Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Analysis of the Combined Heat and Power Plant Neustadt-Glewe

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Keywords: CHP, ORC, thermodynamic optimization, operational data

ABSTRACT

The first geothermal power plant in Germany is an extension of an existing heating plant. It was connected to the mains in November 2003. Since May 2004 the plant is in stable operation. However, the plant works permanently at part load since neither the temperature nor the available mass flow rate reach the design values.

The plant provides data to analyze a low temperature organic Rankine cycle (brine temperature is below 100 °C). A first check-up shows that despite part load the tuning of the process itself has turned out well. Remaining uncertainties concerning the specific heat capacity of the brine as well as the flow conditions in the geothermal loop prevent proper assessment of overall plant performance for the time being. These uncertainties will be cleared up by further measurements as well as by accompanying numerical modeling of the plant in the future.

1. INTRODUCTION

Neustadt-Glewe is situated in the north German basin, between the cities of Berlin and Hamburg (see Figure 1).

Since 1995 the geothermal doublet in Neustadt-Glewe provides brine at 98 °C for a district heating system. The brine is produced from a 2100 to 2300 m deep sandstone aquifer. High salt contents of the brine (Total Dissolved Solids TDS 227 g/l) require the use of resistant materials, e.g. titanium for the heat exchanging equipment. Menzel et al. (2000) gave a short description of the heating plant and reported on the experiences made during the first 5 years of operation. A more detailed report on the geothermal resource and the heating plant can be found in (Schallenberg et al., 1999).

In summer 2003 the heating plant was extended by a binary cycle (Organic Rankine Cycle, ORC) and in November 2003 the first German geothermal power plant was connected to the grid, providing 210 kW gross capacity (performance guarantee, according to ErdwärmeKraft (2003)). GFZ installed a measuring scheme to supervise the plant performance and to get operational data of the very low temperature ORC.

Figure 1: Location of Neustadt-Glewe.

3. PLANT SET UP

The Neustadt-Glewe plant supplies heat and power using a parallel-series connection of power plant and heating station (see Figure 2). The heating station takes priority over the power plant. The incoming mass flow rate of the brine is split and a part is fed to the power plant. The brine leaves the power plant at constant outlet temperature. The two flows, one at initial brine inlet temperature, the other at outlet temperature of the power plant, are joined upstream the heating station. The mixing temperature should be high enough to meet the heating demand. In summertime a minimum temperature of 73 °C is required. To meet the heating demand in wintertime higher temperatures are necessary, amounting up to the initial brine temperature (98 °C).

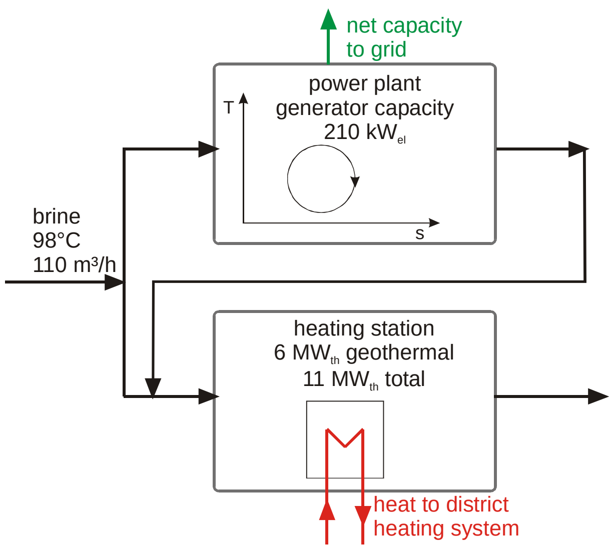

Figure 2: Combined heat and power supply in Neustadt-Glewe, parallel connection of power plant and heating station.

Unlike common combined heat and power plants with combustion or the plant set-up realized with the Husavik plant (Hjartarson et al., 2003), heating station and power plant are competing for the brine. The power plant is fed with variable mass flow rate of the brine at constant temperature, while the heating station is provided with a constant mass flow rate at variable temperature.

