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Maintenance History of a Geothermal Plant: Svartsengi Iceland

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ABSTRACT

The maintenance of a geothermal plant is very dependent on local factors, namely, the geothermal system, location, weather, and climate. During the 28 years of operation of the Svartsengi geothermal power plant, almost every type of problem imaginable has come up, for example, corrosion, stress corrosion cracking, scaling, erosion, and slug flow.

A district heating plant must be extremely reliable. There is no “spare” district heating plant, unlike in a good electrical grid system where there are usually redundancies and “spinning reserves”.

In this paper, the operation of the Svartsengi geothermal power plant will be described, how it was built in various stages, and what have been the most maintenance intensive issues. Solutions to various problems are also described.

1. 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 MW electrical power, and 150 MJ/s (MW_{th}) in the form of hot water. Local factors like the geothermal system, location, weather and climate highly influence the maintenance of the geothermal plant.

The first production at Svartsengi started in 1976, 28 years ago. Since the beginning, the Svartsengi operation and maintenance staff has kept the plant in good order. The plant has been built in several stages, starting with a preliminary plant capable of producing 20 L/s of district heating water corresponding to 3 MJ/s.

1.1 “The troublemakers”

Most problems start and end with chemistry. The geothermal fluid in the Svartsengi reservoir is a 22.000 ppm tds brine with up to 4% gas. In saline solutions, silica precipitation is a lot faster than in low chloride solutions When the steam is condensed we get water with a pH value of 4.

The fresh water, wich is heated in the plant, has 70 ppm Cl, conductivity of 300 µS/cm and some magnesium silicate. When heated, this water becomes corrosive and scaling may happen.

The local weather is characterised by humidity, rain, and salt spray from the ocean. These weather conditions combined with geothermal steam extensively strain all structures exposed.

1.2 Maintenance volume:

The plant maintenance and operating staff, consist of 22 men, regularly attend to 12 turbines, specifically, 5 steam turbines and 7 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.

Figure 1: Svartsengi Power Plant aerial view.

Furthermore, the reliability of the heating plant is extremely important. There is no “spare” heating plant for the district heating system. But the electrical system is connected to the national grid system where redundancies and “spinning reserves” are accessible (of course this costs some money). To ensure a high level of availability, the heat exchange process in Svartsengi is split into several flow streams with many internal redundancies. Turbine downtime means lost money, but district heating downtime means lost votes to municipal politicians!

In the next three sections of this paper, the main functions of the Svartsengi geothermal power plant, flow diagrams and building history will be introduced. In section 5, some main components of the power plant will be described and the main maintenance items discussed.

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 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.

