ Transmission pipeline ▪ Distribution network ▪ Short large dia. pipes that have to be buried in built-up areas ▪ Large consumer market 	<ul style="list-style-type: none"> ▪ High durability ▪ Maintenance cost low ▪ No temp. limitation 	<ul style="list-style-type: none"> ▪ Investment cost high for all pipe sizes 	Single pipe 120-200% Double-pipe 80-150%

2.4 Pipeline costs

In order to assess which system to use for a specific project one must evaluate collectively several parameters such as price, quality, reliability, construction period and density of traffic.

Table 3 Examples of pipeline costs. The table shows approximate range of prices and division between material cost and contractor cost in Iceland.

Single pipeline, US\$ pr. metre					
	<i>DN200</i>	<i>DN300</i>	<i>DN400</i>	<i>DN500</i>	<i>DN600</i>
Pipeline total	130-190	210-290	360-450	420-520	460-560
%material	55		61		67
%contractor	45		39		33
Double pipeline, US\$ pr. metre					
	<i>DN200</i>	<i>DN300</i>	<i>DN400</i>	<i>DN500</i>	<i>DN600</i>
Pipeline total	210-310	350-480	500-630	750-930	850-1040
%material	60		67		71
%contractor	40		33		29

The cost range given in the table shows the cost of a pipeline laid a) in open field, and b) in cities. The total cost includes pipe material (preinsulated steel pipe in PEH sheath and sealing material), earthwork, pipe joints (welding and sealing), removal of rock in pipe channels, surface finishing, as well as design and supervision. The cost of temporary road and pavement bridges is also included in the latter case.

2.5 Heat loss from pipelines

The district heating system pipelines, whether above ground or buried underground, constitute one of the main sources of heat loss in a district heating system and thus a loss in revenue. To minimise this, it is of utmost importance that the pipe insulation does not become damp, since this reduces greatly its thermal resistance and may increase heat losses to such a level as to seriously impair the capacity of the district heating system. A damp layer of insulation on a steel pipe will furthermore induce rapid corrosion of the pipe.

The result of an evaluation of temperature losses in miscellaneous types of pipelines is depicted in Figure 9. The cooling of fluid flowing in pipelines made, for example, from polypropylene pipes installed with mineral wool is similar in range to that of the buried carbon steel pipe, as long as the pipe insulation remains dry. When transmitting hot water over long distances (more than 10 km), only large quantities in well insulated steel pipelines should be considered to keep the temperature drop within reasonable limits. In Iceland, hot water is in some cases transmitted over very long distances. For example the main pipeline from Nesjavellir geothermal field to Reykjavík city, is 27.2 km long, 1800 l/s, DN900 mm steel pipe (Björnsson and Jóhannesson;2). The water flows under gravity from an equalizing tank on a hill near the field, and due to friction the temperature drop is hardly noticeable (less than 1°C.)

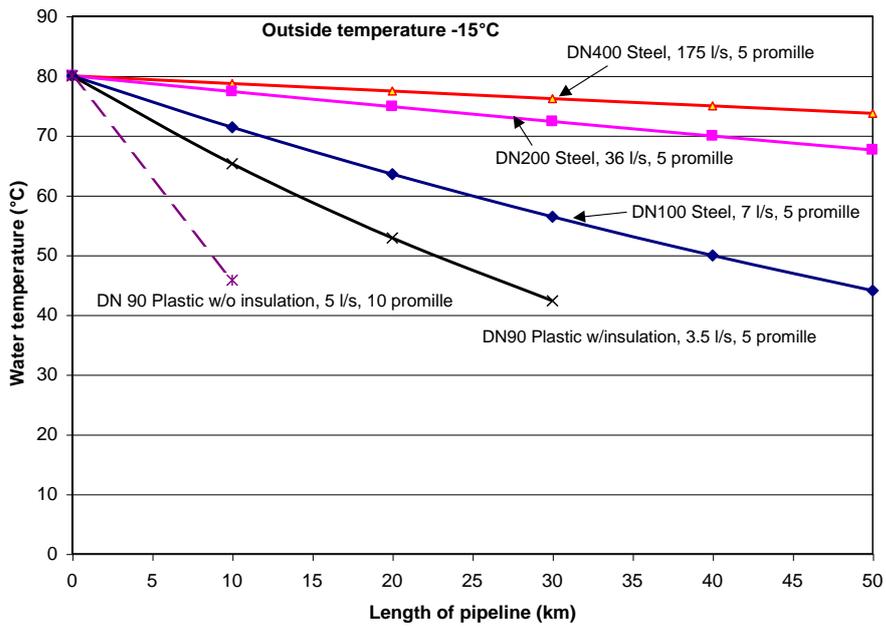


Figure 9 Examples of calculated temperature drop in pipelines.
From top to bottom: Surface mounted steel pipeline, buried pre-insulated pipes and finally two examples of plastic (PP, PB) pipe with and without thermal insulation.

