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Energy Savings in Geothermal District Heating Pumping at Veitur

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ABSTRACT

Most of the Geothermal District heating in the Reykjavik area and surroundings dates back to the 1960s and 1970s, when distribution networks, transmission pipelines, pumping stations and reservoir tanks were built in large quantities. Pumping of geothermal water was originally done with pumps running at fixed speed and all flow and pressure controls were implemented with throttling control valves. Furthermore, pumping between tanks has been the norm since the beginning.

Since electricity costs are a significant figure in the district heating operation of Veitur, there are numerous opportunities for energy savings. In the last 20 years, variable speed drive pumps have been installed in new pumping stations and more recently, the use of control valves for throttling has been minimized. Electrical installations are being upgraded, as older cabinets have poor efficiency and have long since surpassed their operational life. The overall strategy of large transmission pipelines and pumping/throttling between tanks is also being re-evaluated, where the role of the largest pumps is being reduced, resulting in significant electricity savings. Veitur are currently implementing strict measures in design of new installations and performing refurbishments of older pumping stations with this goal in mind.

1. INTRODUCTION

There are three main aspects of energy savings that will be covered in this article. Firstly, the replacement of fixed speed pumps and throttling valve with a variable speed drive pumps, where delivered pressure varies significantly with flow rate.

Secondly, redesigning flow systems, so that unnecessary throttling is eliminated, whether it is within pumping stations or in large transmission pipelines, typically connected to and from tanks.

Thirdly, a more radical approach is presented, in which certain conditions in geothermal district heating systems allow for electrical energy recovery, that can be used for pumping and even additional electricity production to other users.

It should be noted that these above cases apply to single transmission pipeline pumping, where geothermal fluid eventually is discharged to the ocean, which is currently the situation in geothermal heating in the Reykjavik area and nearby district heating systems in South and West Iceland. These energy saving schemes do not in general apply to closed-loop circulation pumping.

In the Laugarnes geothermal field in Reykjavik, water that originates 120-130°C is used for district heating, where return fluid from a double distribution heating network is mixed with the hot water, to cool it down to 80°C supply temperature. In other areas, e.g. in South Iceland, district heating systems have long transmission pipelines and usually a single distribution system network. In that case, such as in Þorlákshöfn, installing a double distribution network is not feasible for these relatively small distribution systems. Geothermal water above 100°C therefore needs to be flashed down to 100°C at atmospheric pressure, so it can be used for heating.

Small binary power plant units are now commercially available for relatively simple and flexible installation. They allow for relatively simple and robust electricity production from water around 100°C, thus allowing for both cooling water down to more manageable temperatures below 100°C and using the produced electricity for pumping and other purposes. This configuration has already been implemented on a small scale in South Iceland and is planned for several geothermal sites around the Capital Area in Iceland.

Another energy recovery scheme has also been considered, in which very large pipelines, with high flow rates and large pressure drops (20-30 bar) may be used for hydroelectric power production, from which electricity can then be used for pumping. There is potential for this type of production but so far, it has not been studied in serious detail.

All these aspects are presented with actual examples, some of which have already been implemented or are planned and the estimated relative energy savings – or even gains - are listed for each type of installation. Energy calculations are based on actual operational logs from the Veitur SCADA system and pump/turbine efficiency calculations are estimated from affinity laws, in the case of variable frequency converters and, in some cases, the actual curves from pump manufacturers.

2. PUMPING IN LARGE TRANSMISSION PIPELINES AND GEOTHERMAL WELLS

Several examples of fitting variable frequency converters (VFDs) in large pumping stations and distribution pipelines in the Reykjavik area are described below, as well as recent developments in refurbishments of downhole pumps in geothermal wells.

2.1 Reykir and Reykjahlíð Pumping Stations

The two largest geothermal fields in the Capital Area – Reykir and Reykjahlíð – are located 4-7 km north-east of Reykjavik, next to the municipality of Mosfellsbær. These 2 geothermal fields supply around 1/3rd of all hot water in the Capital Area during peak load.

These fields have been in operation since the 1940s but since around 1970-1980 have been supplying up to around 1.700 l/s of hot water at an average temperature of 85°C. Water is pumped directly from geothermal wells to a storage tank at Grafarholt in East Reykjavik, where the water level is 110 meters above sea level (m.a.sl.). From there, hot water is pumped directly to radiators and tap water users, from which it cools down to around 30°C and finally ends in the ocean around Reykjavik.

Each geothermal field has a large pumping station, each station has four 450 kW pumps, delivering around 100 meters of water column (mWc) head. The pumps were originally run at fixed speed. The renovation procedure consisted of replacing old electric cabinets, installing frequency converters and electricity (voltage) filters, removing control valves from pipeline and modifying the pumping control system. Schematic diagrams, showing the main system components before and after renovation, are shown in Figure 1.

