SUDURNES REGIONAL HEATING CORPORATION SVARTSENGI, ICELAND

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Figure 1. Svartsengi Power Plant aerial view.

INTRODUCTION

The Svartsengi geothermal plant is a combined heat and power (CHP) plant. The heating plant supplies hot water to a district heating system (hitaveita) serving 20,000 people. The total installed capacity of the combined plants at Svartsengi is 46.4 MWe electrical power and 150 MJ/s (MWth) in the form of hot water.

The Svartsengi geothermal area is close to the town of Grindavik on the Rekjanes peninsula and is part of an active fissure swarm, lined with crater-rows and open fissures and faults (Figure 1). The high-temperature area has an area of 2 sq km and shows only limited signs of geothermal activity at the surface. The reservoir, however, contains lots of energy and 12 wells supply the Svartsengi Power Plant with steam. The steam is not useable for domestic heating purposes; so that, heat exchangers are used to heat cold groundwater with the steam. Some steam is also used for producing 46.4 MWe of electrical power. Figure 2 shows the distribution system piping hot water to nine towns and the Keflavik International Airport. The effluent brine from the Svartsengi Plant is disposed of into a surface pond, called the *Blue Lagoon*, popular to tourists and people suffering from psoriasis and other forms of eczema seeking therapeutic effects from the silica rich brine. This combined power plant and regional district heating system (co-generation) is an interesting and unique design for the application of geothermal energy.

THE GEOTHERMAL RESOURCE

The geothermal system at Svartsengi is on the Reykijanes Peninsula, right on the boundary of the European and American tectonic plates. The power plant was built on a lava field which dates from a volcanic eruption in the year 1226. The first well was drilled in 1972. The number of drilled wells is currently 20. Of these, 12 are production wells and one well is used for reinjection.

Below 600 meters, the reservoir temperature is almost uniform at 240ºC, and the geothermal fluid is brine with salinity approximately 2/3 of seawater, 22,000 ppm total dissolved solids. Since then, the geothermal system has changed from being completely water-dominated, to water-dominated with a steam cap. From the steam cap, saturated steam is produced at 17 to 24 bar wellhead pressure by four shallow wells (400 to 600 m). Other wells produce a mixture of steam and brine, and the range in drilled depth varies from 1000 m to over 2000 m.

THE SVARTSENGI PLANT EVOLUTION

The first heat exchange experiments started in 1974 in a small-scale pilot plant. Deciding from results of this research, a second pilot plant was built in 1976 with enough capacity to supply the town of Grindavik with 20 L/s of hot water. The first plant in Svartsengi, called Power Plant 1, was built in 1976-78. At the time, it was the first of its kind in the

