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Maintenance history of surface pipes and plants – case history of the Svartsengi geothermal plant

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Abstract

This paper describes the operation of the Svartsengi geothermal power plant, how it was built in various stages, and what have been the most maintenance intensive items. Solutions to these problems are described where they have been found.

1 Introduction

The maintenance of a geothermal plant is very dependent on local factors: the geothermal system being utilized, location, weather and climate. During 27 years of operation of the Svartsengi geothermal power plant, almost every type of problem imaginable has come up, e.g. corrosion, stress corrosion cracking, scaling, erosion, and slug flow - just to name a few.

A district heating plant requires extremely high levels of availability. There is no “spare” district heating plant, whereas in a properly managed electrical grid system there are redundancies and “spinning reserves”. To ensure a high level of availability, the heat exchange process is split into several flowstreams with many internal redundancies.

2 The geothermal resource

The geothermal system at Svartsengi is on the Reykjanes 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 fall of the year 1226.

The reservoir temperature below 600 metres is at an almost uniform temperature of 240°C, and the geothermal fluid is a brine with a salinity approx. 2/3 of seawater, 22,000 TDS. Since 1976, when a small pilot plant started production, the geothermal system has changed from being completely water-dominated, to water-dominated with a steam cap. From this steam cap, 2 shallow wells (400 and 600 m) produce saturated steam at 17 to 24 bar wellhead pressure. Other wells produce a mixture of steam and brine and range in drilled depth from 1000 to over 2000 m.

3 Phases of development

The first plant in Svartsengi - Power Plant 1 (PP1), was built from 1976-1978. It was the first of its kind in the world, i.e. the first geothermal power plant using a high-temperature geothermal system for simultaneously producing hot water for district heating and electrical power.

The first heat exchange experiments started in 1974 in a pilot plant. On the basis of these experiments, a temporary pilot plant was built in 1976 with enough capacity to supply the town of Grindavík with 30 l/s of hot water. At the same time, the engineering and construction of PP1 was in progress, based on the pilot plant results. Getting the plant started as soon as possible was extremely important because oil prices had risen to new world record highs and all houses in the region were heated with oil. Cheap geothermal hot water was badly needed and therefore design and construction proceeded simultaneously.

This 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 flowstreams 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 house only pumps. This made further maintenance difficult and time consuming.

Nowadays the Svartsengi Geothermal Power plant consists of the following:

- **PP1** was commissioned in 1977/1978 and the installed heat exchange capacity is 150 l/s for the district heating system, corresponding to 50 MJ/s thermal power. Additionally, two 1 MW back pressure steam turbogenerators were installed. In 2000, half of the heat-exchange system was decommissioned.
- **PP2** was commissioned in 1981. The installed heat exchange capacity is 225 l/s for the district heating, 75 MJ/s thermal power.
- In **PP3,** a 6 MW Fuji Electric back pressure turbine went on-line 1 January, 1981.
- The first part of **PP4** was commissioned in September 1989, with three 1.2 MW Ormat Organic Rankine Cycle units. These units utilise water-cooled condensers. In 1993, four 1.2 MW Ormat units with air-cooled condensers were added.

The project for **PP5** started out as a renewal of PP1. These were the main reasons:

1. The thermal efficiency was not up to today's standards. The small back-pressure steam turbines are especially inefficient. With modern steam turbines and minor changes to the heat exchange process, it was possible to produce 5 MW of electricity with the same steam consumption as needed for producing only 2 MW.
2. Maintenance facilities were absolutely unacceptable due to tightly spaced equipment, no overhead crane, high ambient temperature, and noise.
3. The production capacity of PP1 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 PP2 for more than three consecutive days for maintenance. This made all major overhaul of PP2 difficult, and had impacts on the overall station operational reliability.

In **PP5,** a 30 MW extraction-condensing steam turbine was commissioned in November 1999, and a 75 MJ/s thermal power heat exchange station was commissioned in April 2000.

The total installed capacity of the combined plants at Svartsengi is 46.4 MW electrical power, and 150 MJ/s (MW) in the form of hot water. These 150 MJ/s correspond to a flowrate of 466 l/s, at water temperature of 117°C when leaving the power plant, and 40°C when spent water leaves the heating systems of the customers' buildings. Actual maximum demand is currently approx. 101 MJ/s, 365 l/s and 110°C.

4 Power plant

4.1 Plate heat exchangers

The plate heat exchangers used in PP1 and PP2 are expensive to maintain and are not suitable for continuous operation at elevated temperatures. Temperatures over 100°C cause cracks in the rubber gaskets between the plates of the heat exchanger. Magnesium silicate scaling on heat exchanger surfaces is also a problem. Magnesium silicate is a mineral precipitating from the freshwater which is being heated with steam in the heat exchangers. The higher the temperature, and the higher the pH of the water, the more scaling problems occur. Less scaling has been observed since CO_2 injection into the deaerated fresh water started in order to lower pH.