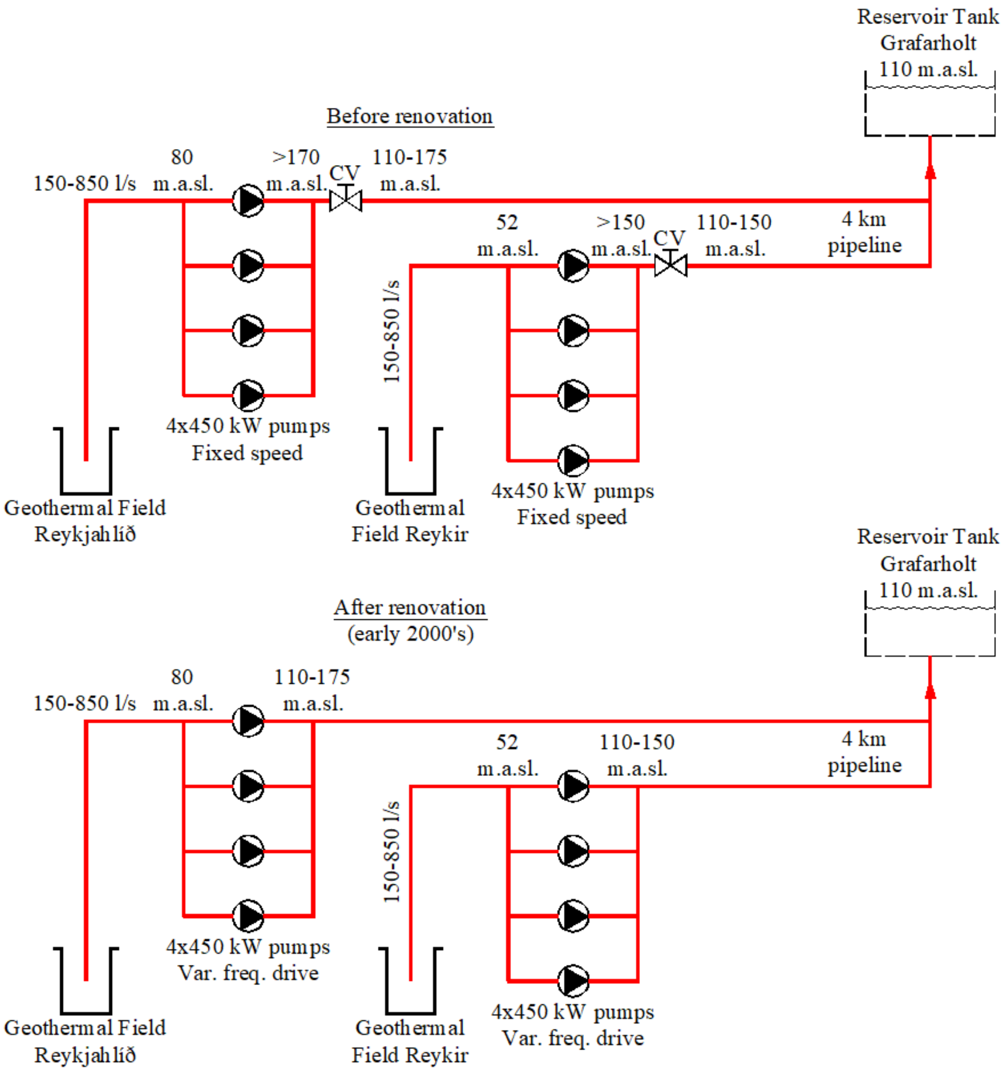

Figure 1: Pumps at Reykir and Reykjahlíð geothermal fields, before and after installation of variable frequency drive.

The actual operational data was taken from Veitur (Orkuveita Reykjavíkur) data logs from the SCADA system, using hourly rates in the period 2003-2004. Pump curves from Floway were used for efficiency and energy calculations. The estimated electricity savings at Reykjahlíð (Fjarhitun 2004) was approximately 100.000 USD/year, from 200.000 with fixed speed pumps lowered to 100.000 USD/year with variable frequency drives. The savings at Reykir pumping station are somewhat less, as pump head is slightly lower and static pump head is relatively higher. However, the renovation costs – installing frequency converters and removing control valves from piping – are estimated to be repaid in approximately 5 years, after which the electricity consumption is significantly less per pumped volume of geothermal water.

2.2 Grafarholt and Öskjuhlíð Pumping Stations

The hot water from the Grafarholt reservoir tanks is further pumped west towards the Reykjavik city center, to storage tanks at Öskjuhlíð, along a double pipeline, approximately 8 km long. The pumps at the Grafarholt pumping station are approximately 40 years old and have a total pumping capacity of around 1.400 l/s with 30-40 mWc head. One of the pumps (the smallest one, 400 kW) can be operated at 2 speeds, high and low, the other two (2x700 kW) are run at fixed speed. Pressure from the Grafarholt pumping station is regulated with a control valve.

A large frequency converter has already been bought for one of the 3 pumps at Grafarholt pumping station and is expected to be installed in the next year. The plan is to replace all electrical cabinets and install frequency converters on all 3 pumps, as well as removing the control valve, so that the pumps will run at partial frequency, thus consuming less power.

At the Öskjuhlíð pumping and control valve station, upstream pressure in the 8 km pipeline is maintained at 95 m.a.sl., from where hot water flows into storage tanks with a 25 mWc pressure drop. During high flow at wintertime, water is pumped to 80 mWc from the storage tanks, with two 185 kW pumps (3^{rd} pump is stand-by) at Öskjuhlíð pumping station.

The storage tanks at Öskjuhlíð are close to 40 years old and require considerable maintenance. It has been considered in the last 1-2 years to decommission these storage tanks and instead, control the supply pressure to Central Reykjavík from Grafarholt, without using the secondary storage tanks at Öskjuhlíð. Storage volume at Grafarholt is found to be more than adequate for future demand from the pipeline to Central Reykjavík.

The current system and proposed future system are shown as 2 schematic diagrams in Figure 2.