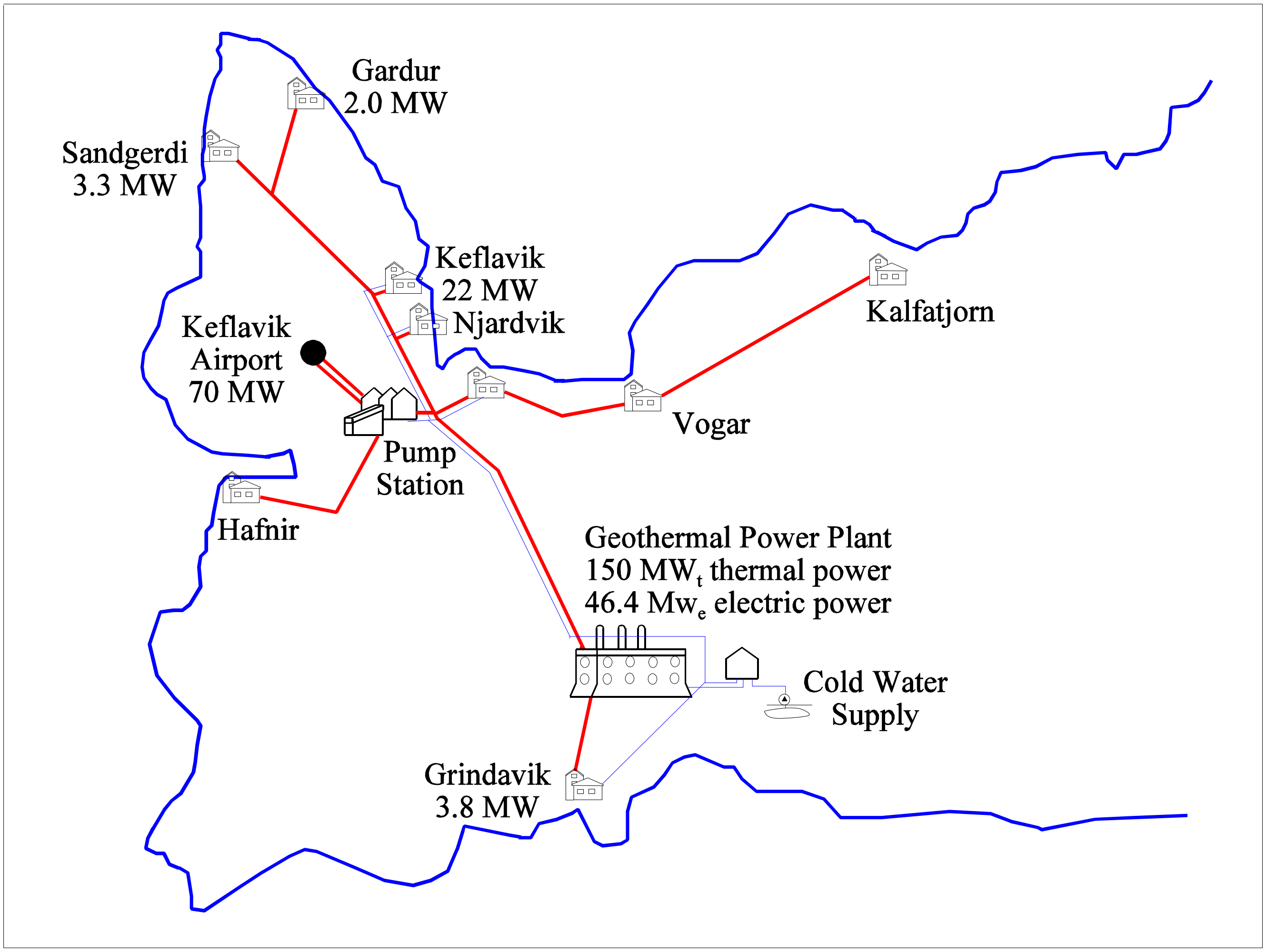

Figure 2. The Sudurnes Regional Heating System layout.

World, it was the first geothermal power plant using a high-temperature geothermal system for simultaneous production of hot water for district heating and electrical power. The engineering and construction of Power Plant 1 was done at the same time as it was a "fast track project." Getting the main plant started as soon as possible was extremely important because oil prices had risen to new world-record highs and almost all houses in the region were heated with oil. Inexpensive geothermal hot water was badly needed and, therefore, design and construction proceeded simultaneously.

This situation created various problems. For example, the plant's main building was originally designed to house two heat-exchange flow streams of 37.5 L/s each. Then, it was decided to double the production capacity and install a total of four flow streams in a building originally designed for two. One of the consequences was that bulky and heavy heat exchangers had to be installed in the basement, originally designed to only house pumps.

Right now, the Svartsengi geothermal power plant consists of the following:

Power Plant 1 commissioned in 1977/78: The installed heat exchange capacity was 150 L/s for the district heating system, corresponding to 50 MJ/s (MWth) thermal power. Additionally, two 1-MWe AEG back-pressure steam turbine generators were installed. In the year 2000, half of the heat-exchange system was decommissioned.

Power Plant 2 commissioned in 1981: The installed heat exchange capacity is 225 L/s for the district heating corresponding to 75 MJ/s (MWth) thermal power.

In **Power Plant 3**, a 6-MWe Fuji Electric back-pressure turbine started commercial production on January 1, 1981.

The first part of **Power Plant 4** was commissioned in September 1989, with three 1.2-MWe ORMAT ORC units. On these units, water-cooled condensers are utilized. The second part was commissioned in 1993 by adding four 1.2-MWe ORMAT units with air-cooled condensers.

In 1995, the project for **Power Plant 5** started out as a renewal of **Power Plant 1**. The main reasons were:

- The thermal efficiency was not up to today's standards, mainly because the small back-pressure steam turbines were very inefficient.
- Maintenance facilities in Power Plant 1 were absolutely unacceptable due to tightly spaced equipment, there were no overhead crane, high-ambient temperature, and a lot of noise.
- The production capacity of Power Plant 1 was not enough to sustain the hot water consumption of the district heating system during even the warmest summer days. Thus, it was impossible to shut down Power Plant 2 for more than three consecutive days for maintenance. This made all major overhauls of Power Plant 2 difficult, and influenced the overall operational reliability.

In **Power Plant 5**, a 30-MWe Fuji Electric extraction-condensing steam turbine was commissioned in November 1999, and in April 2000, a district heating part of 75-MJ/s (MWth) thermal power was commissioned.