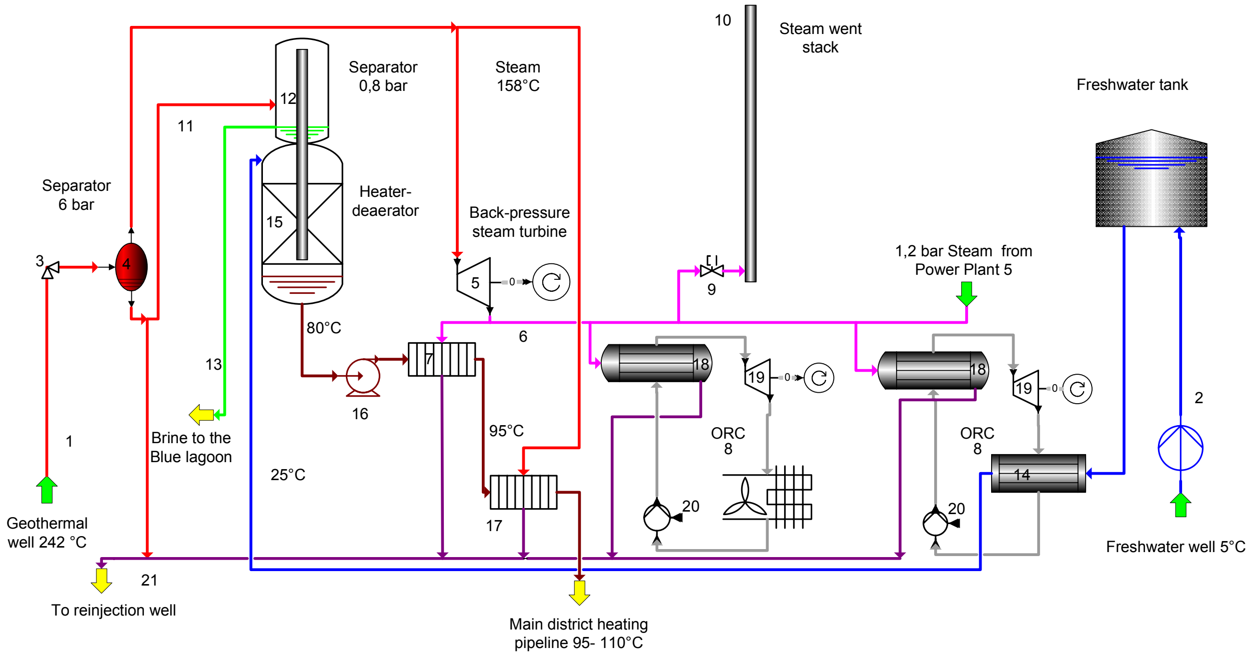

Figure 2: Svartsengi Power Plant flow diagram.

Below 600 metres, the reservoir temperature is almost uniform at 240°C, and the geothermal fluid is brine with salinity approximately 2/3 of seawater, 22,000 ppm total dissolved solids. In 1976, a small pilot plant started production. 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 4 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.

3. 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 Grindavík with 20 L/s of hot water. The first plant in Svartsengi, called Power Plant 1, was built in 1976-1978. At the time it was the first of its kind in the 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 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 1977/1978: The installed heat exchange capacity was 150 L/s for the district heating system, corresponding to 50 MJ/s (MW_{th}) thermal power. Additionally, two 1 MW 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 thermal power.

In **Power Plant 3,** a 6 MW 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 MW Ormat ORC units. On these units, water-cooled condensers are utilised. The second part was commissioned in 1993 by adding four 1.2 MW 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:

1) The thermal efficiency was not up to today's standards, mainly because the small backpressure steam turbines were very inefficient.

2) 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.

3) 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 MW Fuji Electric extraction-condensing steam turbine was commissioned in November 1999, and in April 2000, a district heating part of 75 MJ/s thermal power was commissioned.

The total installed capacity of the combined plants at Svartsengi is 46.4 MW electrical power, and 150 MJ/s (MW_{th}) hot water. The 150 MJ/s correspond to a flow rate of 466 L/s, at water temperature of 117°C. The power equivalent of hot water is calculated according to

$$P = \dot{m} \times c_p \times \left(T_{plant} \div 40°C\right)$$

where $\dot{m}$, c_p and T_{plant} are, mass-flow, specific heat and temperature of the water when leaving the power plant, respectively. The anticipated temperature of the water leaving the heating systems of customers' buildings is 40°C. In 2001, December 28 a maximum demand was recorded at 101 MJ/s and 365 l/s.

4. THE FLOW STREAM

It is practical to start with the "raw materials" of the plant, illustrated in Figure 2. The numbers in parentheses refer to details shown in Figure 2. We have geothermal steam and brine (1) and cold fresh water (2). Brine (1) at 240°C 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 ORC's (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 lava field, about 20 meters above groundwater level.

The cold 5°C fresh water (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 25°C. 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, deaeration (degassing) of the water takes place. The deaeration is essential to prevent the water corroding the steel district-heating pipework. In the deaeration process, dissolved oxygen is rid of. The deaerated water is pumped (16) through a series of plate heat exchangers; the first one heats the water to about 95°C using backpressure 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 3.