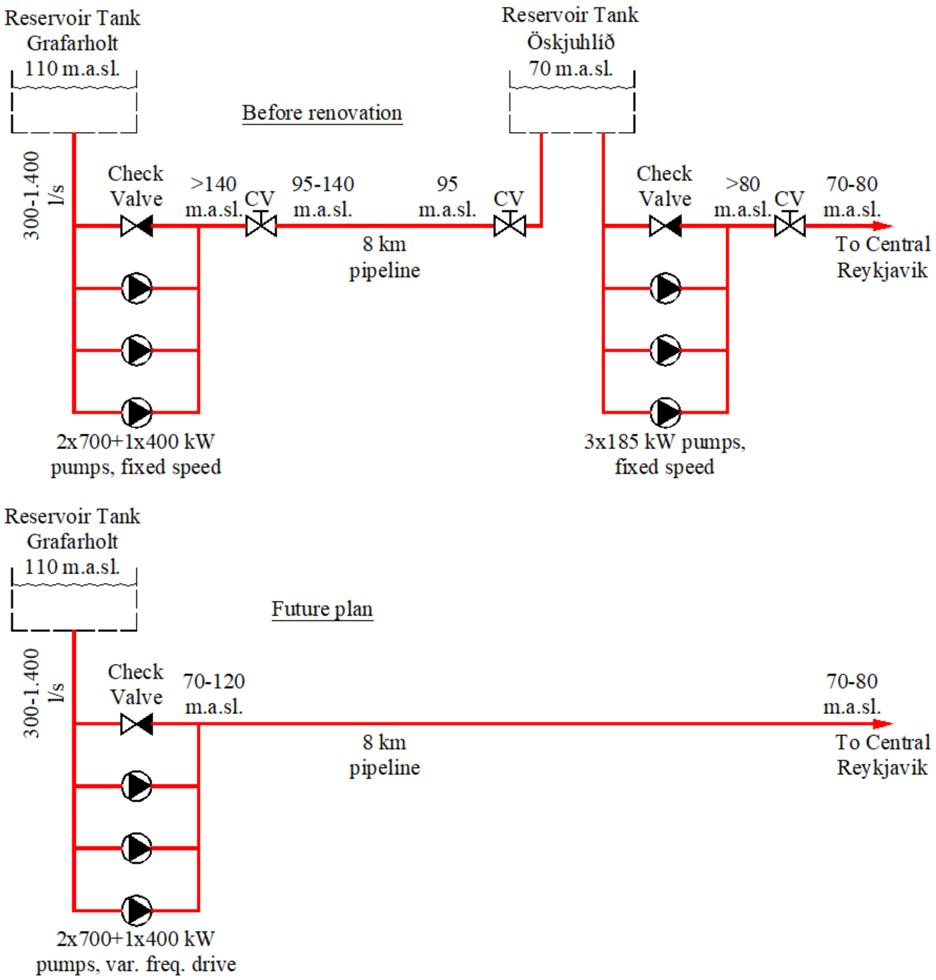

Figure 2: Pumps at Grafarholt and Öskjuhlíð pumping stations, before renovation and future plan.

By decommissioning both the pumps, storage tank and upstream control valve at Öskjuhlíð and, instead, pumping water directly from Grafarholt, the energy savings will be significant. Pumping power would be reduced from well over 1 MWe down to a fraction of that, as pumping from Grafarholt would only take place during peak load and total pumping head would only be around 10 mWc, to ensure adequate water pressure in Central Reykjavik.

The actual operational data was taken from Veitur (Orkuveita Reykjavíkur) data logs from the SCADA system at Grafarholt and Öskjuhlíð Pumping Station, using hourly rates in the periods of 2004-2005 and later from 2016-2017. Pump curves from Floway and Layne Vertiline were used for efficiency and energy calculations. The calculated savings at Grafarholt indicate that renovation costs (installing electric cabinets/frequency converters, remove control valve from piping, re-program controls) will be repaid in around 15 years, since pumping from Grafarholt is currently done during relatively short periods during winter. Pumping from Öskjuhlíð to the City Center is done more often but the pumping power is relatively low, as pump head is only around 10-15 mWc at most.

Overall, by only pumping from Grafarholt when needed and directly maintain pressure at Central Reykjavik, 8 km downstream, would reduce the current pumping capacity to only a fraction of the current electricity consumption. There are, of course, a few things to be considered, such as stability of pressure control and perhaps, a pressure damper might be needed at the west end of the pipeline near the City Center.

Another large pipeline, from storage tanks east of Reykjavik going south-east, approximately 13 km to the town of Hafnarfjörður, is operated in this way today, with 1 booster pump around 2/3rd of the way along the pipeline. The purpose of the storage tanks at Öskjuhlíð, which date back to the 1950s, is no longer relevant, as reservoir capacity in the overall system is currently in other storage tanks, further east. The decommissioning of the tanks and pumping station is planned for the purpose of selling the water tanks and land area for other purposes (tourism, etc.) so the overall feasibility of decommissioning and renovation might be substantial. There might be a control valve installed to control the supply pressure locally, for added stability of the system from Grafarholt tanks to Central Reykjavik. Overall, this plan for the main hot water distribution in Central and West Reykjavik will most certainly save energy in the coming decades and lower operating costs.

2.3 Downhole Pumps

There are approximately 50 geothermal wells with downhole pumps in the Reykjavik Area alone, in 4 geothermal fields (Reykir, Reykjahlíð, Laugarnes and Elliðaár) and several dozen more in South and West Iceland, in geothermal installations operated by Veitur. Many of these pumps – all of them line shaft pumps – have been in operation for several decades. They were originally selected because there was no submersible pump alternative that could withstand temperatures between 80-130°C, unless it was specialized models that were prohibitively expensive at the time. Also, a standard line shaft pump program was developed over the years, allowing for universal spare parts for pressure pipes, shafts, lubrication tubes, pipe/shaft couplings, sleeves, motor brackets, etc.

The pumps themselves have relatively high hydraulic efficiency, often higher than 80%. However, deep installations, between 150-200 meters below well head, result in severe mechanical losses in the pump shaft, resulting in overall hydraulic efficiency (from downhole waterbed to well head pressure level) of only around 50%.

Recently, several pump manufacturers have been developing robust submersible pumps, that can withstand temperatures up to 200°C, even higher. These pumps have high voltage cables, often several kilovolts, meaning that total voltage drop is typically well within 1%. These pumps, developed for oil pumping, usually have low capacities and the largest pumps (typically 60-80 l/s maximum flow) from these manufacturers have relatively low hydraulic efficiency, often less than 70%.

Recently, the purchasing price of these pumps has been found to be equal or even less than the cost of installing line shaft pumps. Also, most line shaft pumps in the Reykjavík Area have reached their operational life and many of them need replacing. Since early 2018, Veitur have decided to develop an installation and operating program, where all line shaft pumps are replaced with suitable submersible pumps. Since May 2019, 2 submersible pumps have been installed by Veitur in South Iceland, operating at downhole temperatures between 95 to 125°C and installation depth of up to 270 m below well head.

