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POWER PLANT PROCESS AT NESJAVELLIR BASED ON EXPERIMENTAL TESTS

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ABSTRACT

This paper describes the result of experimental tests for geothermal heat exchangers and wellhead control valves at the Nesjavellir geothermal field. The power plant started in 1990 by heating of cold potable groundwater with steam to use in district heating in Reykjavík. In 1998 the plant became a combined heat and power (CHP) plant generating 60 MW of electricity. The heat exchange process was modified and geothermal brine was used to heat potable groundwater. Prior to exploitation a pilot plant was operated in the period 1974-1990, supplied with geo-fluid from one of the wells. The purpose of the pilot plant was to explore and perform tests of the processes planned in the power plant. One of the tests was to use geothermal brine in the heat exchanger. These tests were mainly performed in the period 1985-1988 and later 1990-1996 on small-scale in the power plant. Test with geo-fluid heat exchangers was performed in the period 1997-1998. Long-run tests with utilization of geo-fluids and brine in conventional shell and tube heat exchangers indicate reduction of the heat transfer coefficient (k-value) in just a small degree. These results were important and valuable. Tests with wellhead control valves were performed in the period 1994-1998. The tests verified that both the geothermal brine heat exchanger and the wellhead control valves were able to operate sufficiently in the power plant process. At present, heat exchangers using separated geothermal brine are in full-scale operation and are one of the key elements in the utilization of high temperature geothermal fields for district heating. Control valves are in operation at the wellhead of every production well at Nesjavellir with considerable improvements of the plant efficiency. The geo-fluid heat exchangers are now used as reserve district heating for Nesjavellir area.

1. INTRUCTION

The thermal plant at the high-temperature geothermal field at Nesjavellir, SW Iceland, has been in operation since 1990. In the first stage steam was used in a heat exchanger to heat potable groundwater. In 1998 the plant became a CHP plant generating 60 MW electricity. The heat exchange process was modified and geothermal brine was used for the final heating of potable groundwater. The goal of the tests and piloting at Nesjavellir has been to design and build an effective and reliable CHP process. A pilot plant was operated at Nesjavellir in 1974-1990 to test equipment and processes both with regard to generation of electricity and heating of potable groundwater for district heating purposes. One of the key factors for good efficiency is utilization of the geothermal brine. Because of relatively high content of dissolved solids it was believed that conventional heat exchangers couldn't be used in the process. For this reason self-cleaning heat exchangers, so-called "fluidized bed heat exchangers" FBHX were tested. These heat exchangers were mainly tested in the pilot plant in the period 1985-1988. To obtain more operational experience, the same type of heat exchanger was installed in the power plant. In 1992-1996 these heat exchangers were modified and tested as conventional heat exchangers and polymerization test on the geothermal brine were performed. From the start of the power plant to the present the geothermal brine has constantly increased with corresponding decrease in enthalpy. Most of the brine was disposed of in nearby creek. At the start of the power plant in 1990 only a small quantity of brine was available. Only few years after start up the available brine reached 100 kg/s. At the same time an almost constant quantity of steam from the production wells was used to produce 400-800 kg/s of hot water for district heating, depending on seasonal variation of the demand. The excess steam was wasted through exhaust in quantity of 5-40 kg/s (5-40 %). At this time, interest increased for full-scale utilization of geothermal brine and better flow control from the production wells. Tests of different types of wellhead control valves and study of heat exchanger processes for full-scale utilization of the geothermal brine were commenced.

2. GEOTHERMAL HEAT EXCHANGER TESTS

Utilization of geothermal brine was one of the key factors in the planned power plant process. Relatively high content of dissolved solids (TDS 1200 mg/kg) in the brine can cause scaling of heat exchangers. Therefore tests were performed to find the most suitable process to utilize the brine. Typical chemical composition of the geo-fluid is given in Table 1.

2.1 Fluidized bed heat exchangers - FBHX

Tests with two self-cleaning heat exchanger or so-called "fluidset bed heat exchangers" (FBHX) was first performed in the pilot plant and continued later in the power plant. These FBHX were made by Sceffers-Eskla BV in the Netherlands. The FBHX are shell and tube heat exchangers, made of 316 stainless steel, operating in vertical position and connected in series. Stainless steel balls, 1.5 mm in diameter, circulate in the stream of the brine. They impact continuously against the pipe surfaces and remove any scaling that may form. A mechanical device fitted in inlet and outlet of the heat exchangers keeps the steel ball evenly distributed in the flow stream. To keep the ball in circulation, the flow must be relative constant.

