Exergy Analysis of Double Flash Geothermal Power Plant, SABALAN, IRAN

Saeid Jalilinasrabady*, Gudrun Saevarsdottir* and Pall Valdimarsson**

* Department of Mechanical Engineering, University of Iceland,
Hjardarhagi 2-6, 107 Reykjavik, Iceland: jalilina@yahoo.com, gudrunsa@hi.is
** University of Iceland / Enex ehf., Skúlagata 19, 101 Reykjavík, Iceland; pallv@hi.is

ABSTRACT

The Mt Sabalan geothermal field in NW of Iran is currently under development. A double flash cycle has been selected for power generation. The obtained results show that the maximum power output from the plant can be 54 MWe with pressures equal to 5.5, 0.9 and 0.1 bar for high and low pressure steps and condenser, respectively. Mathematical models for energy and exergy flows were developed and implemented in the Engineering Equation Solver (EES) software. A few assumptions and simplifications were made. The energy and exergy rates of the waste brine have been calculated as 18.7% and 15.8% of the total available energy and exergy rates, respectively. The separated brine can be used as a heat source for a district heating system or some other forms of direct use. Reinjection should also be taken into account. The parts of the system with largest exergy destruction are the condenser, the low pressure turbine, the low pressure separator and the disposed waste brine. The overall exergy efficiency for the power plant is 45.2% and the overall energy efficiency is 9.4%. Exergy analysis was found helpful and important tool for analyzing the geothermal plant and should be considered at early stages of designs.

Keywords: sabalan geothermal power plant, energy, exergy, double flash, Iran.

1 INTRODUCTION

The increase in energy demands, decline in energy resources and the link between energy utilization and environmental impact have resulted in calls for sustainable approach to the development and management of the earth's energy resources [1]. With finite energy resources and large (and increasing) energy demands, it becomes increasingly important to understand the mechanisms which degrade the quality of energy and energy resources and to develop systematic approaches to improve the systems [2]. Systems and processes that degrade the quality of energy resources can only be identified through a detailed analysis of the whole system.

Exergy is defined as energy which can be converted into other energy forms, such as the portion of heat which can theoretically be converted into work (electricity). Exergy analysis is based on the assumption that only the exergy contained in any heat stream has value, then non-convertible part of the heat stream (anergy) has no value. Exergy analysis has been cited by many researchers and practicing engineers to be a powerful tool to identify and quantify energy degrading processes since it enables the types, locations and quantities of energy losses to be evaluated.

Meshkinshahr is a city in NW-Iran with a population of 164,000. Sabalan Mountain is located southeast of Meshkinshahr, 4811 m high and at 25 km distance from the city. The Meshkinshahr geothermal prospect lies in the Moil valley on the western slopes of Mt. Sabalan, approximately 16 km southeast of the Meshkinshahr city. The area includes three geothermal fields located in the northern, eastern and southern parts of the Sabalan central volcano, and a number of geothermal prospects are associated with these [3]. The Meshkinshahr prospect has been identified as the best of these prospects. Geology, geothermal manifestation, geochemical, geophysical explorations have been done in the area and exploration drilling has given sufficiently good results to go into production drilling.

This paper presents the theoretical framework and mathematical formulations on which the exergy analysis is based, the steps followed in the study (methodology) are described. Then the detailed exergy analysis was done for each subsystem with the equations used, procedures and simplifying assumptions. The results of the analysis as performed in EES are presented and their significance is discussed and conclusions made.

2 GEOTHERMAL POWER CYCLE

A diagram of the power cycle is shown in Figure 1. If in addition to the main cycle, a flash vessel is employed to generate secondary steam from the liquid at stage 7, the resulting double-flash plant will be more efficient than a single-flash plant. Either a dual-admission turbine or two separate tandem compound turbines could be used. The pressure of the water at stage 7 is the same as the wellhead pressure and is lowered isenthalpically through a throttling valve, generating a mixture of water and steam at a lower pressure level. The steam is then separated from the mixture and fed into a law pressure turbine along with the steam from the high pressure turbine outlet [4].

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3 METHODOLOGY

This paper contains performance analysis and optimization of the double-flash power plant (see Fig. 1). Mathematical models for exergy and energy were developed and analyzed using the Engineering Equation Solver (EES) software to perform the calculations. The results from well testing and exploration drilling in Sabalan geothermal field was used to evaluate the initial values to perform more accurate analysis. Reservoir enthalpy and mass flow rate for geothermal fluid are 960 kj/kg and 600 kg/s respectively.