A key feature of submersible pumps is that there is almost no limit to the installation depth. Only the flow friction loss in the discharge pipe, from pump to well head results in lowered overall efficiency, not so much the voltage drop in the power cable. These pumps are therefore less affected by reservoir water level variations than line shaft pumps, which have limited installation depth, typically up to 200-250 m below well head.

Although some line shaft pumps are operated with variable frequency drives, it does appear that submersible pumps have more operational flexibility. Also, replacing submersible pumps takes only a couple of days, whereas line shaft pump replacement can take up to 1-2 weeks. This allows for using e.g. 2 pumps in the same well, that has high seasonal variation in reservoir water level, selecting 2 submersible pumps with different pump heads that run at an optimum point in each case.

This submersible pump program at Veitur is still in its infancy and several lessons will be learned in the coming years. Overall, this appears to be promising and should also result in significant energy savings, as both overall efficiency and operational flexibility seem higher than in line shaft pumps.

3. MODIFICATION OF PIPING AND CONTROLS IN PUMPING STATIONS

Two actual examples are presented. The first is re-design of combined pump and control valve operation for minimal energy consumption, the other is a planned refurbishment of a 35 year old pumping station, both for energy saving and other purposes.

3.1 Pump and Control Valve Combination in Kauptún Pumping Station

The Kauptún Pumping Station in the town of Garðabær, south of Reykjavík, will be put in operation in the fall of 2019. The hot water to the station comes from a 13 km long pipeline at variable pressure between 100 m.a.sl. in winter and 150 m.a.sl. during summer. Part of the water flowing through the station is delivered at 125 m.a.sl. pressure, meaning that pumping is required during winter and pressure throttling via control valve during summer. Pumping is through a 30 kW pump (2 pumps, one stand-by), operated approximately 5-6 months per year. A simple schematic diagram of this system is shown in Figure 3.

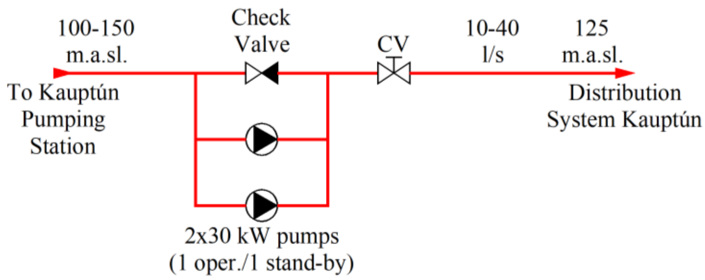

Figure 3: Pump and control valve combination at Kauptún Pumping Station.

There are 3 ways possible to operate this system:

- Start one pump at full speed when control valve is fully open, stop the pump when pressure to station is ≥125 m.a.sl.
- Maintains a certain pressure drop (5 mWc) over control valve, when pumping is needed.
- Only pump through fully open control valve when pressure to station is ≤125 m.a.sl.

The variation of pump head with flow (from approximately 55-100% of maximum flow) is shown in Figure 4 for these 3 cases.

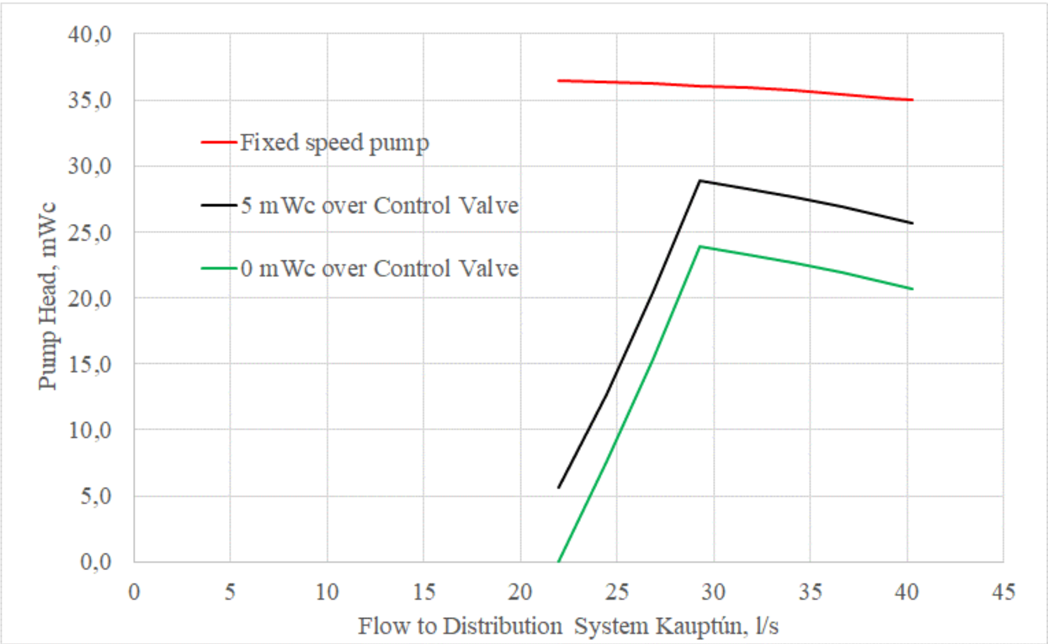

Figure 4: Pumping/Throttling in Kauptún Pumping Station: Pump head vs. flow for fixed speed (red curve), 5 mWc pressure drop over control valve (black curve) and no pressure drop over control valve (green curve).

The reason for the break in the pressure curve over 30 l/s is due to the pressure control in the large pipeline, from which water to Kauptún Pumping Station is delivered, as when flow rate is around 75% of maximum, pressure in the main pipeline is maintained fairly constant. From 55-75% flow rate, the pressure in the main pipeline declines, from around 130 down to 100 m.a.sl.