3 AUTOMATIC CONTROL

The main parameters to watch and control in geothermal energy systems is the flow and pressure in the wells, and flow, pressure and temperature in the distribution network. Due to the complexity of the geothermal source, it is also of fundamental importance to keep a close eye on the chemistry of the geothermal fluid and the water balance of the geothermal reservoir. Following is a brief summary of the monitoring and control strategy that has been developed in Iceland for geothermal district heating systems.

3.1 Geothermal monitoring assemblage

Orkustofnun (National Energy Authority of Iceland) has developed an inexpensive comprehensive geothermal monitoring system to monitor the water withdrawal, the well drawdown and water temperature in low to medium temperature reservoirs (Eliasson; 3). A prerequisite for the system is ready access to a stable source of electricity (220-240V, 50 Hz) and telephone. The data can also be dumped onto a diskette via a portable computer or directly connected to a given data collection centre via cable. The transducers can, however, be far away from the data collection centre.

An example of the type of data the digital data logger can collect is collated in **Table** below; the maximum number of data sets is 16.

Table 3 Samples of data types that can be collected

Data type	Measuring unit	Frequency	Sensitivity
Water level	m	4 per day	< 0,5
Water temperature	°C		
Instantaneous flow rate	l/s		10%
Accumulative mean flow	m ³		5%
Power use	kWh		
Variable pump motor frequency	Hz		
Current	A		
Operating period	h		
Outdoor temperature	°C		0,5
Pressure	bar gauge		0,05

The standard data collection station comprises a computer component, signal transformer, power pack and a modem. Figure 10 depicts a schematic diagram of a monitoring station, in which the well head temperature, the flow rate from the well, the drawdown in the well and the ambient outdoors temperature are monitored simultaneously. The computer component has 16 parallel signal-in ports and one signal-out port. This signifies that it can accept signals from 16 different signal transducers. It has an 8.000 digit memory, which is sufficient for a few months operation and

over-writes the oldest memory portion once the memory is full. The computer component is connected to a modem, which enables the data to be accessed via telephone.

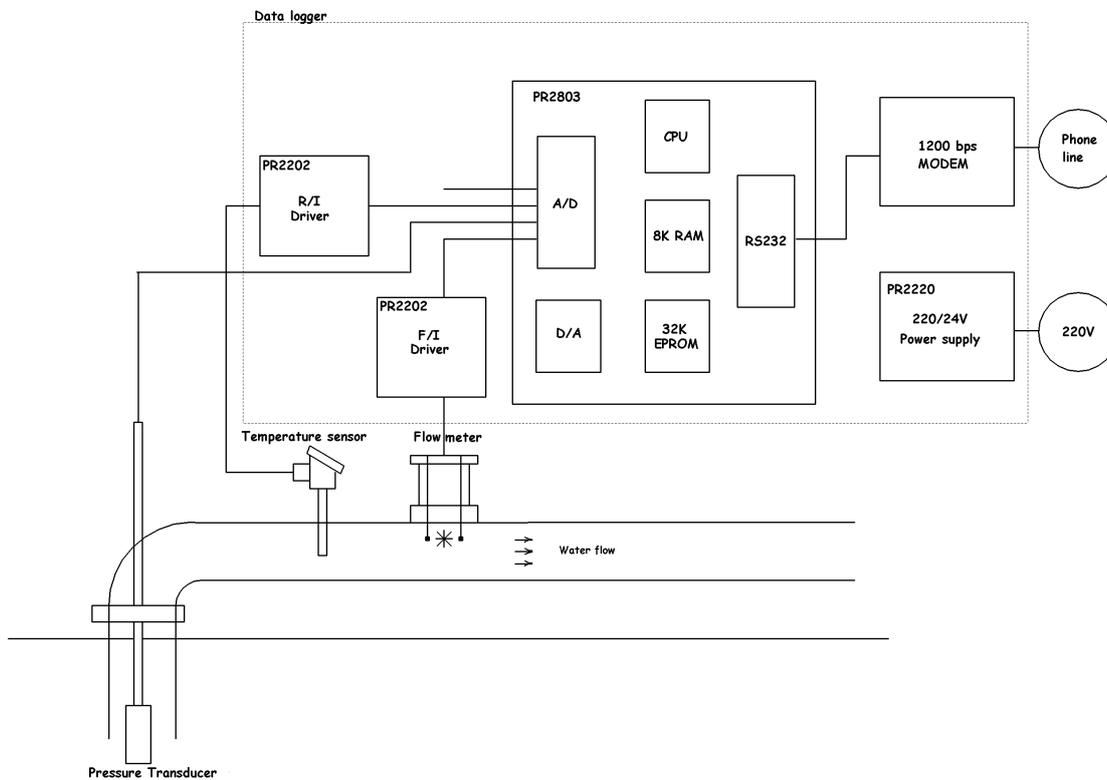


Figure 10 Typical monitoring and data collection system

Transducers can be of any known type so long as they can produce an electric signal of 4 to 20 mA strength. Figure 10 shows a Pt100 temperature sensor, which is connected to a R/I transformer that observes the varying resistance value of the transducer and transforms it into a signal current.

