COMBINED GENERATION OF HEAT AND ELECTRICITY FROM A GEOTHERMAL BRINE AT SVARTSENGI IN S.W. ICELAND

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ABSTRACT

At Svartsengi in Iceland, a geothermal plant has been built to generate 50 MW_t (megawatt thermal) and 2 MW_e (megawatt electricity) for a district heating system. A 75 MW_t and a 6 MW_e addition will be completed in two years. What makes the plant at Svartsengi unique is that it makes better use of thermal energy than is normal for a high-temperature geothermal installation. It also differs from other district heating systems in Iceland because of its use of heat-exchangers to utilize the 240°C brine source. The heat is extracted by flashing the brine in two stages to 60°C and using the flash steam for heat and electricity generation.

INTRODUCTION

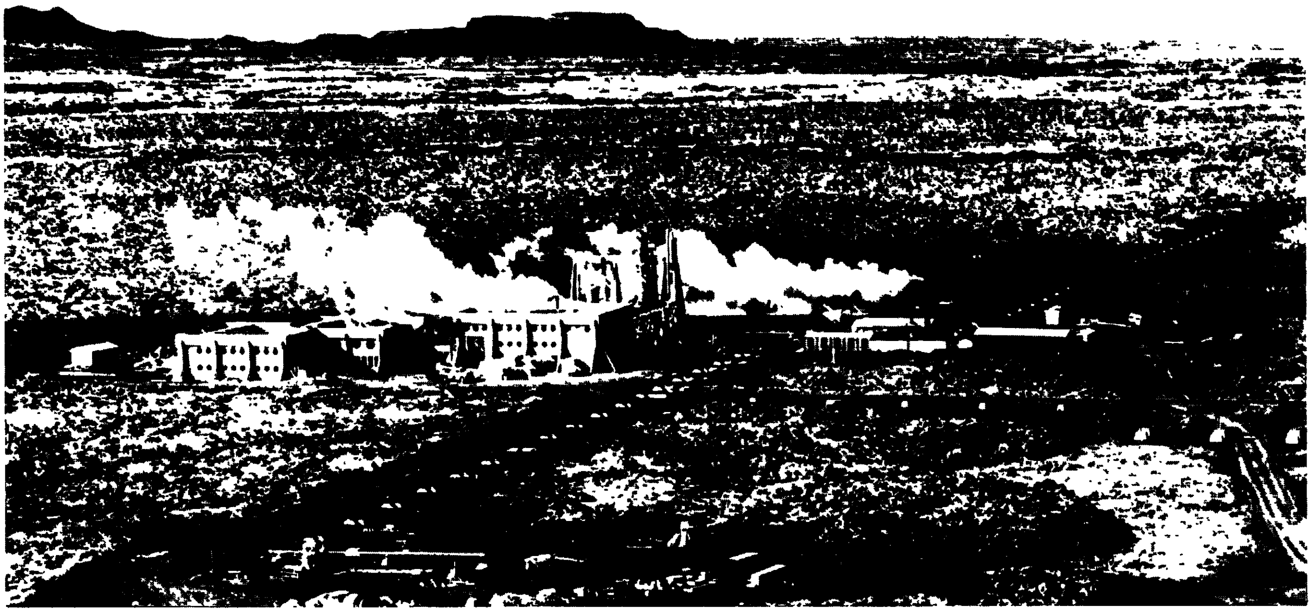
At present (1979) geothermal district heating systems in Iceland have a total nominal peak load of 600 MW_t and supply 2500 GWh of heat energy to 148,000 persons, or to 66 per cent of the population. The project described in this paper is one of many geothermal projects in Iceland that have been undertaken over the past few years for reducing the use of imported oil for space heating purposes. A joint district heating system for the six communities on the Reykjanes peninsula -Keflavik, Njardvik, Sandgerdi, Gerdar, Vogar, Grindavik- (overall pop. some 13,000) and the airport and NATO base at Keflavik (pop. some 7,000) was proposed after two successful wells had been drilled in 1971 at Svartsengi. Heat-exchangers had to be used and a pilot-plant study was carried out in 1974-1975 (ARNORSSON, et al. 1975). The municipalities of the area and the state of Iceland formed a corporation in 1975, The Sudurnes Regional Heating, and in December 1975 contracts were signed with the Icelandic consulting engineering firms Fjarhitun h.f. and Verkfraedistofa Gudmundar & Kristjans for design and supervision of works. The National Energy Authority has carried out, the exploration and drilling of the geothermal field and fresh water reservoir, the pilot-plant study and has since 1975 collaborated with the engineering firms.