The energy used for pumping is calculated, using the pump curve from the pump manufacturer (head and power vs. flow). The pump head varies parabolically with pump frequency and pump power varies cubically with pump frequency, according to pump affinity laws found in various publications (Gerhart, Gross & Hochstein, page 550). It can be seen that by running the pump at fixed speed (red curve in Figure 4), pump head will always be over 35 mWc and pressure drop over the control valve will thus be between 15-35 mWc. Pumping energy will be quite high, or around 30.000 kWh/year.

The reason for maintaining 5 mWc over control valve (black curve in Figure 4) is to simplify the controls, so that one controller is only looking at supply pressure by varying the opening of the control valve and a second controller is focused on maintaining minimum pressure drop over the control valve. The annual pumping energy with this setup is around 10.000 kWh/year, only a third of what running the pump at fixed speed (50 Hz) would require.

The third option – never using excess pressure drop over control valve – means that controls have to very precisely defined. Both the pump and the control valve are running on the same input signal, the supply pressure. The pump must be started at a precise speed (around 20-25 Hz) when the control valve has been fully open during a specific time and, conversely, when the pumps have been running under that same frequency for a certain duration, they are shut down. This could lead to rapid starting/stopping of pumps during certain periods, where pressure to the pump station is the same as the supply pressure but can be eliminated by ensuring a certain minimum running time of pump at the threshold frequency (and also, some time before stopping the pump when it has been running at the threshold frequency). If this is properly programmed, the annual energy consumption is estimated to be as low as 6000-7000 kWh/year, which is 30% less than using a small pressure drop over the valve.

The method of using a small pressure drop over a control valve has been used in pumping stations in the Reykjavik area in the last 20 years or so. If this control scheme in Kauptún - whereby absolutely no pumping head is wasted – proves to be successful and without any stability problems, it is likely to be implemented in other stations as well, to save several dozen percent of electricity in this type of pumping.

3.2 Logafold Pumping Station System Renovation

The Logafold Pumping station, located in North-West Reykjavik was built in 1984-1985. It has 3 pumps (2 operational, 1 stand-by serving as back-up pump for the other two), one for pumping water to a high-pressure zone, the other for pumping/gathering return water to a collection pipeline. The station receives water at a temperature of over 80°C and the correct temperature is obtained by mixing 30°C return water from the double distribution system and mixing it with a temperature control valve.

The station serves 2 pressure zones, where higher/lower supply pressure is 125/90 m.a.sl. Pressure of return water from radiators is 100/65 m.a.sl. from the high/low pressure zones. Total maximum supplied flow is around 130 l/s, of which around 16% goes to the high-pressure zone. A small portion of the return water is mixed with the 83-85°C hot water entering the station, the rest is usually pumped to a return water gathering pipeline. In case of return water pumping failure, there is a control valve (connected in parallel with a safety valve) that discharges excess return water to a nearby sewage well.

The setup of the station is such, that all the water at high pressure (125-155 m.a.sl.) is throttled down to the lower pressure zone supply pressure (90 m.a.sl.). Around 1/6th is then pumped back up to 125 m.a.sl., to the high-pressure zone. Also, all pumps are running at fixed speed, with pressure being controlled with control valves only. This setup is shown in the upper diagram in Figure 5.

This setup was redesigned a few years ago, where unnecessary pumping to the high-pressure zone (from 90 to 125 m.a.sl.) is eliminated through piping reconnection. An existing control valve is repurposed as a second throttling valve, connected in series with the current one, where high- and low-pressure zones get the correct pressure from each stage, without any unnecessary pumping. Also, all pumps (2 operational, 1 stand-by) are fitted with frequency converters and supply temperature through mixing is done with direct pumping, without control valve. One pump is replaced with a smaller, more suitable one and the number of active control valves is reduced by one. Lastly, a couple of branches are fitted with flow sensors, which are rather limited in the current system. This setup is shown in Figure 5, lower diagram.