2.2 FBHX tests in pilot plant 1985-1988

The FBHX were operated mainly with the self-cleaning balls throughout the period. Comparison test were made for the last three-month when the FBHX were operated without any self-cleaning balls, as conventional heat exchangers. The heat transfer coefficient or K-value was registered and inspection of the tubes was performed and reported several times. The main parameters are given in Figure 1. The main results were:

- No considerable reduction in K-value appeared in the period and the pipe wall was clean when inspection was performed.
- The operation of the FBHX is much more difficult than conventional shell and tube heat exchanger.

• Reduction in K-value for the operation without self-cleaning balls was much slower than expect but the running period was to short to obtain more reliable result.

2.3 FBHX tests in power plant 1990-1996

These heat exchangers were identical to the FBHX in the pilot plant, but larger in size. The main purpose with the installation was to obtain operational experience. The main operation parameters are given in Figure 2. K-value was registered and inspections of the heat exchanger were performed and reported periodically. Silica polymerization tests were performed several times, normally indicating no silica polymerization. The tests are divided into three main test periods:

1. FBHX 1 and 2, operated with self-cleaning balls, 1990-1992: Some reduction in K-value occurs. Inspection shows that part of the distribution device was clogged but pipe walls were clean. Few operation failures occurred in the period.
2. FBHX 1, operated with self-cleaning balls and FBHX 2 without self-cleaning balls, 1992-1994: Based on the results of the operation of the last three months in the pilot plant it was decided to operate FBHX 2 as conventional heat exchanger, simply by removing the fluid bed balls. FBHX 2 operated at higher temperature than FBHX 1 and therefore it was believed that scaling was less likely to occur. Reduction in K-value was in a small degree and a difference between FBHX 1 and 2 could not be seen. Inspection shown clean surfaces on FBHX 1, but a small amount scaling on FBHX 2.
3. FBHX 1 and 2, operated without self-cleaning balls 1994-1996: Reduction in K-value was in a small degree and a difference between FBHX 1 and 2 could not be seen. Inspection indicated small amount of scales on both FBHX. Results of the last six months are given in Figure 4.

2.4 Chemical tests in 1994-1995

In 1994 a silica precipitation tests were made by chemical engineers from New Zealand. The knowledge of the polymerization of silica in the brine of Nesjavellir increased. In 1995 a study was performed on the rate of silica polymerization in turbulent flow at difference temperatures and different mixtures with condensed steam. The main result were as follows:

• If the dwelling time of the brine in the heat exchanger is short, polymerization will just occur in very small degree.

• The time factor is longer for low temperatures (30-100°C) than for high temperatures (100-160°C). It means less risk of scaling inside the heat exchanger tubes at lower temperatures compared to higher temperatures. The amorphous silica saturation is reached in the brine at Nesjavellir at about 180°C

• The impact of injection of condensate steam in the brine was reduction in the rate of polymerization and corresponding decreasing in risk of scaling.

2.5 Geo-fluid heat exchanger tests, 1997-1998

Based on the test result above the following question was asked: Is it possible to use unseparated two-phase geo-fluid directly to heat potable groundwater? To answer this question a small conventional shell and tube heat exchangers was connected to one of the production wells and tested in the period 1997-1998. The test was more successful than expected. The process was very stable and reduction in K-value was insignificant. Flow parameters and K-values are given in Figure 5. Inspection of equipment showed clean tubes, except for small areas around the inlet where some scaling occurred. Silica polymerization tests on a mixture of condensate steam and brine showed no polymerization. As a consequence of these tests, an additional heat exchanger of the same type was installed to obtain sufficient capacity for the use of local district heating. This process was used continuously during six-months without any problems. It will also be used as reserve district heating for Nesjavellir area in the future. The main parameters are given in Figure 3.

2.6 Full-scale heat exchanger operation in the power plant

Operation with full-scale heat exchangers commenced in December 1997. Two conventional shell and tube heat exchangers made of 316 stainless steel were installed. Geothermal brine inside the tubes heats the potable groundwater on the shell side. The capacity was increased in October 1998 by installing two identical, parallel-connected shell and tube heat exchangers. All these heat exchangers have been in operation since without any problems. The design aimed to keep the dwelling time of the geothermal brine within certain time limit in the heat exchanger process. Flow diagram of the present process is shown in Figure 8.