DISTRICT HEATING

The peak nominal load for the six communities on Reykjanes is at present 38 MW_t. The total amount of energy supplied is 154 GWh per yr for the heating of 1.7×10^6 m^3 of space. In 1990 this is expected to increase to 60 MW_t and 242 GWh per yr. In addition to this, the airport facilities at Keflavik will be heated from Svartsengi in 1981 with a nom. peak load of 55 MW_t. Because the low population density of the six coastal communities and the long distances involved, it was decided to use a single-pipe distribution system but a two pipe system for the airport. The water is pumped to Grindavik at 85°C, but at 125°C to Keflavik where it will be mixed with 54°C return water from the airport. This arrangement reduces the fresh water requirements by about 50%. The hot water supply temp. to the consumer is 80°C in the communities and 94°C at the airport. Tap water requirements are met directly from the system, and this in part dictates the maximum temperature of 80°C. The spent water is discharged to the sewer system at 30-40°C. At present the connection charge (paid only once) for a typical 400 m^3 single family house is $1250, and the monthly hot water bill comes to $54.

PROCESS DESCRIPTION

The power plant at Svartsengi is designed for heating fresh water for a district heating system by using geothermal steam. The fresh water is pumped from shallow wells 4 km away from the plant. The fresh water aquifer is in porous surface lavas, where a fresh water lens of only 45 m is floating on sea water below (INGIMARSSON, et al. 1978). The Svartsengi geothermal site is a part of a high temperature area with a base temperature of 240°C and containing a brine whose salinity is roughly 2/3 that of sea water (KJARAN, et al. 1979). The chemical composition of the geothermal brine is shown in Table 1. Scaling of equipment is an operating problem because of the high silica content (600 ppm). High fouling rates of heat-exchanger surfaces dictated that only flash steam be used for the the heat-exchange process (GUDMUNDSSON, 1979). The pilot plant study demonstrated, moreover, that the flash steam could be used directly (ARNORSSON, et al. 1975) to heat the fresh water by injection. Subsequent tests showed that because of high CO_2 content, the deaeration was much easier to accomplish if the H.P. (high pressure) steam was condensed in a surface heat-exchanger, rather than being injected. The plant's flow diagram is shown on Fig. 1, and so is the flow rate and temperature for each flow stream.



Photograph of the geothermal powerplant at Svartsengi.