The power plant is a simple organic Rankine cycle (ORC) using n-Perfluorpentane (C_5F_{12},) as working fluid. An additional pump was installed in the geothermal loop to control the mass flow rate fed to the power plant and to overcome the pressure losses of the brine in the heat exchanging equipment of the power plant. Parasitic loads in the plant include all pumps (brine pump, feed pump 10 kW, cooling water pump in cooling circuit, 15 kW), the ventilators in the cooling tower (16 kW), the cooling water pump in the well and several dosing pumps in the make up-system for the cooling water. Only the down hole pump in the production well is not included n the parasitic loads. The generator capacity and the parasitic loads are recorded as well. However, the parasitic loads are only measured as total sum. Data sets are registered in constant 10-minute intervals.

The set-up of the plant is shown schematically in Figure 3. The figure includes the positions of the measuring equipment installed by GFZ. In total 3 pressure values, 7 temperature values and three flow meters allow to set up the complete energy balance of the plant as well as analysis of single components, e.g. the turbine. The outside temperature is recorded as well.

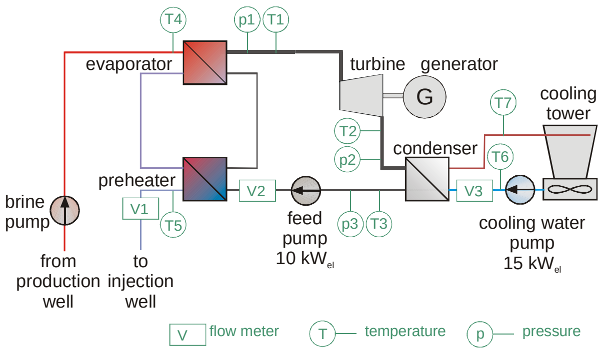

Figure 3: Schematic set-up of Neustadt-Glewe power plant with positions of measuring equipment installed in the plant.

Figure 4 illustrates the process in a temperature-entropy diagram. The working fluid is preheated and evaporated (3→1) at high pressure. It expands in the turbine (1→2), where work is extracted from the process. Afterwards desuperheating and condensation take place at low pressure in the condenser (2→3). To close the cycle the feed pump lifts the pressure back to the evaporation pressure. Since the temperature increase due to pumping is very small this process is not visible Figure 4.

The plant was connected to the grid November 12, 2003 but due to necessary improvements after start-up regular operation did not start until April 2004. This was harmless, since in wintertime almost all the heat supplied by the well is used in the district heating system. Full load operation is not expected until the end of the heating period (end of May). However, we got data sets of the plant for the period April 1st through May 16th, sufficient for a first check-up, which we will present in the following. The first day with complete data-sets, that is 24 h operation as planned, was May 6th 2004.

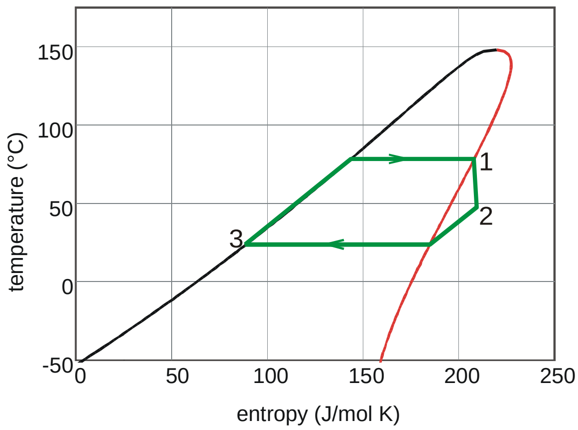

Figure 4: Temperature-entropy diagram of working fluid (PF5050) with sketch of the process (derived from measured data).

4. PLANT PERFORMANCE

The only time for the plant to work close to design conditions was a short interval on May 8th. Even then the volume flow rate of the brine fed to the plant was not more than 97 m³/h and the temperature of the brine was as low as 95.7 °C.