3. CONTROL VALVES ON WELLHEADS OF THE PRODUCTION WELLS

More or less constant flow of steam has been used to heat 400-800 kg/s of water for district heating. The variable hot water production depends on seasonal variation in demand by the district heating utility. The excess steam has been wasted through exhaust in quantity of 5-40 kg/s (5-40 %). In order to increase the efficiency tests to use control valve instead of throttle plate at the wellhead of production well were performed in 1995. Prior to the tests the two-phase flow was measured with a series of throttle plates at different sizes.

3.1 Test with wellhead throttle plates

When construction of the power plant started in 1987, twelve production wells were available. Soon after drilling the two-phase flow of the wells was measured with throttle plates in order to define the capacity curves of the wells, wellhead pressure as function of total flow. The wells could be divided in two main groups, five high enthalpy wells (2200-2400 kJ/kg) with flat flow-pressure characteristic and seven low enthalpy wells (1200-1400 kJ/kg) with curved flow-pressure characteristic. Wells with curved characteristic are more suitable to control with throttle than those with flat characteristic. In 1994, two of these five high enthalpy wells were operated with different sizes of throttle plates at the wellhead. From 1987 the enthalpy from these wells has been decreasing and is now 1500-1800 kJ/kg. Lower enthalpy resulted in more curved pressure-flow characteristics of the wells hence better throttling control ability. The change in flow for well NJ-11 for the period is shown in Figure 6.

3.2 Test with wellhead control valves 1995-1997

In order to increase the efficiency, tests with control valves instead of throttle plates started in 1995. Control valves with high pressure- and temperature rating were selected, as they were believed to be resistant to erosion in the scaling environments. In the period 1995-1997, three different types of valves were tested. The working conditions were as follows: Inlet pressures 20-40 barg, outlet pressures 14 barg. The inlet and outlet pressure was registered and inspection was performed and reported for each test period. The result indicated that all of the three types of valves tested were well suited for throttling the two-phase flow.

3.3 Installation of wellhead control valves 1998

In 1998 valves were installed on the remaining wells (8 of 10). The valves were of a rotating plug type and clamped between flanges. The selection was based on low cost, low weight, small dimension and resistance against erosion and chemical deposits, and also suitable control characteristics. Total production capacity of the nine production wells now connected to the power plant is at present around 380 kg/s at 1550 kJ/kg (well NJ-15 closed 1999). Total consumption of the power plant of geothermal fluid is estimated to be 280-350 kg/s, depending on seasonal variation of the demand. At present there is only small amount of excessive steam (1-3 %) available, which is clear evidence that the valves at the wellheads have increased the efficiency of the power plant. Maximum flows from production wells are given in Table 2 and regulated flow in Table 3. Installation of these valves is shown in Figure 7.

4. CONCLUSION

- Geothermal brine heat exchanger: It vas verified in long-run tests, that reduction in the heat transfer was in a small degree, both regarding to self-cleaning heat exchangers (FBHX) and the conventional shell and tube heat exchangers. Selection criteria were made for feasible geothermal brine heat exchanger processes. It was decided to use conventional shell and tube heat exchangers instead of earlier tested FBHX. This selection was based on lower cost and wider ranges in flow compared to FBHX. Requirement for minimum intervals between cleaning of the heat exchangers or not more frequent than yearly seems also to be fulfilled.
- Wellhead control valves: In the present process, installation of the valves, results in estimated 10-80 kg/s less mass extraction of the reservoir, without reduce the outputs of the power plant. The tests were more promising than expected. The impact of the two-phase flow on the valves could not be seen. The explanation can be the relatively high pressure of the steam gathering system (11-14 barg). This pressure is above the amorphous silica saturation of the fluid reducing the risk of scaling in the valves. Higher pressure means also lower flowrate trough the valves relative to the flow rate of the gathering system operating at lower pressure. Lower flowrate means also reduced risk of wear and erosion of valves.
- Similar results may be obtained in other high-temperature fields based on high content of dissolved solid. Due to different chemical compositions and characteristic of the well fluids working condition and material choices of the component in the process etc. special experimental tests have to be carried out in each field.

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Table 1. Chemical composition of fluids to power plant at 14 barg, 200 °C.