The plant maintenance and operating staff, consist of 22 men, regularly attend to 12 turbines, specifically, five steam turbines and seven Organic Rankine Cycle (ORC) units. In addition, they look after 36 cooling fans, 17 geothermal wells and wellheads, 70 control valves, 100 pumps, 20 kilometer pipelines and thousands of valves that require maintenance.

THE FLOW STREAM

It is practical to start with the "raw materials" of the plant, illustrated in Figure 3. The numbers in parentheses refer to details shown in Figure 3. We have geothermal steam and brine (1) and cold freshwater (2). Brine (1) at 240ºC flows into the wells through the holes in a slotted liner. On its way up, the brine starts to boil because of the pressure drop. In the wellhead (3), there is a mixture of steam and brine at about 16 bar. The pressure is reduced to 6 bar before the mixture enters the connecting pipelines to the separators (4). From the separators, steam goes to the back-pressure turbine (5). Back-pressure steam (6) is consumed either by the heat exchangers (7) or the ORCs (8). The back-pressure is controlled by control valves (9) venting the steam to the atmosphere through exhaust stacks (10).

The brine (11) from the separator (4) is flashed into a low-pressure separator (12) operating at 0.8 bar. The brine then flows through a barometric pipe (13) into the "Blue Lagoon." From this brine, silica precipitates rapidly and makes the normally permeable lava practically watertight, and thus, the "Blue Lagoon" is formed in a trough in the lave field, about 20 meters above groundwater level.

The cold 5ºC freshwater (2) is pumped from shallow wells and rifts about 5 km north of the power plant. The first stage in the heating process is the condenser of the water cooled ORCs (14). Here the water is heated to 25ºC. The next stage in the production of district heating water is a direct contact heat exchanger (15); where, the water is heated against the stream of low-pressure steam. At the same time, de-aeration (degassing) of the water takes place. The deaeration is essential to prevent the water corroding the steel district-

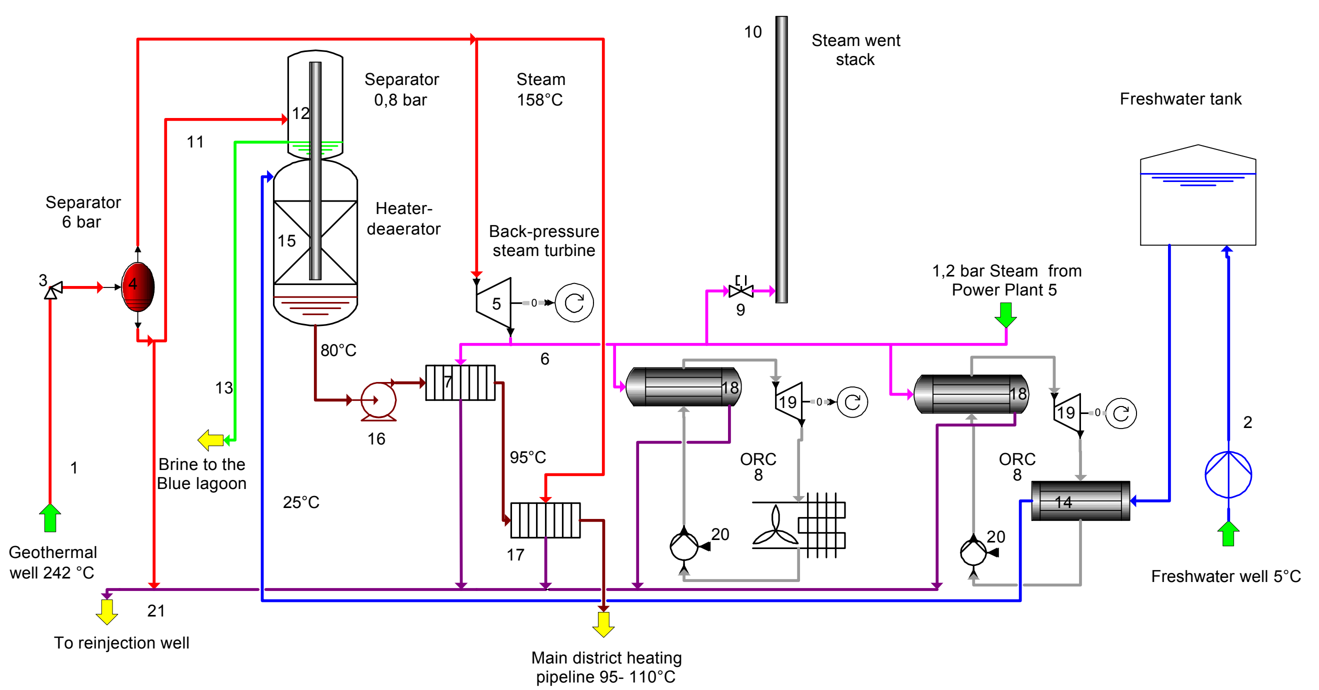

Figure 3. Svartsengi Power Plant flow diagram.