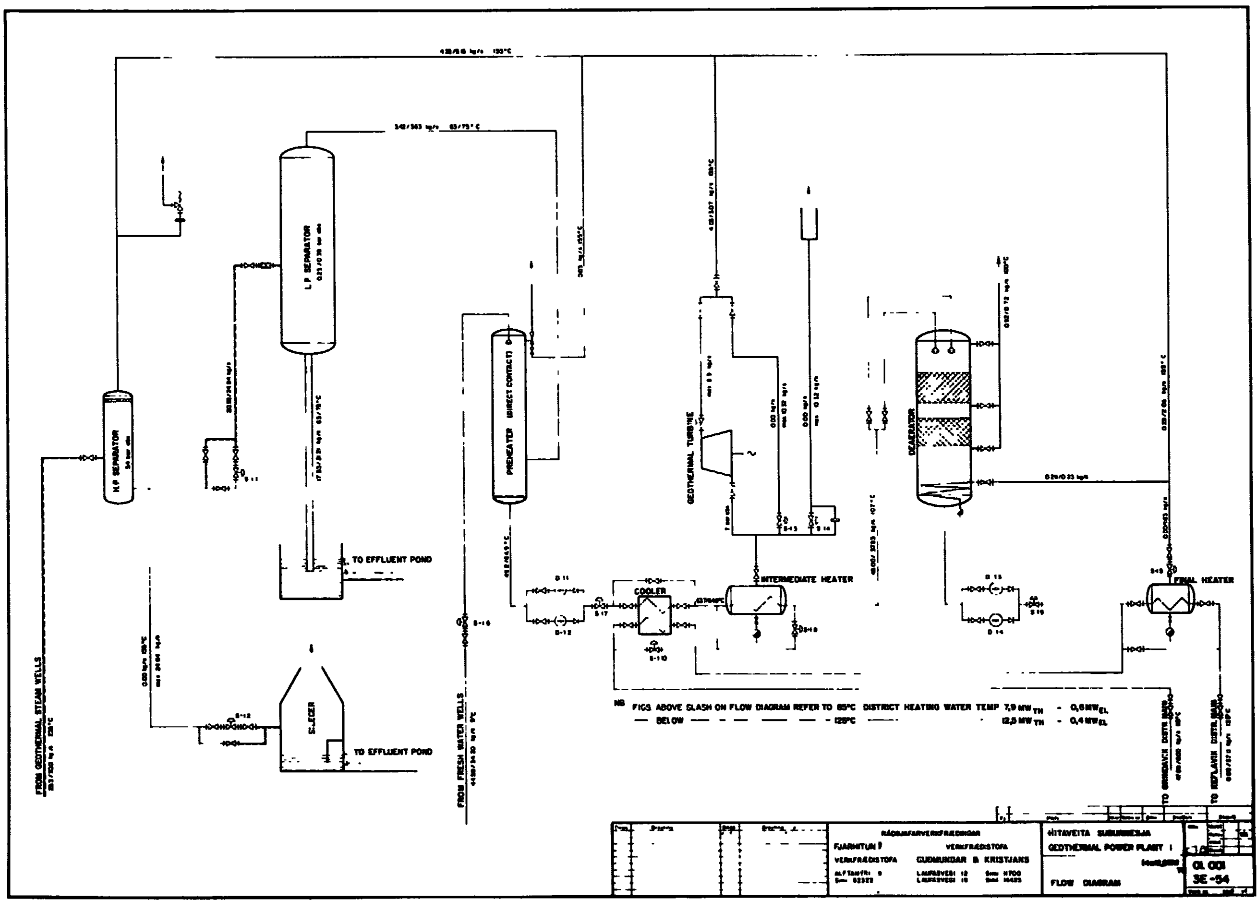


Fig. 1 Flow diagram of the geothermal powerplant at Svartsengi.

Table 1. Chemical composition of formation water at Svartsengi. Concentrations in mg/kg.

PROPERTY	WELL 3 (402 m deep)	WELL 4 (1670 m deep)
Date	19.04.78	18.04.78
Temperature (°C)	235	240
SiO_2	447	437
Na^+	6959	6837
K^+	1140	1060
Ca^{++}	1021	1036
Mg^{++}	0.74	1.08
SO_4^{--}	36.1	31.6
Cl^-	12440	12593
F^-	0.10	0.11
H_2S (total)	4.03	6.82
CO_2 (total)	183	360
TDS	22244	21400

Table 2. Composition of high-pressure and low-pressure flash steam from well H-4. Concentrations in mg/kg.