Since May 10th the plant is in stable operation. Figure 5 presents volume flow rate and temperature of the brine, generator capacity and outside temperature all measured on a fine day in spring (May 16th). The brine temperature does not exceed 95.6 °C (design value 98 °C), neither does the volume flow rate of the brine reach the design value of 110 m³/h. Moreover, the volume flow rate of the brine oscillates around 70 m³/h (mean value is 71 m³/h, minimum 57 m³/h, maximum 85 m³/h).

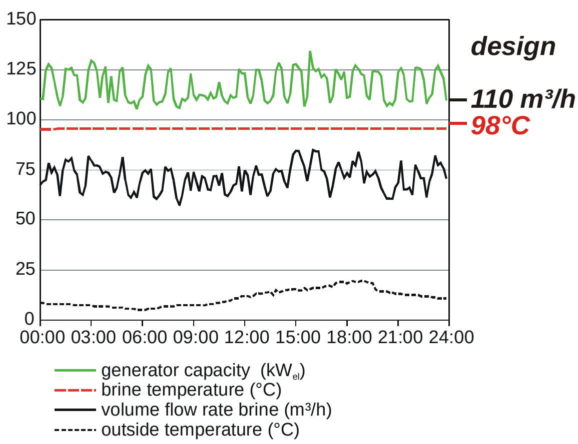

Figure 5: Performance of Neustadt-Glewe power plant May 16th 2004.

Since the measuring scheme does not include the heat delivered to the district heating system, we can only speculate whether the insufficient heat input in the power plant results from heat demand in the district heating system (although outside temperature goes up to almost 20 °C, indicating that heat demand should be low) or from insufficient hydraulic adjustment in the geothermal loop or from other effects in the geothermal loop, e.g. degassing processes in the brine. In the considered time scale we found no correlation between outside temperature and volume flow rate of the brine available for the power plant. A satisfactory explanation for the oscillation of the brine flow rate is not found yet.

The heat added in the preheater and evaporator and the heat rejected in the condenser is calculated using equation (1).

$$\dot{Q} = \dot{V} \cdot c \cdot (T_{in} - T_{out}) \qquad (1)$$

where $\dot{Q}$, $\dot{V}$, c, T_{in}, T_{out}, are heat capacity (kW_{th}), volume flow rate of heating/cooling fluid (m^3/s), specific heat capacity of the fluid (kJ/m^3 K), temperature of stream entering the plant (°C) and temperature of stream leaving the plant (°C), respectively. The specific heat capacity of the brine and the cooling water are assumed 3750 kJ/m^3 K (Broßmann, 2004) and 4180 kJ/m^3 K (VDI, 2002), respectively.

The load balance of the power plant becomes:

$$\dot{Q}_{in} - \dot{Q}_{out} - (P_{net} + P_{par}) - \dot{Q}_{loss} = 0 \qquad (2)$$

where $\dot{Q}_{in}$, $\dot{Q}_{out}$, P_{net}, P_{par}, $\dot{Q}_{loss}$ are added and rejected heat, net capacity, parasitic loads and other losses, respectively. Adding up the measured values over 24 h, one gets the energy balance for one day. The energy balance for May 16^{th} is presented in Figure 6. 6.4 % of the total added heat is transformed to electrical energy (measured at generator clamps), of which 1.3 % are used directly in the plant to drive the pumps and ventilators (parasitic loads) and 5.1 % are fed into the mains. Other losses in the plant and uncertainties account for about 10 % of the added heat.

