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Three Decades of Power Generation-Svartsengi Power Plant

Albert Albertsson, Geir Þórólfsson, Júlíus Jónsson

HS Orka hf, Brekkustígur 36, 260 Reykjanesbær, Iceland

albert@hs.is, geir@hs.is, julius@hs.is

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ABSTRACT

The combined geothermal heat and power plant (CHP) in Svartsengi, located on the Reykjanes peninsula, Iceland commenced its commercial operation in 1976. Today there are in total six building phases with 12 turbine generators, 3 back pressure units, 7 binary units and two condensing units. The Reykjanes power plant located at the tip of the Reykjanes peninsula comprising two double flow sea water cooled 50 MW_e condensing turbine generators commenced its commercial operation in June 2006. The paper describes the development of the plants and the different unique turbine generators installed. Co-generation of power and heat and optimized harnessing of the geothermal reservoir is emphasized.

1. INTRODUCTION

By the initiative of the town council of Grindavík, located some 3 km south of the existing power plant complex, two geothermal exploration wells were drilled in the year 1972. The wells were vertically drilled down to 239 and 402 meters with 8 and 9 inch production casings respectively. Whereas flow tests revealed that one had hit a geothermal reservoir, the reservoir temperature was 240 °C, the fluid rich (saturated) of dissolved minerals and its salinity was two third that of sea water a direct use of the fluid for district heating in Grindavík was out of the question. Whereas district heating was the main issue, some kind of a heat exchange plant was needed to utilize the geothermal fluid and whereas it was far too expensive and too complicated task to undertake by the small town, seven municipalities on the southern part of the Reykjanes peninsula jointed their forces and established Hitaveita Suðurnesja in December 1974. Today, according to law the company has been split into two companies HS Orka hf and HS Veitur hf both limited liability companies. HS Orka hf harnesses the ample geo resources. HS Veitur hf owns and operates the distribution systems (hot water, ground water, electricity). In order to find out how the geothermal resource could be used for producing hot water for district heating one had to find ground water to be heated. Whereas it was a complicated task to utilize the geothermal resource for production of district heating water, Orkustofnun (The National Energy Authority) was consulted. Consulting Orkustofnun was the beginning of the three decade long history of the power plant complex/Resource Park in Svartsengi.

2. DESK STUDY AND TWO PILOT PLANTS

Ingenious scientists at Orkustofnun (OS) came up with a smart way of using the geothermal reservoir fluid to heat and deaerate ground water. The scientists recommended a dual flash plant in which the ground water was heated by direct contact heat exchange with steam from a second flashing stage. The heat exchange process and expected technical difficulties were outlined in a desk study which today is still valid. Whereas the geothermal fluid was a difficult one to deal with and the heat exchange process was a prototype, pilot tests had to be done. Two pilot plants were built the first one in the year 1972 and the second one in the year 1976. The first pilot plant, erected adjacent to the two exploration wells examined heat exchange processes and the scaling process taking place. Whereas the outcome of the first pilot test was very promising and in harmony with the desk study it was decided to build a second pilot plant capable of producing district heating water for Grindavik. As in the first pilot plant heat exchange methods were further tested, scaling and corrosion mechanism studied as well as deaeration of heated ground water. The second pilot plant in operation for around 25 months got geothermal fluid from a 1.713 m deep vertically drilled well (9 5/8” production casing), drilled in 1974. Whereas the experience gained from the design and operation of the second pilot plant was very encouraging it was decided to design and build the first phase of a full scale power plant. The way of working in a group of interdisciplinary people, importing knowledge into the company, by innovative thinking, by outsourcing complicated tasks in close cooperation with the employees of the company and carry out complicated tasks based on innovative ideas, desk study and piloting has turned out to be very successful and is today one of the basic components in the Resource Park Concept dealt with in a special paper.

3. THE SVARTSENGI POWER PLANT

Today the power plant complex comprises of six building phases named Power Plant 1 (PP-1), Power Plant 2 (PP-2),…., Power Plant 6 (PP-6).