The scaling in the final heaters need more frequent cleaning than is possible with the current system. Often the efficiency has dropped much too low before cleaning. This cleaning process is expensive and time consuming. The heat exchangers have to be dismantled and the plates put into an acid bath for several days. Then the gaskets have to be torn off and the old gasket glue has to be scraped and brushed off. Finally, new gaskets have to be glued on each plate. For one heat exchanger, this operation may take up to one month to complete. Cleaning of shell and tube heat exchangers is much easier by high-pressure water jet.

4.2 Pumps

Proper alignment of the motor and pump is essential. To assist the mechanics, an investment was made in a laser alignment tool. To keep shaft leaks to a minimum, double mechanical seals with cooling have proved best.

4.3 Control system

H_2S gas plus humidity corrodes copper in electronic and electrical systems. All sensitive equipment has to be in air-conditioned rooms. In the A/C units, Purafil is used as an H_2S scavenger.

5 The flow stream

It is convenient to follow the "raw materials" of the plant. We have:

1. Geothermal steam and brine.
2. Cold fresh water.

And the products:

1. Electrical power.
2. District heating water.
3. Brine for recreation and health.

Let's follow the flow streams, starting in the geothermal boreholes. Brine at 240°C flows through slots in the liner into the well. On the way up, the pressure drops until boiling starts. In the early years of operation, calcite scaling used to form in the boiling zone at 500 to 600 m depth. The scaling had to be cleaned by drilling approximately every 2 years. Hitaveita Suðurnesja, together with Orkustofnun (now ISOR) and Jarðboranir, devised a drilling method which made it possible to drill out the scaling, and bring the debris to the surface while the well was kept flowing.

The master valves on the wellheads are very important and have demanded considerable maintenance. The valves have been modified to be operated by a hydraulic jack powered by a portable Diesel-driven hydraulic pump. Pitting corrosion of valve stems have been serious, but custom-made stems made of SAF 2205 duplex stainless steel have proved successful.

By the wellhead, the pressure is reduced to 5.5 to 6.5 bar. In the early years, an orifice plate was used. Control valves for two-phase flow with high-pressure drop and scaling are not on the market. Therefore, we designed and built our own needle control valve, called "Ella – loki", after its inventor.

Two phase pipelines from boreholes are mostly without problems, unless they are upwards sloping or long horizontal runs. Then, there is the problem of slug flow because of unfavourable enthalpy.

6 Scaling and corrosion

Silica scaling begins as the temperature is lowered below 150°C. The pressure in the separators and brine pipes is kept as high as necessary to prevent silica scaling. The problems start with the level control valves for the brine in the separators. Here the pressure is reduced to atmospheric into silencers. These valves used to get stuck or the stems wore down very quickly. This was solved by modifying the butterfly control valves (from Fisher Controls). Hot water (deaerated) is injected into the stuffing box at a pressure of about 9 bars. This drives the brine with silica particles out of the bearings.

In the early years, there was trouble with rupture disks because of premature failures. The main reason was unsuitable disks because of improper specification. The rupture pressure of the type BV disks was too close to the working pressure. Now S- type disks from BS & B are used with very good results.

Silencers for the flashing brine have been developed through the years. The newest version is a water-filled basin where the brine inlet is 4 meters deep. The basin is made of high strength concrete, and the reinforcing steel is epoxy coated. An aluminum hood lifts the steam up high enough to prevent ground fog. This type is easy to clean with a backhoe when the hood has been detached.

Separators have mist eliminator pads made of wire mesh. These have to be renewed every 2 or 3 years because of stress corrosion cracking of the stainless steel wire. Ideally, it would be best to have a titanium wire mesh, but unfortunately it has been impossible to get for a reasonable price. Incolloy wire mesh has been tried; it is better than SST but is not worth the increased price.

Steam turbines have to be dismantled every year to clean first stage steam nozzles. The scale in the nozzles is usually silica or calcite. This problem has not yet been solved adequately.

The steam condensate is corrosive because of low pH. By selecting type 316 stainless steel for pipes and vessels, it is not causing any problems.

7 Organic Rankine Cycle

Several improvements have been made in the Organic Rankine Cycle equipment, that generates electricity from steam at atmospheric pressure, such as:

- Cooling fan belts on air cooled condensers. Belts got hard because of sulfur and high humidity.
- Control system used to suffer from H_2S corrosion, unnecessary functions blocked (simplified program).

8 Conclusions

The key to success at the Svartsengi Power Plant has been primarily attributed to:

- Skilled operators and maintenance people.
- Monitoring and condition-based maintenance.
- Monitoring vibration with suitable sensors.
- Outdoor equipment is in coastal atmosphere, high humidity, high winds, and corrosive atmosphere. Steelwork has to have good corrosion protection: hot dip galvanizing + painting.