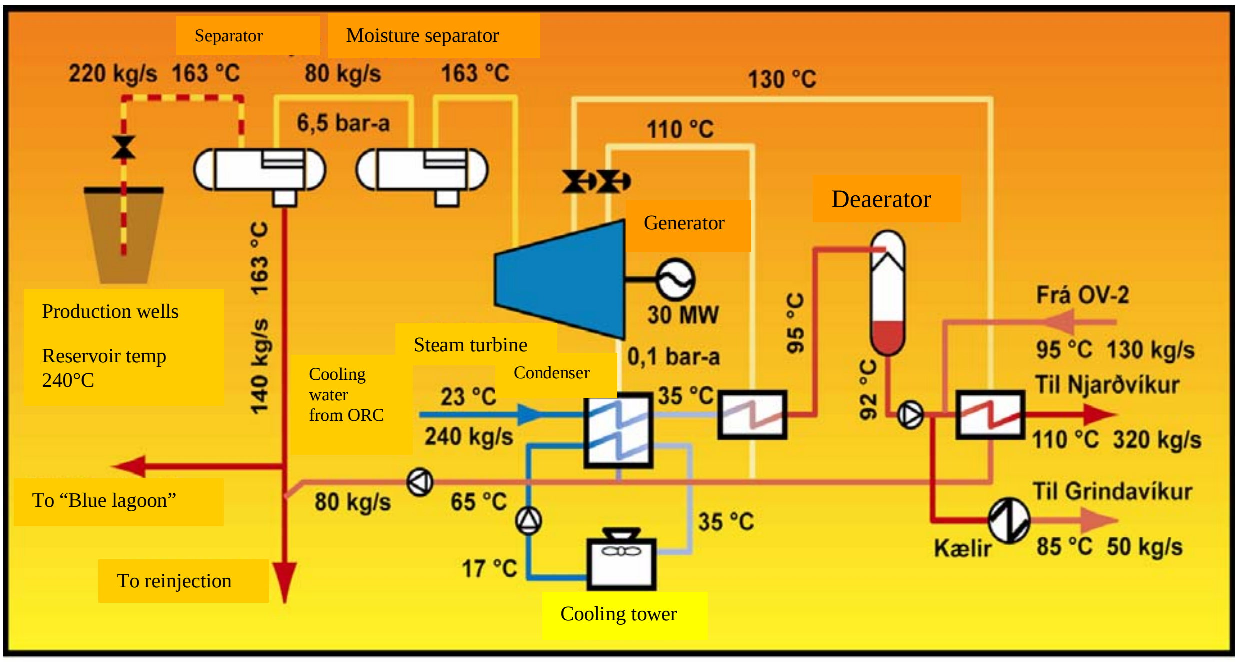

Figure 3: Power Plant 5 flow diagram

5. POWER PLANT COMPONENTS

5.1 Wells

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 (Iceland Drilling Company), devised a drilling method which made it possible to drill out the scaling while the well was kept flowing and the debris was brought to the surface. The workover is done with the well flowing, by using a drilling rig with a top drive and flush coupling drill pipes. The wellhead has a stuffing box and a water-cooled spool piece flow diverter.

Due to small changes in the carbon dioxide content of the geothermal fluid during the recent years, the calcite-scaling problem has almost disappeared.

Figure 4: From left: Stuffing box, BOP, spool-piece, and drill bit.

Figure 5: Workover showing rig and silencer.

The master valves on the wellheads have to be extremely reliable but have required more maintenance than originally expected. It is gate valve type with expanding gate. Pitting corrosion of valve stems made of both 13 % Cr steel and hard chromed steel has been serious. Changing stem material to SAF 2205 duplex and 17- 4 PH stainless steel have eliminated the pitting corrosion problem. Stem handwheel thrust bearings used to fail after only a few operations of the valves. The valves have been modified to be operated by a hydraulic jack powered by a portable diesel-driven hydraulic pump or a stationary electric pump.

Figure 6: Wellhead master valve with hydraulic jack and spray on insulation.

In the early years, an orifice plate was used to reduce the wellhead pressure (14 to 25 bar) down to separator pressure. Control valves for two-phase flow with a 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, Erlendur Guðmundsson, a plant mechanic.

5.2 Slug flow

Slug flow sometimes occurs in two-phase-flow pipelines. Two-phase pipelines from boreholes are generally without problems, unless they slope upwards or have long horizontal runs. Slug flow has knocked pipes off their supports as can be seen in Figure 7. Methods to keep the pipes free from slugs while negotiating for an upwards sloping grade are being investigated and tested.

Figure 7: Slug flow knocked the pipe off its supports.

5.3 Plate heat exchangers

The plate heat exchangers used in Power Plants 1 and 2 are expensive to maintain and they are not suitable for continuous operation at elevated temperatures. Temperature over 100°C combined with hydrogen sulphide in the steam harden the EPDM rubber gaskets between the plates of the heat exchanger. Eventually, cracks develop in the gaskets gradually leading to leaks. Magnesium-silicate scaling on the heat-exchanger surfaces is also a problem. Magnesium silicate is a mineral precipitating from the freshwater heated with steam in the heat exchangers. The higher the temperature and the higher the pH of the water, the more scaling problems occur. To prevent scaling, pH value is controlled by injecting CO_2 into the deaerated fresh water.