<u>PP-1:</u> PP-1 the Demonstration Plant, inaugurated in 1977 proved the commercial and technical viability of the design

methods used. The plant comprises of two 1 MW_e AEG back pressure turbine generators (5.5/1.2 bar) and four 12.5 MW_t heat exchange-deaerator streams (MW_t based on temperature drop of hot water from 125 °C down to 40 °C). Unfortunately or fortunately the turbine generators were not specially designed as geothermal units resulting in difficult operational problems due to scaling and stress corrosion cracking of the riveted shrouds of the turbine blades. The stationary blade holders were slit into grooves in the casing causing difficult sticking problems due to scaling build up in the grooves. The turbine generators are not in operation any longer but can be started up if needed (very high specific steam consumption, difficult to get spare parts). The main learning: geothermal turbines should have loose fitted (bolted) stationary blade holders, integral shroud had to be used instead of riveted shrouds, linear sliding movements in control and emergency stop valves had to be avoided and proper turbine material to be selected based on in situ corrosion tests. Whereas there were no moisture separators in front of the turbines, the separators were located very close to the turbines and the efficiency of the separators were not high enough the quality of the steam was poor. The separators had to be of a better design and developed further for the next phase of the power plant. The heat exchange streams comprises of a direct contact heat exchanger (steam from a second flash directly mixed with the ground water), deaerator, plate heat exchangers and pumps. The plate heat exchangers (two temperature levels) got steam on one hand form the exhaust of the turbines and on the other hand from the first flash. The experience gained, from the operation of the streams were good except for stress corrosion cracking of stainless steel heat exchanger plates and to fast aging (vulcanization) of plate gaskets. The main learning: as long as plate heat exchangers are selected one has to carefully select proper material based on in situ corrosion tests for the plates and “high” temperature rubber gaskets (EPDM) had to be selected.

PP-2: PP-2 inaugurated in the year 1981 comprises three hot water flow streams, 25 MW_t each. Each stream consists of one combined low pressure separator, direct contact heat exchanger, deaerator column (HXDS), two sets of plate heat exchangers (102 °C/115 °C), hot water pumps, vacuum pumps and a condensate collecting system. The experience gained from the design and operation of the HX streams in PP-1 led to the idea of combining in one unit the second flash separator, the direct contact HX and the deaerator, the HXDS column was born. The HDXS column has turned out to be very effective and almost maintenance free. The plate HX selected have more or less shown the same problems as in PP-1. Selection of proper plate materials being a great issue, we ended up with titanium plates, too short lifetime of plate gaskets, the plates very thin (<1.0 mm) and difficult to handle and problematic to remove silica encrustation and glue rests from the gasket grooves. The pumps and the condensate collecting system have worked very satisfactorily. The main learning: HXDS column a very cost effective reliable low maintenance piece of equipment, plate HX not to be selected and the CHP scheme proved to be very cost effective.

PP-3: PP-3, a 6 MW_e backpressure turbine generator (5.5 ba/1,2 bar) manufactured by Fuji Electric was inaugurated late December 1980. The turbine is a typical impulse turbine. The turbine wheel is a two raw Curtis stage with integral shroud on blades in both rows. The stationary blade holders are bolted to the casing and the shaft seals (Labyrinths) are fed with clean gland steam. The backpressure steam (1.2 bar) is on one hand fed to the ORC´s in PP-4 and on the other hand fed to the plate HX in PP-2. The turbine generator, the biggest backpressure unit Fuji has manufactured is an extremely reliable piece of machinery (over 99% availability) with low maintenance cost. After two years of operation the hard chromium plated surface of the labyrinth area of the turbine shaft had disintegrated and was replaced in Iceland with type 316 stainless steel weld overlay. After 19 years of continuous operation one of the blades in the first stage cracked due to fatigue. Main learning: the lesson learned in PP-1 concerning the design criteria to be set for the steam path of the turbine and proper material selection proved to be true (integral shroud and bolted stationary blade holders), hard chromium plated surfaces in geothermal environment is not suitable and CHP operation is very reliable and effective. More refined design of the vertical steam/brine separators did not deliver pure enough steam to the turbine. The separators are still too close to the turbine and no moisture separators were installed in front of the turbine. The turbine is overhauled and cleaned once a year. The overhaul takes around one week thanks to the bolted stationary blade holders and highly skilled employees.