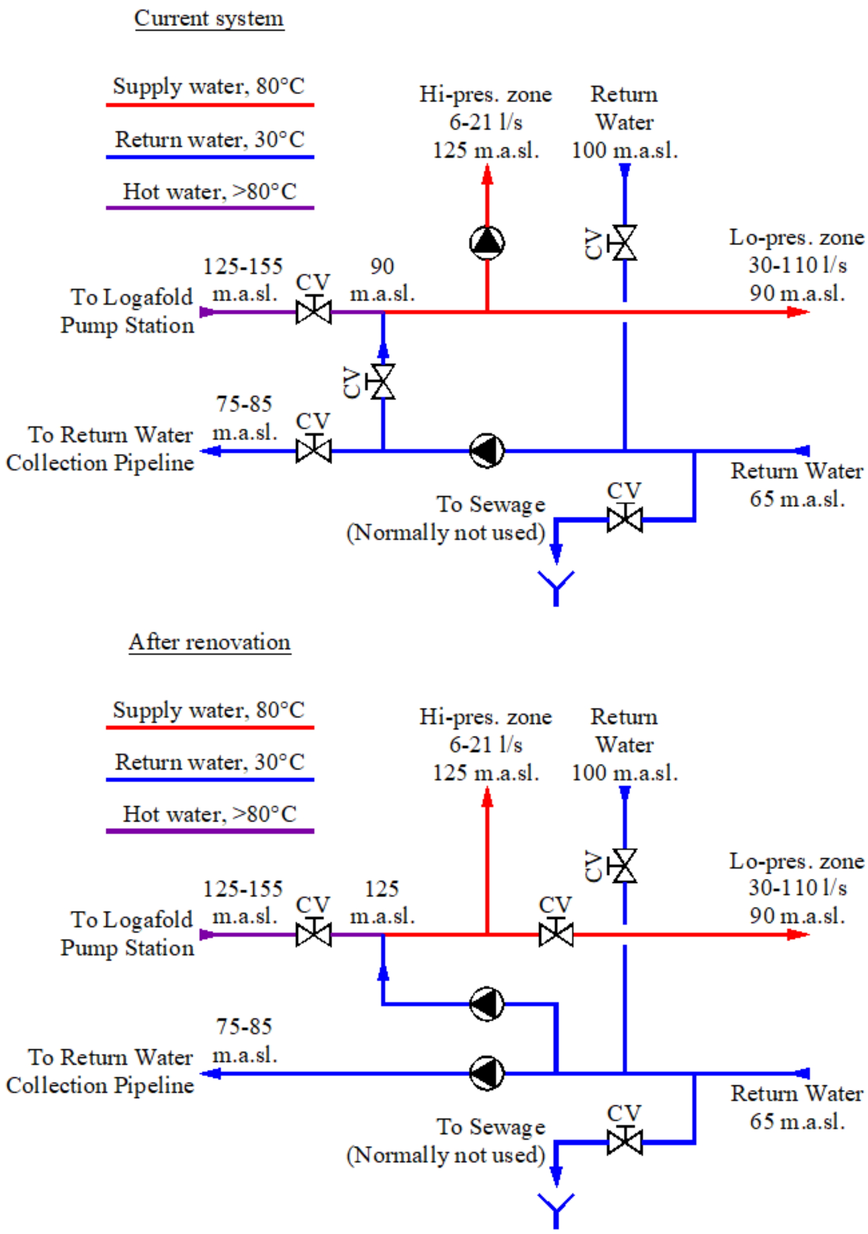

Figure 5: System modification at Logafold Pumping Station, before and after renovation (stand-by pump not shown for simplicity).

This refurbishment requires a rather large-scale piping replacement operation in a station running all year, 24 hours a day and is not an easy operation. The foreseen energy savings are not very economical compared to larger scale systems. There are quite a few modifications planned for this station with other goals than just saving energy. Using frequency converters will lower noise in the station and there was need for more extensive flow sensors and logging, as this station serves a rather large district in Reykjavik. By throttling pressure in 2 stages through a serial connection between high- and low-pressure zones, noise from control valves is also reduced, as lower pressure drop over each stage means significantly lower noise.

4. ENERGY RECOVERY AND SURPLUS PRODUCTION

Two examples are presented below: One is an Organic Rankine Cycle (ORC) power plant project that is rather likely to be implemented in the coming years, the other is an earlier idea of using hydroelectric generation instead of a control valve in large transmission pipelines.

4.1 Electricity Production from Surplus Heat

Bakki II is a geothermal field just west of the town of Hveragerði in South Iceland. Two geothermal wells are currently operated at the site, total flow from the wells is currently over 50 l/s of 110-120°C hot water. The system is being expanded, with the completed system being able of delivering between 150-200 l/s of hot water in the winter of 2019-2020. The water is used for heating in the town of Þorlákshöfn, 11 km south-west of the site and part of the water is used for fish farming. The geothermal field will consist of 4-5 geothermal wells (each delivering 40-50 l/s of water with downhole pumps) and 4 can pumps in the pumping station. An electrical installation of approximately 800 kWe is planned for the completed geothermal field and pumping station.

The water is all used directly without heat exchangers. Water temperature of over 100°C is impossible for direct use in heating, as it would flash when used in taps. Installing a double distribution system and pumping return water back to Bakki II for mixing/cooling – a distance of 11 km – is not feasible for a district heating of this size. Therefore, the water must be sent through a separator, where it is flashed down to atmospheric pressure, from 120 down to 100°C. By doing this, non-condensable gas, such as CO_2 and H_2S, are removed from the fluid, with the steam that evaporates from the process. This procedure releases a very significant portion of usable heat from the resource, up to 20% of total energy from the wells. A simplified diagram of the system being constructed in 2019 is shown in Figure 6, upper diagram.

The heat being rejected from the system through flashing is up to 15-20 MWt, both as high-enthalpy heat and mass flow lost from the process (around 3,5% of total fluid flow). The temperature from the wells, around 120°C, is suitable for low-temperature binary power generation, for which there are now available compact ORC units (typically 100-200 kWe each), converting water between 90-140°C to electricity. These units can be connected in series and parallel and need to be connected to a cold end supply, either direct cooling water from rivers, lakes, ocean, etc. or via closed-loop fluid through air coolers.

At these geothermal fluid temperatures – from 120 down to 100°C – the thermal conversion factor is expected to be around 10%, meaning that 200 kg/s of 120°C water has the potential to produce over 1,5 MWe, which is double the power needed for pumping from geothermal wells and in the pumping station to Þorlákshöfn. The energy conversion units do not require much space themselves but since there is no large river, lake or ocean nearby, it is likely that air coolers would be needed. A simplified diagram of this proposed future system can be seen in the lower diagram in Figure 6.