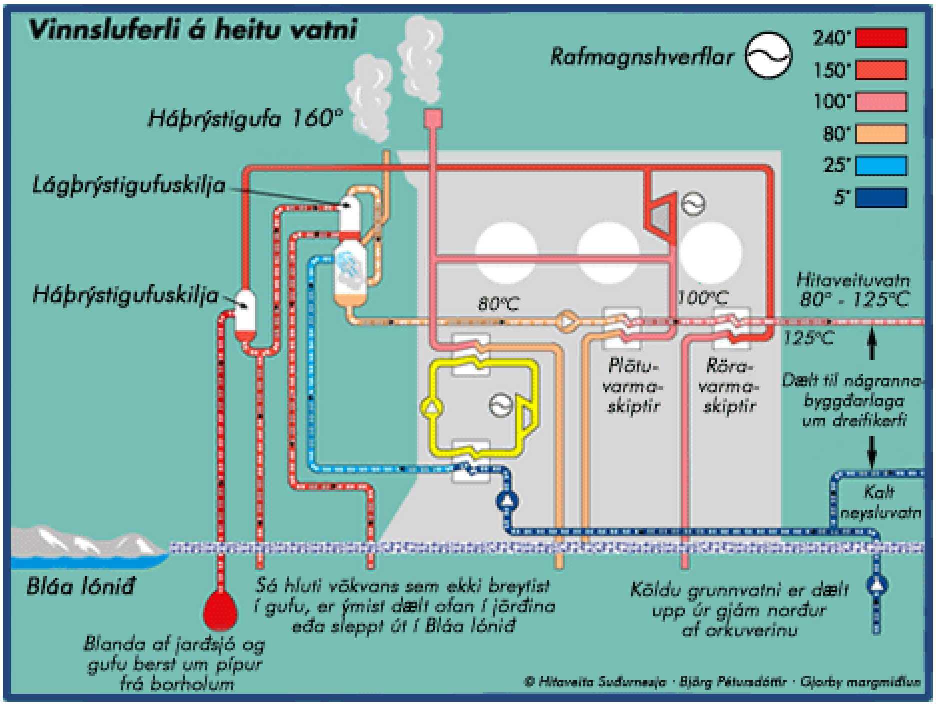

Figure 1: Svartsengi power plant flow diagram, PP2, PP3, and PP4.

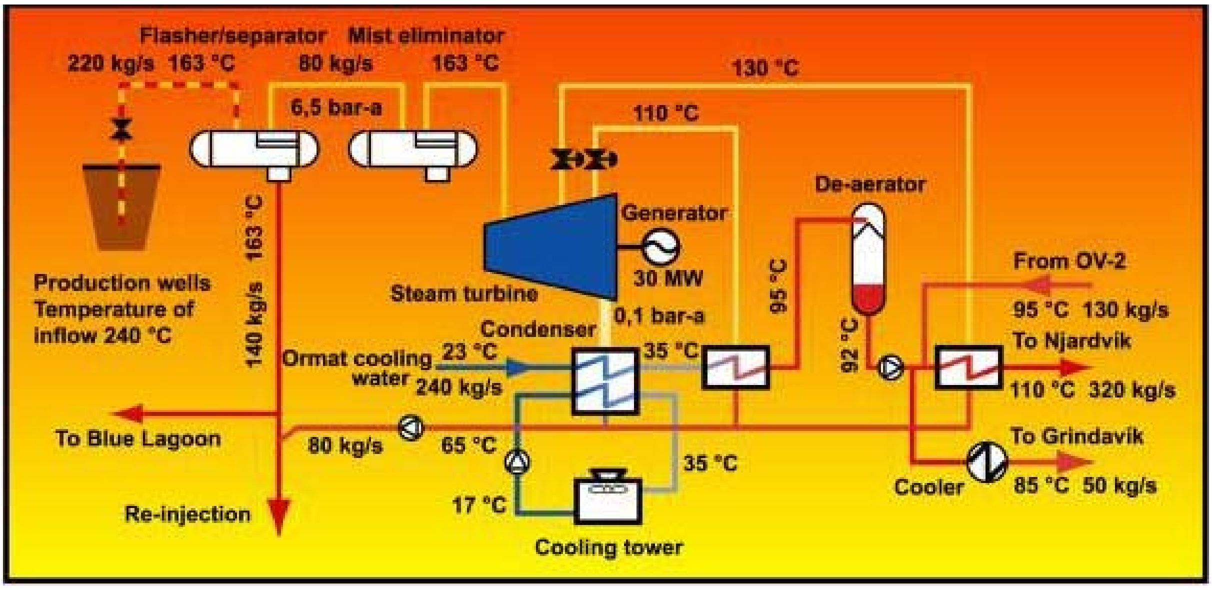

Figure 2: Combined production of power and hot water for district heating, PP5.