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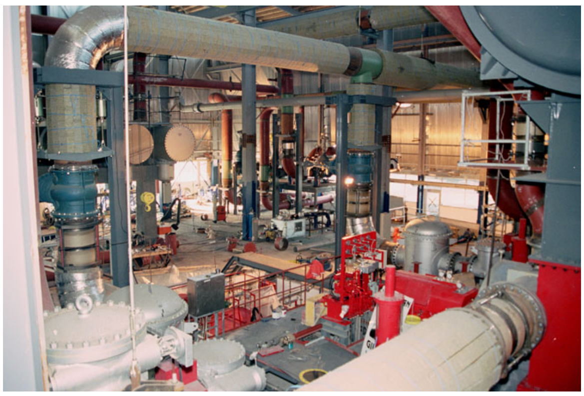
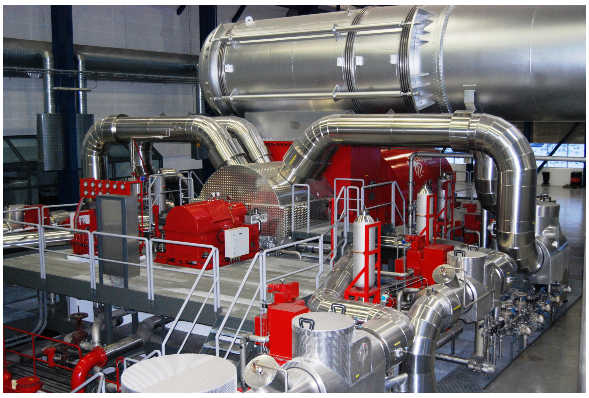
PP-4: PP-4 consists of two sets of ORC´s from ORMAT inaugurated in the year 1989 and 1993 respectively. The first set of ORC´s comprises three ground water cooled, synchronous ORC units, each generating 1.2 MW_e net to the grid. The ground water at 5 °C entering the condensers leaves them at around 25 °C heading for the HX streams. By other words the condensers are used as pre heaters for the hot water production. The second set of ORC´s comprises 4 air cooled asynchronous units, each generating 1.2 MW_e net to the grid. The ORC units generate in total 8.4 MW_e net to the grid. According to ORMAT it was in Svartsengi that for the first time in the world an ORC unit was directly connected to a backpressure turbine as a bottoming unit. The ORC units have been reliable even though the gearboxes of the synchronous units made by Lufkin were of poor quality (loose fly wheel, very poorly balanced shafts, debris from manufacturing found in the gear box) and the fan belts of the air coolers did not last long due unfavorable design and the H_2S content of the humid air. Today the fans are driven by an integrated gear and motor on the top of the air coolers. The iso-pentane boilers, the condensers, the iso-pentane pumps, and the turbines with associated control equipment are very reliable piece of equipment. Main learning: in holistic harnessing of a geothermal resource an ORC unit either separate or as a bottoming unit is vital, the ORC units increased the total efficiency of the power plant complex, the ORC units are reliable and easily maintained and the fruitful cooperation with ORMAT opened our eyes for the importance of holistic approach in harnessing geothermal resources.

PP-5: PP-5 inaugurated in November 1999 comprises one single flow 30 MW_e condensing turbine generator with two steam extractions (6.5/2.1/1.1 bar), made by Fuji Electric Systems and a 75 MW_t hot water stream. Due to scaling build up at the tip of the shroud of the first blade row of the turbine wheel the first row had to be re-bladed at site. Inspections show that this problem does not exist any longer. The gas extraction system comprising two vacuum pumps and one spare ejector system has worked faultlessly. Today the steam supply system comprises horizontal separator and a horizontal moisture separator both with mist-eliminator pads installed. The distance from the separator and the turbine is around 200 m. Today the steam to the turbine is almost free of brine droplets. The steam main for the turbine is fitted with condensate washing equipment which has never been used only tested. The turbine itself is designed for condensate washing under load which enables one to elongate the time between overhauls and cleaning of the steam path. The time between overhauls and cleaning of the steam path is 3 – 4 years. Due to maintenance friendly design of the turbine (bolted stationary blade holders etc) it takes three weeks or less to overhaul and clean the turbine. Except for too low pressure rating of the heat exchangers end heads and too much integrated design of the steam piping the hot water streams have turned out to be very effective and reliable. Main learning: condensate washing of turbines under load is commercially important and possible, the detail design of turbine blades have to aim at "low" steel temperatures at critical spots in order to avoid evaporation/boiling of brine droplets, all equipment has to be designed in a maintenance friendly way, extracting steam from the turbine is reliable, easy controlled and does not cause any additional scaling/erosion problems and the CHP operation of the power plant has turned out to be technically and commercially viable.