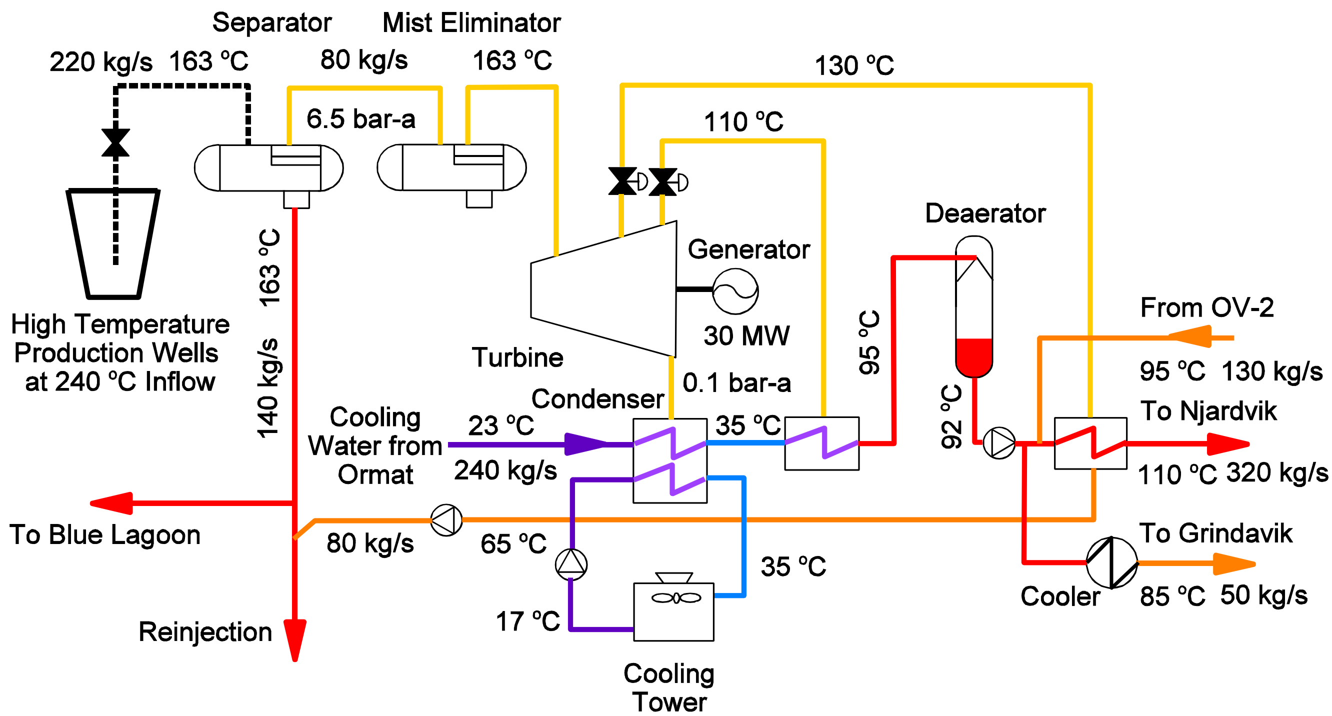

Figure 4. Power Plant 5 flow diagram.

heating pipework. In the deaeration process, dissolved oxygen is eliminated. The deaerated water is pumped (16) through a series of plate heat exchangers; the first one heats the water to about 95°C using back-pressure steam and the second (17) to over 100°C or up to 117°C depending on demand of the district heating system.

The ORC (8) is a vapor power cycle. The working fluid in the cycle is isopentane, a hydrocarbon with a boiling point of 27°C at atmospheric pressure. The back-pressure steam is used to heat the isopentane in a vaporizer (18) at approximately 6 bar pressure. The isopentane gas is then expanded in a turbine (19) which turns a generator. A condenser (14) receives the gas from the turbine, the heat is removed with cooling water and the gas is condensed into a liquid at atmospheric pressure. Finally, the cycle is closed by pumping (20) the isopentane liquid again, under pressure, into the vaporizer.

Finally, the condensate is mixed with brine and injected back to the geothermal reservoir (21). The flow stream of Power Plant 5 is shown in Figure 4.