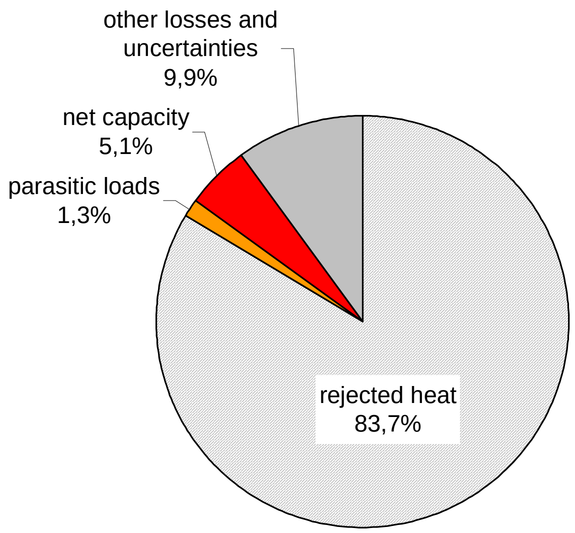

Figure 6: Energy balance of the Neustadt-Glewe power plant, May 16^{th} 2004. Total added heat was 44.3 MWh_{th}.

Other losses could be losses in the turbine and generator or heat losses due to insufficient insulation. However, heat losses over 150 kW_{th} would heat up the surrounding of the plant significantly. Since no remarkable temperature increase in the plant building was observed, the uneven energy balance must have other reasons.

Due to lack of data the heat input is calculated by using a single data point for the specific heat capacity of the brine. Moreover, the brine suffers from high gas content and degassing processes are happening in the geothermal loop, reducing the actual density of the fluid and consequently the specific heat capacity. The reduced density is not taken into account yet. These uncertainties will be reduced by better measurements of brine properties, which are currently under way. In addition a check of the geothermal loop will show where degassing happens and how it could be avoided.

5. TUNING OF THE PROCESS

In the following we will analyze the operational data recorded May 16^{th}. The saturation curve of Perfluorpentane with the states of the working fluid at the point 1 (turbine entry), 2 (turbine exit) and 3 (condenser exit) in the cycle is shown in Figure 7. The fluid at the turbine entry is mostly at saturated conditions. The steam at the turbine exit is about 20 K superheated. The liquid at the condenser exit is saturated. We see no unnecessary superheating or subcooling in the whole cycle. This indicates good tuning of mass flow rates and flow rate ratios in the process.

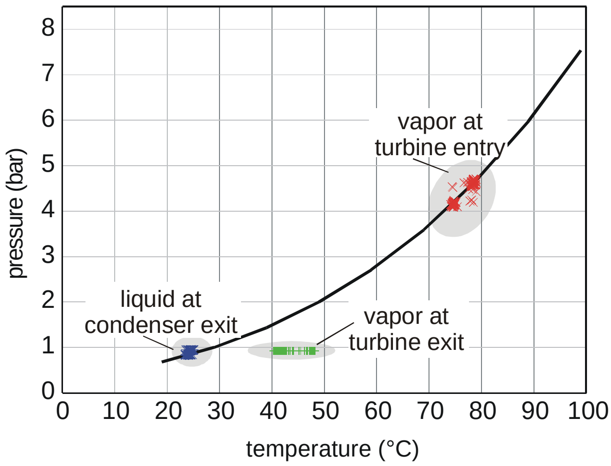

Figure 7: Saturation curve of Perfluorpentane (data provided by 3M Deutschland GmbH (2003)) with measured data at turbine entry, turbine exit and condenser exit.

6. CONCLUSIONS AND OUTLOOK

The Neustadt-Glewe plant is still in the adjustment and tuning process. Due the combined heat and power supply, the power plant suffered from non-constant heat input. The available data proves that the plant is running. However, for more detailed statements concerning the plant performance a longer period of observation (at least one summer season of undisturbed operation, including periods of full load operation) is needed. The specific heat capacity of the brine needs to be measured to allow more precise calculation of heat input in the plant and therefore system performance.

Proper analysis and assessment of the plant requires accompanying numerical simulations. The models are currently prepared. Cross-checks of the numerical results with the operational data will allow adjustment and validation of the models. After validation the models will serve to identify of points of superior performance of the combined heat and power plant as well as optimization potentials regarding the plant management. Moreover, characteristics of the machinery e.g. isentropic efficiency of the turbine, derived by analyzing the operational data, will be valuable information for future plant modeling and design.

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