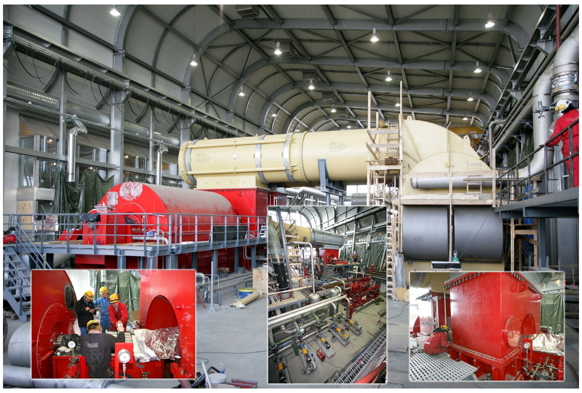


PP-6: PP-6 inaugurated in December 2007 comprises one single flow, triple steam inlet (16/6.5/1.2 bar) 30 MW_e turbine generator manufactured by Fuji Electric Systems. The developed steam cap with steam pressure of around and above 20 bar had for years been harnessed for the power plant complex working on 6.5 bar. Unique homemade control valves were used to throttle the steam with associated energy losses. A topping unit was evident. Extensive study of the steam consumption of the power plant complex in a holistic way revealed that a 30 MW_e triple steam inlet turbine was a favorable and economical option. The unit, nicknamed the Octopus because of the many steam inlet/outlet pipes of the turbine interconnected all the steam turbines on the low pressure steam side. Today all the turbine generators are interconnected on the low pressure steam side as well as on the electrical side which makes the power production of the power plant complex very flexible. The hot water production of PP-2, PP-4 and PP-5 is interconnected making the hot water production flexible. Sophisticated maintenance schedules and interconnection of the different power plants is the base for optimized operation and minimum down time. Main learning: long term multiple steam inlet turbine generators are a good option for optimized harnessing of geothermal fields, multiple geothermal steam inlet/outlet turbines fit well with heat demanding downstream industrial processes.



4. THE REYKJANES POWER PLANT

The Reykjanes Power plant (RPP), inaugurated in June 2006 comprises two sea water cooled double flow 50 MW_e turbine generators (18 barg steam inlet pressure) manufactured by Fuji Electric Systems. Whereas the reservoir temperature is around 300 °C and above and the salinity of the reservoir fluid is the same as sea water the design principles of the Svartsengi power plant complex could not been applied. Therefore extensive studies on the scaling mechanisms were undertaken by mapping the chemical reactions at different temperatures in an autoclave. The outcome was that in order to avoid silica scaling on the turbine blades, the steam inlet pressure had to be as high as 18 barg which is a real challenge for the turbine manufacturer. The two units have two separate steam supply systems partly interconnected on the well side. The steam supply system comprises two steam separators (18 barg), 1200 m long steam supply pipes, moisture separators and separator silencers (separate paper by Geir Þórólfsson). The steam and moisture separators have mist pads installed. The steam supply system is very effective and works well. Main problems encountered are: cracks found in the heat affected zone of some of the welds and material failures of the mist pads. The brine at 210 °C is mixed with condensate and 35 °C sea water from the condensers (the brine/condensate heavily diluted) and the fluid mixture conveyed in a concrete culvert to the sea. The sea water for cooling is pumped from wells drilled close to the coast, each well delivering 400 l/sec and more. The sea water (8 °C) filtered by the lava formation is free of animals and seaweed. Two extensive inspections of the steam supply system and bore scope inspections of the turbines indicate that the design principles fulfill expectations and the time between overhauls and cleaning of the turbines is at least 4 years. The turbines are designed for condensate washing under load and the condensers are fitted with pig cleaning systems. Today neither have the turbines been condensate washed nor the condensers pig cleaned. Main learning: 1000 m long insulated steam admission pipe makes the moisture separation effective, proper selection of the material of the mist pads is vital, in case the mist pads disintegrates the steam path has to be designed in such a way that parts of the pad do not enter the turbine. Due to the H_2S content of the steam and the high temperature, a steel with very low manganese (Mn) content has to be selected. The 35 °C pure sea water from the condensers is very well suited for all kind of aqua culture and today 3 year long operation of the power plant has been successful and the operation is commercially viable.



5. DISCUSSIONS

The total number of employees operating, maintaining and gathering valuable design and maintenance data at Svartsengi and Reykjanes are 23 out of which 12 are highly skilled marine engineers and mechanics and trained as seamen. There is one central control room located in Svatsengi from which the machine fleet is monitored and controlled. The power plants are secured by surveillance systems and are unmanned during night and weekends. A sophisticated proactive maintenance system supported by ingenious soft ware system has been developed. The above mentioned and easy accessible and maintenance friendly design principles results in moderate operating cost. Innovative thinking, entrepreneurial thinking, interdisciplinary cooperation of many and research and development are of vital importance in dealing with natural resources.

6. CONCLUSIONS

Three decade long successful operation of the Svartsengi power plant complex and 3 year long operation of the Reykjanes power plant has proved that geothermal resources and ground water resources are highly reliable resources and the geothermal steam is well suited for power production as well as industrial usage. The experience of HS Orka hf gained from green field harnessing of the geothermal resource in Svartsengi has revealed that harnessing in increasing steps is recommended. The experience gained from the field operation, reinjection included has revealed that bigger steps with acceptable risk can be taken as the data gathered and operational experience gained increases with time. The time between power plant extensions is around 3 to 5 years. Today a three decade long experience of field operation in Svartsengi has revealed that the production capacity of the geothermal field is much greater than expected in the beginning. Geothermal CHP operation has proved its viability and competitiveness. Geothermal power and hot water are competitive in price compared to other form of energy sources. Geothermal is green.