PROPERTY	H.P.	L.P.
Date	19.07.78	19.07.78
Pressure, bar, abs.	4.6	1.0
pH/°C	5.35/28	5.37/30
CO_2 (total)	2011	61.3
H_2S (total)	27.3	2.3
Carry over (brine)	50	

The decision to run the H.P. separator above the amorpous silica saturation temperature of 140°C, and to use thermal deaeration at atmospheric pressure, determines the temperatures and flow within the system. The flow is balanced to use all of the H.P. and L.P. steam generated, based on a reservoir temperature of 240°C. Each geothermal well is designed to produce 60 kg/s, an output which is split between two units as shown on Fig. 1, and the power plant consists of a total of four parallel units (4 x 12.5 MW_t). The geothermal fluid is piped in two-phase flow from the wells to a flash plant located by the power-house. Two centrifugal steam separators in series produce the H.P. (5.4 bar abs) and L.P. (0.25-0.39 bar abs) steam. The composition of the flash steam is shown in Table 2. Water level in the H.P. separator is controlled and the spent brine discharged from the barometric leg of the L.P. separator to surface disposal. The H.P. steam is used for generation of electricity in a back-pressure turbine before being condensed in a plate heat-exchanger. The L.P. steam is piped to a direct-contact condenser where it preheats the fresh water from 5°C to 65°C and removes 90% of the dissolved gases from the fresh water. This water is pumped to a second heat-exchanger (intercooler) and on to the turbine condenser mentioned above. There, the water is heated to 105°C before the atmospheric deaeration. At this point, the hot water is potable and is either cooled to 85°C in the intercooler for direct use in the town of Grindavik, or heated further by H.P. steam in a plate heat-exchanger to 125°C for pumping to Keflavik. The degree of instrumentation allows the plant at Svartsengi to be run by one operator per shift.

EQUIPMENT AND MATERIALS SELECTION

The equipment for the plant is mostly of standard manufacture, selected with the service conditions in mind. The flash plant and deaerating equipment is specially designed. Mild steel is used for the geothermal brine, steam pipes and equipment. Stainless steel and reinforced epoxy pipes are used for the heated fresh water before deaeration and for the steam condensate. The plate heat-exchangers are from titanium and stainless steel. Degradation of materials has not been noted except for corrosion of mild steel from the H.P. condensate, and cracking of the epoxy pipes. Scaling in the H.P. separator (water phase) has been 0-2 mm per year, and 1-3 mm per year in the L.P. separator. Silica scaling from stagnant water in pipe branches is a problem at present, which requires design modifications.

ELECTRICITY GENERATION

Co-generation of electricity and heat is common in district heating plants burning fossil fuels. A plant of that type might generate 0.5 MW_e per MW_t. At Svartsengi, the electricity produced is only 0.03 MW_e per MW_t (BJÖRNSSON, 1978), but if all available steam were to be used for electricity production only, the output would be appr. 7 MW_e, compared to the present output of 1.2 MW_e and 50 MW_t. The turbines selected (2 x 1 MW) are conventional double row Curtis type with few modifications made for the geothermal service (steam rate 32 kg/kWh). Operating experience has been satisfactory, except for corrosion in the labyrinth seal and of the governor valve spindle in the gland.

CHANGES IN DESIGN

The plant has been run for one and a half year, and in this period operating problems have been few. The deep wells (H-4, H-5) 1500-1700 m have to be cleaned of calcite deposits in the 9 5/8" casing at a depth of 350-400 m (ARNORSSON, 1978). However a shallow well (H-3) which is only 400 m deep, has been operated for two years without signs of plugging, because boiling takes place outside the well in the reservoir. The wells to be drilled for the future extensions will be provided with a 13 3/8" casing to allow for more area for scaling. The second power plant scheduled for completion in 1981, a different arrangement of L.P. separator, preheater and deaerator has been selected. Successful tests were carried out in a unit where these three pieces of equipment were combined in one column. The L.P. steam goes to a heater/deaerator which is operated under vacuum, and the water heated further in a plate heat-exchanger using back-pressure steam from the turbine and H.P. steam. At present the geothermal brine is being discharged to a pond where a silica sludge is deposited, and the water percolates into the surface lavas. Eventually, reinjection will be tested, but different alternatives are now under study. One interesting aspect of that study is the possibility of producing silica of high purity. The commercial value and methods of recovery are now being evaluated.

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