Steam	ppm	Brine	ppm
CO2	2000 - 2500	ph/°C	7.5 - 8.0/25
H2S	500 - 1500	SiO2	700 - 1000
H2	70 - 170	Na	80 - 130
O2	0 - 5	K	20 - 30
CH4	2 - 10	Ca	0.3 - 1.0
N2	50 - 120	Mg	0 - 0.1
		SO4	10 - 50
		Cl	2 - 100
		H2S	50 - 100
		CO2	20 - 40

Total dissolved solids (TDS): 1000 - 2000 ppm

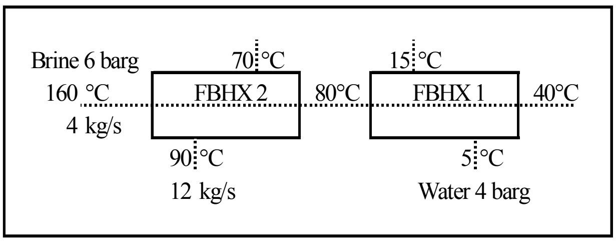

Figure 1. Typical parameters for heat exchanger tests in the pilot plant.

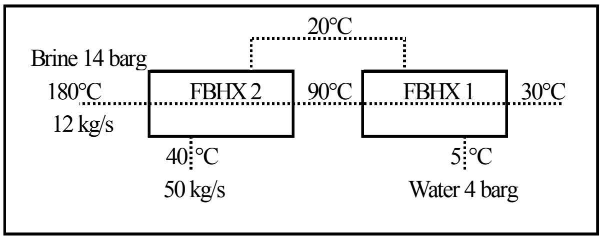

Figure 2. Typical parameters for heat exchanger tests in the power plant.

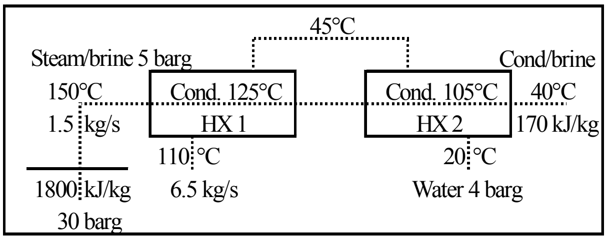

Figure 3. Heat exchanger tests with two-phase geo-fluid.

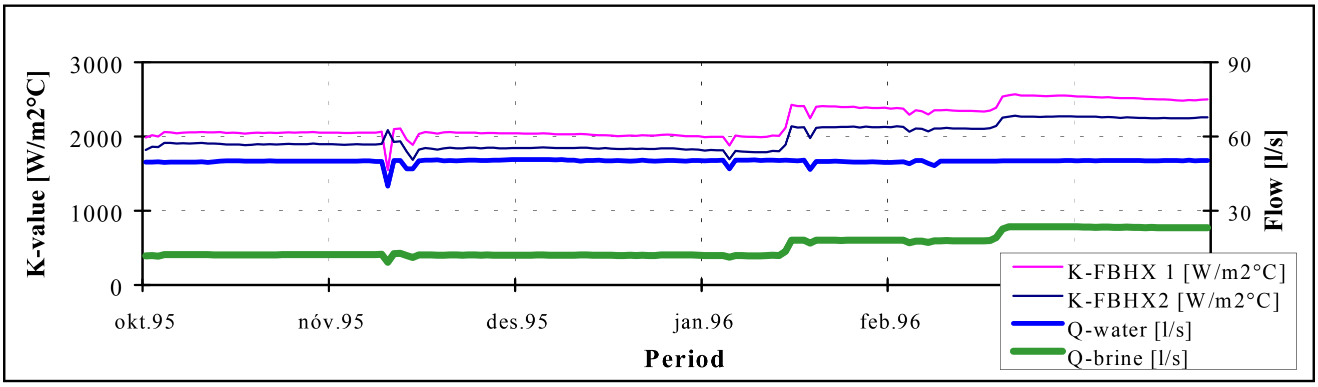

Figure 4. Registration of last 6 month test in the power plant.