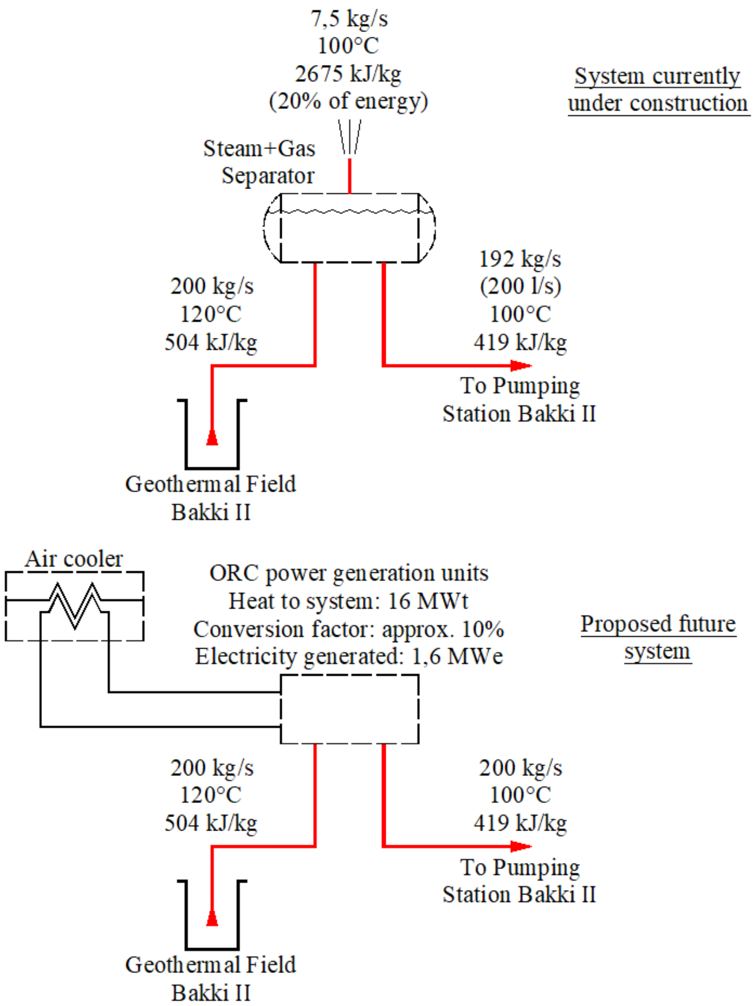

Figure 6: Geothermal field and pumping station Bakki II, current and proposed future system.

This system has a double purpose: It both recovers close to double the energy needed for pumping of geothermal fluid to Þorlákshöfn and cools the geothermal water down to a suitable temperature, without any of the fluid being wasted through flashing in a separator. It is also rather robust in a way, that when hot water demand is low, the electricity needed for pumping is also low, so that variable electricity production (approximately 30-100% of maximum) follows the demand of the hot water pumping. By using multiple, small modules, variable flow and electricity production is a relatively simple task, as the number of operational modules can be easily varied. Excess electricity, that may not be fully used for pumping (several hundred kWe), can be used in the nearby towns of Hveragerði and Þorlákshöfn or perhaps be sold to the electrical grid in South Iceland.

The separator, pumping station and underground piping for the expanded geothermal system at Bakki has been designed so that connection to a future ORC power plant can be done without any modifications to the hot water installation. Of course, there will be issues with the control systems of both heating and power generation, where adequate cooling of water below 100°C must be ensured.

A by-pass connection to the air coolers – past the electricity generation units – may be needed for this purpose. The non-condensable gases in the water from the electricity generation cycle must still be removed. For this purpose, the gas/steam separator which will be operational in 2019 has been designed so that minimal modifications are needed for gas removal from water below 100°C, at atmospheric pressure.

4.2 Hydraulic Electricity Production on Large Pipelines

Hot water from the Hellisheiði and Nesjavellir Power Plants comes from co-generation of heat and power, where 5°C cold water is heated (passed through condensers and heated with condensate from turbines) and de-aerated up to 80-90°C. It is then pumped to level tanks at 410 m.a.sl. (from Nesjavellir) and 270 m.a.sl.(from Hellisheiði), from where water flow down to a control valve station at Reynisvatnsheiði, just east of Reykjavik, where pressure is throttled from up to 27 bar at low flow down 2 bar. The pipelines from Hellisheiði and Nesjavellir power plants have transmission capacity of approximately 2.000 and 1.600 l/s, respectively and are designed so that during maximum flow, nearly all the pressure loss is in the pipeline, with close to no pressure drop in the control valve.

Several years ago, the possibility of replacing control valves with hydraulic power generating turbines/generators was briefly considered and is repeated here in a simplified way: Assuming 80% constant hydraulic efficiency of several turbines, parallel connected from the 2 pipelines (which, incidentally go through the same building at Reynisvatnsheiði), the following power generation capacity is estimated as (Gerhard, Gross, Hochstein, section 7.5):

- Power from turbine = water flow [l/s] ^{x} 982 kg/m³ ^{x} 9,81 m/s² ^{x} pressure drop over turbine [mWc] ^{x} 80% / 10^6 [kWe]

Water density of 982 kg/m³ applies to water at around 80°C. The result is shown for each pipeline and the total power generation capacity, in Figure 7, where up to 2 MWe could theoretically be generated at favorable flow conditions.