POWER PLANT OV-5

The new power plant at Svartsengi (OV-5) is designed for 3 MWe electricity generation and 70 MWt heating output (Figure 4). The district heating part is designed to heat from about 23°C to 90-95°C, and deaerate 240 kg/s of pre-heated freshwater coming from the ORMAT turbines. The pumps, final-heaters and coolers pump 70 kg/s of 85°C water to the town of Grindavik and/or 240 kg/s of 110-115°C water to the town of Njardvik. The maximum pumped in OV-5 to these towns is 240 kg/s. Turbine extractions supply enough low-pressure steam for after-heating and final-heating of the district heating water.

It is also possible to receive up to 150 kg/s of district heating water at about 95°C from Power Plant 2 (OV-2), and heat it to 110-115°C, together with the water produced by OV-5. This solution is adopted because the steam in OV-5 is extraction steam (2.5 bara); whereas, the steam in OV2 is high-pressure steam (6.5 bara) that has been used as possible for electrical production. OV-2 pumps this water through the final heaters in OV-5. In this way, OV-5 can simultaneously supply 320 kg/s of 110-115°C hot water to the Njardvik pipeline and 70 kg/s of 85°C hot water to the Grindavik pipeline. Figure 4 shows a flow diagram of the OV-5 power plant.

The turbine is designed to operate at full-load and also supply extraction steam for the district heating system. If the power is reduced, eventually the extraction steam pressure becomes too low to be used for the district heating heat exchangers, and instead of the extraction steam, the high-pressure steam, taken through the bypass valves, must be used to heat the district heating water.

The high steam pressure to the turbine will be controlled by the existing control valves in OV-2. In addition, the turbine will be equipped with a valve that reduces the turbine power if the steam pressure drops below 6.5 bara.

The medium pressure (first extraction) varies with the district heating load, 2.7 to 3 bara. If the turbine load is reduced, this pressure drops. In order to maintain minimum pressure, a bypass valve controls steam from the high-pressure steam supply in order to prevent the medium pressure from dropping below 2.5 bara.

The low pressure (second extraction) varies with the district heating load (1.4 bara at maximum and 1.9 bara at the minimum district heating load). A control valve between power plants OV-5 and OV-2 controls the extraction pressure based on a variable set-point that depends on the district heating load as measured by a flow meter. It is assumed that the turbine is run at maximum load (30 MWe). If the turbine load is reduced, the extraction pressure drops below 1.3 bara at some point. Then, a bypass control valve opens to maintain the pressure at 1.3 bara. At the same time, the check valve reduces the steam coming from the extraction. Chimney valves in OV-2 control the pressure at 1.3 bara at that side, so that the 6-MWe turbine and the ORMAT turbine will not be disturbed because of variability in low-pressure steam in OV-5.

The condenser pressure is controlled by the temperature of the cooling water from the cooling tower. The mixture of condensate water with brine is controlled by two valves that are operated by the same regulator (one opens–whereas, the other closes).

CONCLUSIONS

The total performance of the new geothermal co-generation power plant at Svartsengi is improved by using turbine extractions, instead of high pressure steam, to heat freshwater to 110°C in heat exchangers. Energy balance calculations show that the utilization efficiency of the power plant OV-5 is improved by 15% with this type of operation and by 14-22% at different heat loads. The turbine model shows that at 21-24 MWe, electrical output and different heat loads, the pressure of the first and second extractions drops below 2.5 bara and 1.3 bara, respectively. At this point, it is necessary to supply high pressure steam to the heat exchangers.

Geothermal power plants, particularly those operating on the flash-steam principle, offer the opportunity to combine electricity generation with direct heat applications. The latter utilization can be accomplished using the thermal energy available in a waste brine and rejected heat in a condenser to heat freshwater, which can then be distributed to a variety of end users. The technical feasibility and design of such co-generation power plants depend on a number of factors, including the reservoir temperature of the geothermal fluid, the type of flash system used in the power plant (single- or double-flash), the distance to end users and the types of applications. The climate, topography and cost of other energy alternatives will also influence the final decision on whether to use geothermal co-generation power plants.

ACKNOWLEDGMENT

This paper is an edited summary of two papers presented at the World Geothermal Congress 2000 (WGC2000) and 2005 (WGC2005): "Simulation and Performance Analysis of the New Geothermal Co-Generation Power Plant (OV-5) at Svartsengi" by Soltoni-Hosseini, Masoud; Sigurdsson, Hallgrimur G. and Geir Thorolfsson, WGC2000, Japan and"Maintenance History of a Geothermal Plant: Svartsengi Iceland" by Geir Thorolfsson, WGC2005, Turkey.