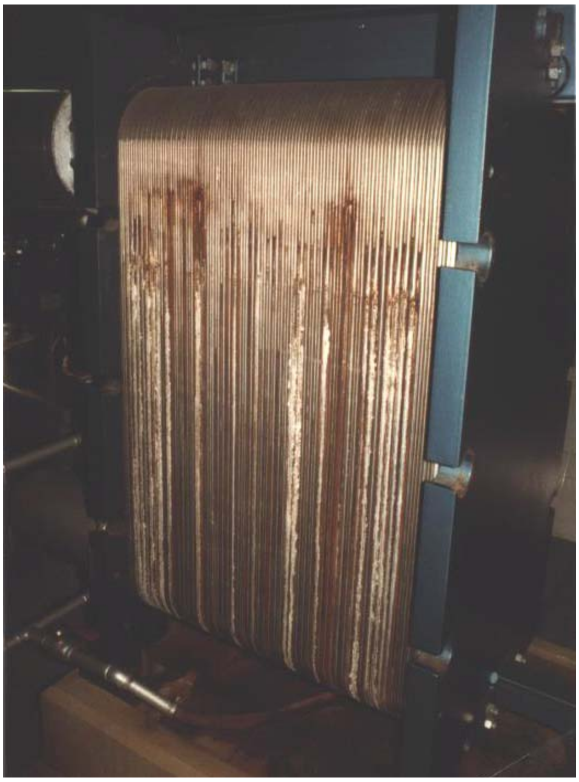

Figure 8: A plate heat exchanger with leaks.

Scaling in high-temperature heaters requires more frequent cleaning than currently possible. Often, the efficiency has dropped too much before cleaning can be completed. The cleaning process is expensive and time-consuming. The heat exchanger has to be dismantled and the plates put into an acid bath for several days. The gaskets have to be torn off and the old gasket glue has to be scraped and brushed off. 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. This is done by using a high pressure water jet, hydroblasting, to clean the scaling from the inside of the tubes. The steam is on the shell side and no scaling has been observed there.

5.4 Pumps

Proper alignment of the motor and pump is essential to obtain a long lifetime of bearings and for vibration-free running. To assist the mechanics, when aligning pumps, a laser alignment tool was purchased. To minimize shaft leaks, double mechanical seals with cooling have been the most effective.

5.5 Control system corrosion

Hydrogen sulphide combined with humid air corrodes copper. This is a problem especially in the computers, and electronic, low voltage electrical systems. All sensitive equipment has to be in rooms where H_2S gas has been cleaned from the ambient air. In the A/C units, Purafil is used as an H_2S scavenger.

5.6 Scaling in brine pipelines

The silica scaling in the brine pipelines 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. Scaling problems, however, are prominent in the level control valves for the brine in the separators. The level control valves reduce the pressure to atmospheric before the brine enters the silencers. The valves were prone to get stuck and, when they did not stick, the valve stems wore down very quickly. Both problems were addressed by modifying the butterfly control valves (from Fisher Controls). Now, hot water (deaerated) is injected into the stuffing box at a pressure of about 9 bars. This drives the brine together with silica particles out of the bearings.

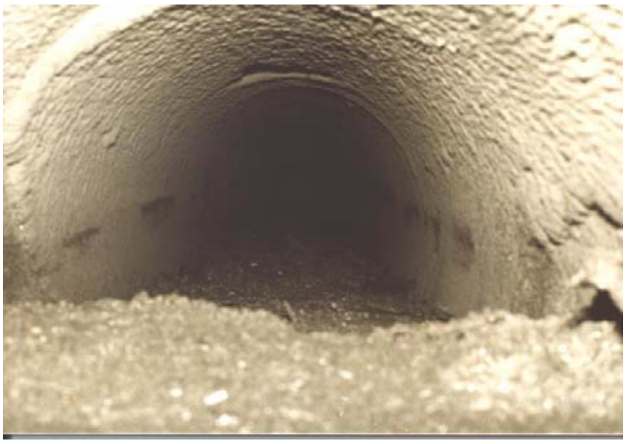

Figure 9: Silica scaling in a 500 mm brine pipe.

5.7 Rupture disks

In the early years, some premature failures of rupture disks caused a lot of trouble. The main reason was that the operation pressure was too close to the bursting pressure and the design operating pressure of the disks was only 50% of bursting pressure. Also, the rupture disks used were not suitable when vibration of pipes, acoustic waves and pressure fluctuations were present. Currently, we use reverse buckling disks with a design operating pressure of 90% bursting pressure, with very good results.