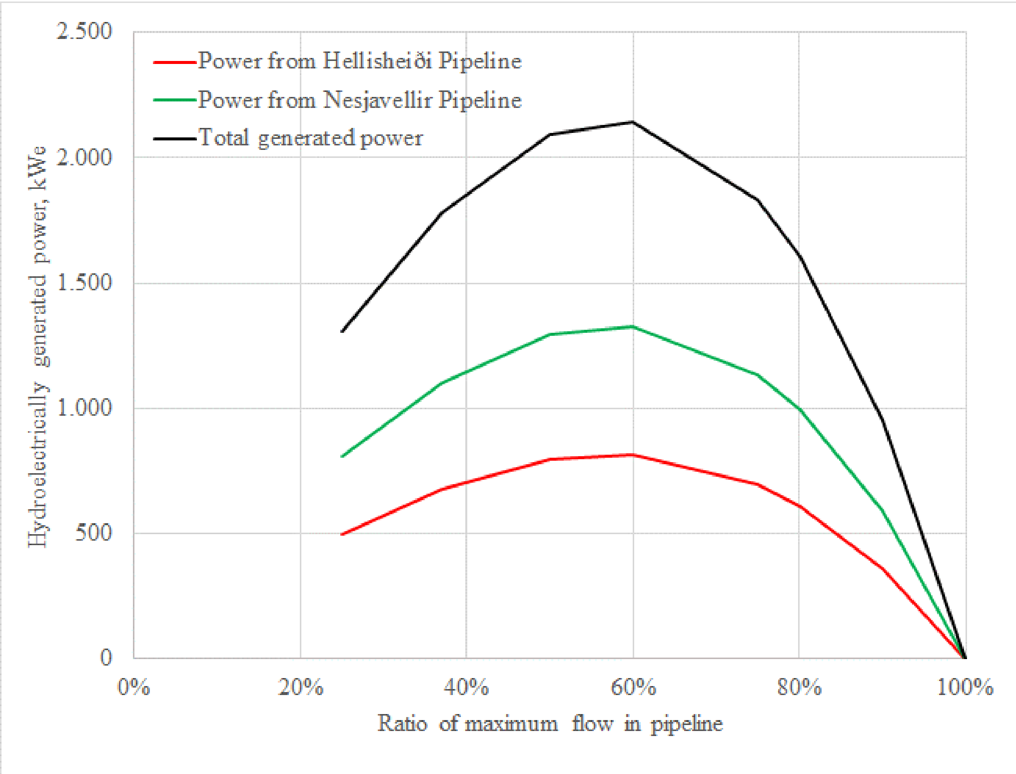

Figure 7: Potential hydroelectricity generation from geothermal fluid pipelines at various flow rates, from Hellisheiði pipeline (red curve), Nesjavellir pipeline (green curve) and both pipelines (black curve).

At the west end of each pipeline, where the turbines would be located instead of the current control valves, high flow rate means low remaining pressure drop over the turbines and vice versa, with a somewhat maximum power generation capacity around 60% of maximum flow. Pressure drop in the 2 pipelines varies approximately parabolically with increased flow, meaning that when flow exceeds 70% of maximum (when water pumping is most needed in a nearby pumping station), the remaining head loss over the turbines would vanish very rapidly, so that a small increase in flow (and pumping demand) would result in drastic drop in power generated.

Replacing the current 4 (and a planned 5th) control valves in the Reynisvatnsheiði control valve station with suitable turbines would be problematic, as hydroelectric generation has, until now, not been used with hot water, which might present certain cavitation problems. Also, the turbines would have to both function as electricity generation units and water level controllers for the level tanks at the Nesjavellir and Hellisheiði power plant sites (for which the control valves are used for in the current system). This system might therefore require parallel connection through control valves, meaning that an entirely new power generation facility would be built beside the current valve station.

Even though this system may produce sellable electricity during a large part of the year, it counteracts the electricity demand of the large pumps at the nearby Reynisvatnsheiði pumping station (up to 1,4 MWe pumping at maximum flow). Compare this to the system at Bakki II from the previous section, where the electricity demand for pumping is directly proportional to the electricity produced from excess heat in geothermal fluid. This is not the case with the hydroelectric generation in large pipelines and this idea has not been considered much beyond these brief calculations.

5. CONCLUSIONS

A significant part of the geothermal heating installations in the Reykjavik area date from the 1960s-70s and some of them have remained mostly unchanged since then. Starting some 20-25 years ago, when variable frequency converters (VFDs) became more feasible, both technically and commercially, the common setup of fixed speed motor pumping and pressure control through a control valve started to vanish from pumping station designs and instead, direct pressure control with pumps (with or without control valves) became prevalent. The pumping systems in larger pumping stations, where electricity consumption was rather significant, was then re-evaluated and modified in the larger stations, allowing for significant electricity savings in many cases. This is mostly applicable, when pump pressure varies significantly with flow rate, i.e. static head pumping is only partial. As water is often pumped through long pipelines, ranging over 10 km in some cases, this is usually the case and variable supply pressure with flow is indeed rather common.

Lately, Veitur have been focusing on even tighter energy conservation measures, even minimizing power consumption in small pumping stations, where energy savings of several dozen percent is always considered. These measures, especially when pumping through single/open-loop (as opposed to closed-loop) piping systems are being enforced in latest designs and all unnecessary use of level tanks and throttling, followed by re-pumping is being eliminated. Whenever an old pumping station is being refurbished – whether it is replacing equipment, adding sensors or other measures – they are always modified so that energy consumption will be minimized.

Direct monetary benefits of electricity savings can repay the investment of modifications of current systems in as short periods as 5-10 years but, of course, these figures vary highly. It is usually more beneficial in large pumping stations where pressure variation with flow is significant. Currently, Veitur are spending around 5 million US$ annually in electricity for pumping, both in downhole pumps in geothermal wells and pumping stations, large and small. With renovations, refurbishment and improved future design, there is therefore potential for saving several hundreds of thousands of dollars each year.

One area where the water pumping cannot be managed through “smart” piping is pumping from geothermal wells. Veitur are currently replacing old line shaft pumps - which suffer from mechanical losses in deep pumps and overall low electrical efficiency – with electrical submersible pumps. These pumps appear to have somewhat higher efficiency than line shaft pumps but have the added benefit of being able to be installed much deeper than line shaft pumps, with moderate efficiency loss. Also, they are easily removed/replaced in geothermal wells and could even be installed at variable depths in the same well, should water level be highly variable between winter and summer, as is the case in certain geothermal fields.

Energy recovery from waste heat, where water for geothermal heating/direct use needs to be cooled due to excessively high temperatures, appears to be a promising solution in several cases around South and West Iceland. One of the most important qualities of such a system is that power generation capacity is proportional to energy required for hot water pumping in the geothermal wells and pumping stations, from where the fluid is delivered. An earlier study, where using the hydraulic energy lost to control valves on long transmission pipelines and replace them with hydroelectric turbines is not an ideal solution, as power generation decreases very rapidly when flow in the pipelines reaches maximum capacity, making it an unstable and unreliable source of surplus energy.

There are other measures being implemented at Veitur, in order to conserve energy in general. Insulation in new pump stations, distribution systems and – most importantly – in house connections, where heat loss is most significant, is being improved in future designs, to lower heat loss from the system. Lower heat loss results in less geothermal fluid needed and, conversely, less electrical energy for fluid pumping. Temperature of return water from users can be 30°C or even higher in certain districts. Measures for collecting this return water and utilizing the heat (e.g. with heat pumps) have been studied recently, as the overall goal for future district heating at Veitur is to minimize waste of both geothermal fluid and thermal energy.

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