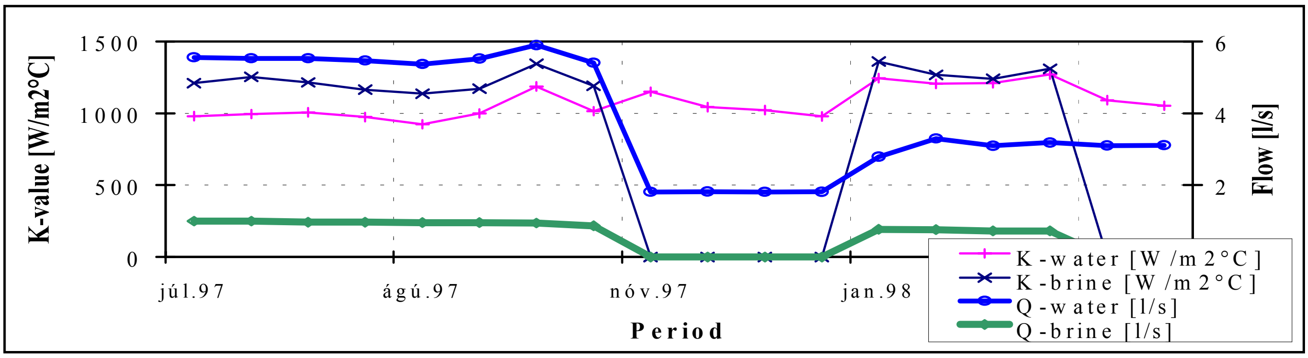

Figure 5. Registration of K-value and flow for the two-phase geo-fluid.

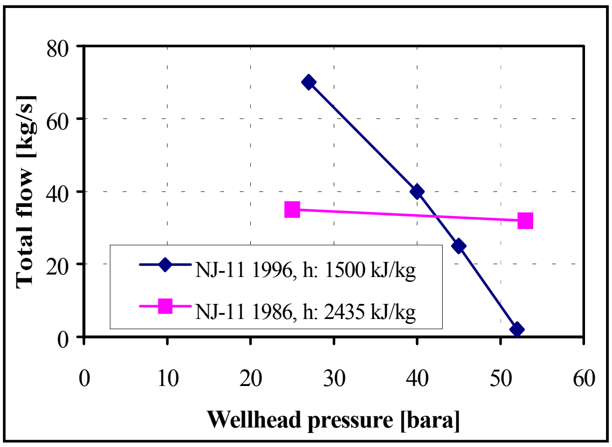

Figure 6. Change in flow characteristic for well NJ-11.

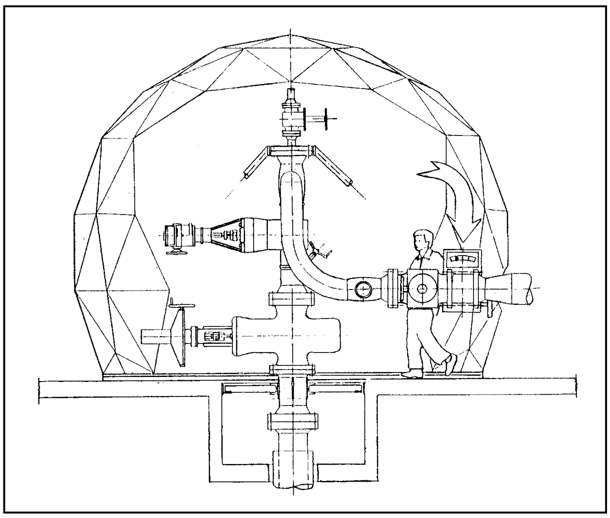

Figure 7. Typical installation of wellhead control valve.

Table 2. Maximum flow from production wells.

Well [NR.]	Control valve pos [%]	Total flow [kg/s]	Steam [kg/s]	Brine [kg/s]	Enthalpy [kJ/kg]
NG-5	40	15	8	8	1800
NG-6	75	43	22	20	1800
NG-7	50	30	8	22	1300
NG-9	55	40	18	22	1700
NG-10	75	47	10	38	1200
NJ-11	85	54	24	29	1700
NJ-13	60	60	24	36	1600
NJ-14	75	58	18	40	1400
NJ-15	0	0	0	0	1300
NJ-16	55	28	13	15	1700
Total:		**375**	**145**	**230**	**1560**

Table 3. Regulated flow to power plant for 60 MWe.