5.8 Silencers

Flashing brine makes a lot of noise when it is vented directly to the atmosphere. Therefore various types of silencers have been used since the start up of the first power plant. The main source for flashing brine is from the level control valves of the separators. The most recent type of silencer 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. Flash steam is vented through an aluminium hood extending high enough to prevent ground fog. This silencer is easy to clean with a backhoe when the hood has been detached.

Figure 10: Silencer after cleaning. Inlet pipe can be seen on the bottom.

5.9 Separators

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

5.10 Steam turbines

Steam turbines have to be dismantled every year to clean the scaling from the first-stage steam nozzles. The scale in the nozzles is usually silica or calcite. This nozzle scaling problem has not yet been solved adequately but some methods of steam scrubbing are being tested.

Figure 11: Steam turbine inlet nozzles with intensive scaling.

5.11 Condensate

The steam condensate is corrosive because of low pH. By selecting type 316 stainless steel for condensate pipes and vessels, this problem is prevented.

5.12 Outdoor steelwork

As stated in section 1.1, the outdoor equipment is strained by weather conditions, which are the high humidity, high winds, and corrosive atmosphere. Steelwork requires a good corrosion protection: The best results have been with hot dip galvanizing and painting. Aluminium also lasts quite long, but is not as cost effective as galvanized steel for structural purposes.

5.13 Organic Rankine Cycle

Several improvements have been made in the ORC equipment:

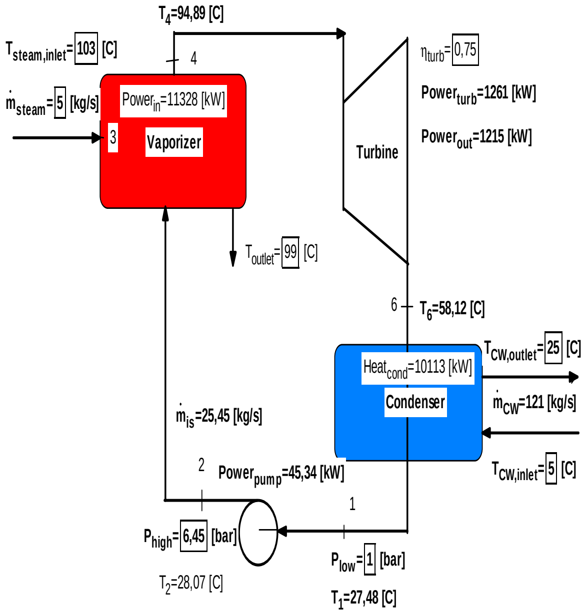

Figure 12: Organic Rankine Cycle diagram

Figure 13: ORC cooling fan with gear motor.

The fan belts on the air cooled condensers used to snap at an alarming rate. The fan belts hardened because of hydrogen sulphide in the atmosphere and high humidity. This problem was solved by installing geared electrical motors for the fans.

Before an effective air cleaning system was installed (see section 5.5), the control system hardware used to suffer from H_2S corrosion. Some unnecessary PLC computer program functions were also blocked (simplified program).

5.14 Gaskets

"They don't make them as they used to do" has certainly become true nowadays. Since asbestos based gaskets became illegal on the market several types have been tested. Gaskets with similar properties as the old asbestos-made ones cost a lot more money.

6. EQUIPMENT AND ASSISTANT SYSTEMS

Aside from ordinary workshop tools, the plants' operating and maintenance department has acquired some helpful extra tools through the years. IRD vibration analyser is used for periodic measurements on bearing vibration. An accompanying computer program allows history comparison. A laser alignment tool is especially efficient when aligning the centrifugal pumps, the ORCs and vacuum pumps. Pneumatic wrenches are used extensively on flange bolts. Hydraulic wrenches are mainly used on turbine casing bolts.

To help manage the maintenance tasks, the maintenance department uses the KKS (Kraftwerk Kennzeichnung System) coding for all plant systems and a computerised maintenance management system called DMM.

It is also obvious that having all the systems and tools in the world is useless unless there is a force of skilled workers who know what they are doing and how to use the tools and systems.

7 CONCLUSIONS

The key to the reliable operation of the Svartsengi Power Plant can be primarily attributed to:

Redundancies for safeguarded operation are incorporated in the design.

Constant monitoring and condition-based maintenance.

Skilled and creative operators and maintenance staff.

Benefits from the gradual extensions of the power plant. In this way it has been possible to incorporate operating experience in each new step.

ADDITIONAL READINGS

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