The drawdown in the well can be measure by two methods, viz. installing a permanent pressure transducer at the well pump and measure the pressure at that point or using the nitrogen bubble technique. This technique involves installing a capillary tube or a small bore plastic tube in the well down to the well pump depth (or a depth well below the maximum anticipated depression of the water level). A nitrogen bottle bleeds nitrogen gas down the tube and the pressure required is a measure of the water level. In order to minimise the gas consumption the collection system can be used to control the gas flow, by opening the gas inlet valve just before the reading is taken and closing it once the reading is completed.

24 V DC obtained from an automatically adjustable 220 V AC to 24 V DC power converter drive the collection system. A reserve 11 x 2 V DC rechargeable battery pack is installed to provide a stand-by 24 V energy source in case of mains breakdown. This is sufficient for a normal 10-hour operation of the data collection system.

3.2 Supervision, Control And Data Acquisition system (SCADA):

Supervision, Control And Data Acquisition (SCADA) system is employed in large and complicated systems to facilitate control and supervision of the system operation, as for example described in a recent feasibility study for Košice town in Slovakia (VIRKIR Engineering Group and others; 4.)

This is usually located in a central building, often the control and administration building. Monitoring and remote control of all pump and heat exchanger stations is possible from there. The interconnection with the SCADA system requires dedicated communication lines from the pump and heat exchanger stations etc. to the control centre. Standard telephone lines are suitable for this purpose.

The SCADA system gathers data from Programmable Controllers. From the SCADA system PID loop controller set point and manual output and tuning can be performed. Starting and stopping of remotely controlled pumps, boiler etc. can also be performed from the SCADA system. The SCADA system includes one or more graphical displays for each connected pump or heat exchanger station. From the graphical display the operator can:

- ❑ Monitor analogue measuring signals.
- ❑ Monitor alarm signals.
- ❑ Monitor PID loop controllers, change set point and manual output.
- ❑ Tune PID controllers.
- ❑ Start and stop remotely controlled pumps.
- ❑ View alarm list.
- ❑ Historic trending.
- ❑ An UPS (uninterrupted power supply) for the SCADA system is usually installed for safety.

3.3 Programmable Logic Controllers (PLC):

Programmable controllers take care of all automatic control in the pump stations (including well pumps), heat exchanger stations and distribution centres etc. They also gather data for and receive commands from the SCADA system. A modem connects the PLC's to telephone lines for communication with the SCADA system. The Programmable Controllers are powered by 24 VDC that is supplied from maintenance free batteries and a battery charger. A maintenance free battery pack, with charger shall be installed in for every Programmable Controller. The battery capacity shall be sufficient for 10-hour operation of the Programmable Controller and the 4-20 mA measurement circuits. An operator console will be installed in the pumping stations and used for the following tasks:

- ❑ Control loop mode selection, set-point control and manual control,
- ❑ Analogue measurement readout,
- ❑ Pump control.

3.4 Pump Control

In pump stations where two or more pumps are connected in parallel for reasons of safety and controllability, one of the pumps may be controlled by a variable speed drive (VSD). Take for example a pump station with four parallel pumps. The VSD pump will first be started. When the VSD pump has reached it's maximum output, the second pump will be started through an electronic soft starter and at the same time the speed of the VSD pump will be reduced. When the load increases and the VSD has reached it's maximum output again, the third pump will be started etc. The fourth pump is for reserve and will be automatically started if one of the other pumps fails. Soft starters are used to reduce pressure shocks when pumps are started. The soft starters are an order of magnitude less expensive than VSD and therefore a VSD is only used for one of the pumps.

References

(1) Eliasson et. al.

Geothermal Handbook

(2) Björnsson, O.B. and Jóhannesson, Þ.

”Design and full-scale tests of anti-waterhammer air vessels in a large transmission pipeline system”. 2nd International Conference on Water Pipeline Systems, BHR Group Conference Series, Publication No.10, 1994.

(3) Einar Tjörvi Eliasson, Orkustofnun (National Energy Authority of Iceland).

“Geothermal Monitoring Assemblage – Brief description”

(4) “Geothermal Energy for Kosice District Heating” , Feasibility Study

CFG, Slovgeoterm, VIRKIR, April 1999.