Well [NR.]	Control valve pos [%]	Total flow [kg/s]	Steam [kg/s]	Brine [kg/s]	Enthalpy [kJ/kg]
NG-5	40	16	8	8	1800
NG-6	70	42	21	20	1800
NG-7	30	19	5	14	1300
NG-9	50	38	17	21	1700
NG-10	40	27	6	21	1200
NJ-11	50	31	14	17	1700
NJ-13	40	50	20	30	1600
NJ-14	40	45	14	31	1400
NJ-15	0	0	0	0	1300
NJ-16	50	27	12	15	1700
Total:		**295**	**116**	**178**	**1590**

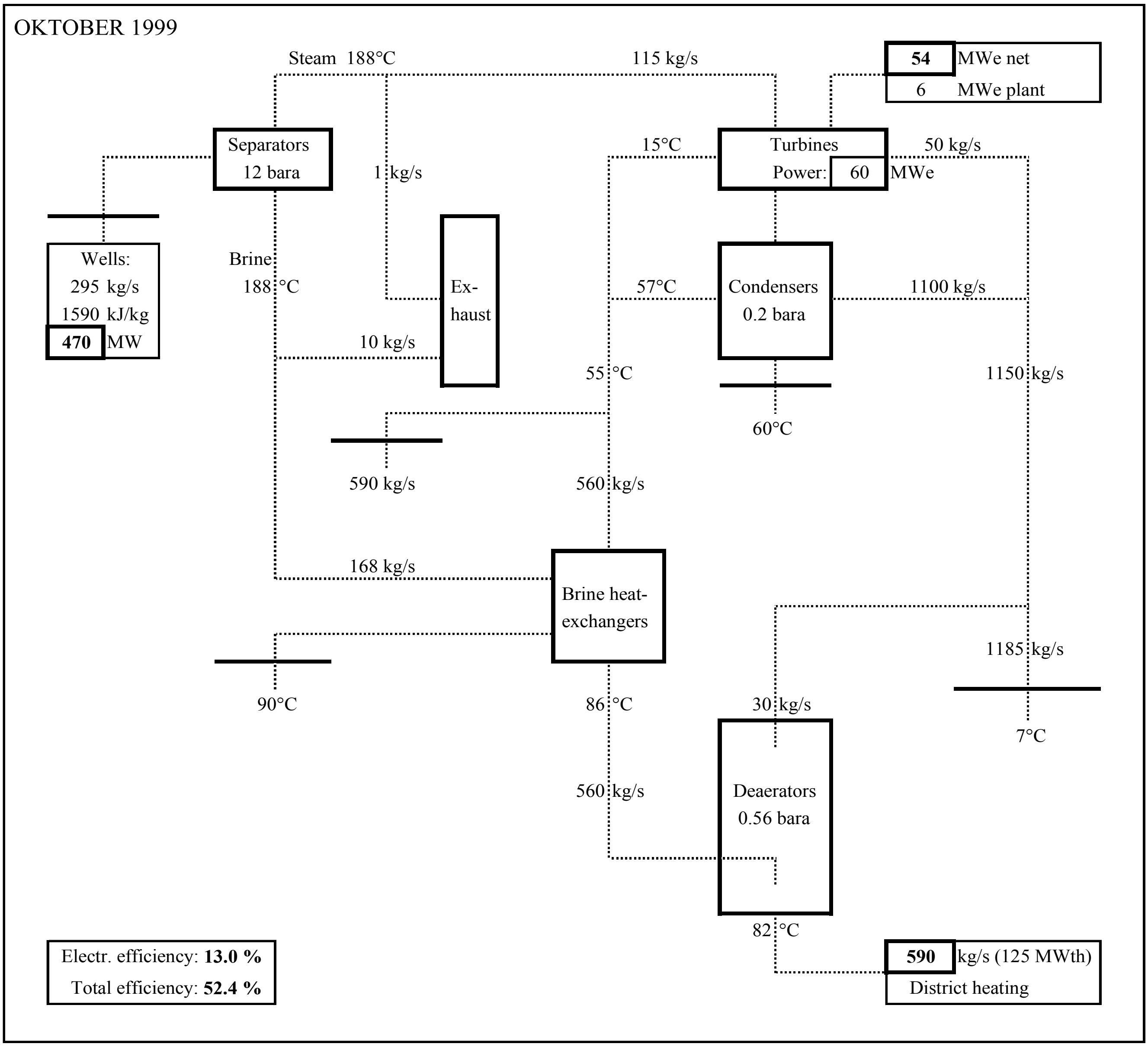

Figure 8. Flow diagram for the Nesjavellir power plant.