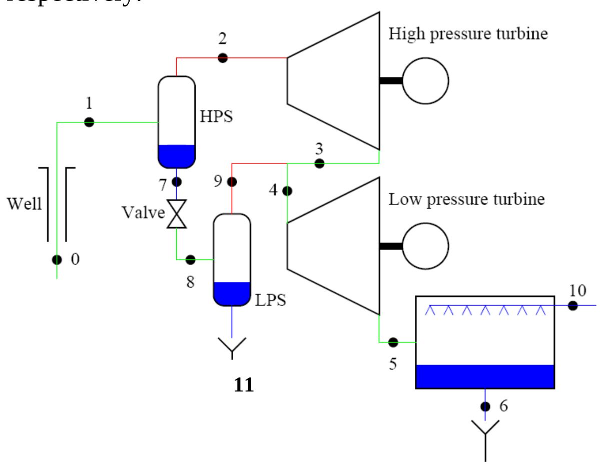

Figure 1: A process diagram of a double flash cycle [5].

3.1 OPTIMIZATION

The separation pressure is vey important and a critical parameter to get optimal values for the plant performance. The pressures that yield maximum total net power output have been calculated using EES and selected as optimum separation pressures. According to calculations, optimum pressure value for high pressure (HP) separation part is 5.5 bar, and for low pressure (LP) separation part is 0.9 bar (see Fig. 2).

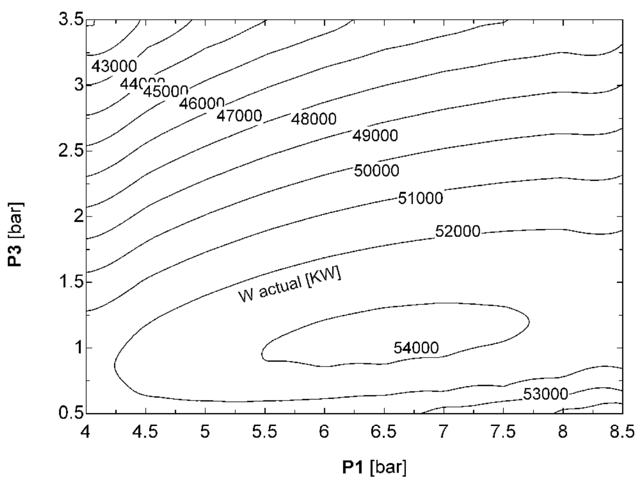

Figure 2: Pressure optimization in LP and HP parts of plan.

3.2 Exergy and Energy

Exergy analysis has been applied for each component such as separators, turbines, condenser, etc. For a stream of fluid, the total exergy flow can be expressed as:

$$E_{total} = E_{KE} + E_{PE} + E_{PH} + E_{O} \quad (1)$$

Where:

E_{KE} = Kinetic exergy
E_{PE} = Potential exergy
E_{PH} = Physical exergy
E_{O} = Chemical exergy

Both E_{KE} and E_{PE} are associated with high-grade energy and are fully convertible to work, while E_{PH} and E_{O} are low-grade energy where the stream has to undergo physical and chemical processes while interacting with the environment. For this study, only physical-exergy shall be considered since the process involves only fixed composition flows [6]. Therefore, the exergy will be expressed as equal to the maximum work when the stream of substance is brought from its initial state to the environmental state defined by P_0 and T_0 by physical processes involving only thermal interaction with the environment [7].

$$E_{total} = E_{PH} = m_i\left[(h_i - h_0) - T_0(s_i - s_0)\right] \quad (2)$$

Where:

i = Refers to state points
0 = Refers to the environmental state
m = Refers to mass flow rates
h = Enthalpy
s = Entropy
T_0 = Temperature $^{\circ}$K

For a control volume, an exergy balance equation can be expressed as:

$$E_{input} = E_{desired} + E_{waste} + E_{destroyed} \quad (3)$$

Where:

E_{input} = Total exergy inflow into the control volume
$E_{desired}$ = Total desired exergy output (net work output)
E_{waste} = Sum of exergy from the system other than the desired
$E_{destroyed}$ = Sum of exergy lost in the system as a result of irreversibility.

4 RESULTS AND DISCUSSION

Table 1 shows the most important values of power plant. The net power output of the plant is 54005 KW_e. The high pressure turbine produces 21318 KW_e and the remaining 36755 KW_e are produced in the low pressure turbine. Pumps and compressor will use 2496 KW_e and 1512 KW_e, respectively. The overall first and second law efficiencies of the power plant are 9.4% and 45.2% respectively. The reference conditions for exergy analysis are 15ºC and atmospheric pressure. Figure 3 shows exergy destruction at different stages of the plant. 1.63% of the total exergy destruction is due to transmission from the reservoir to wellhead. 1.57% of the exergy is destroyed at the high pressure separation step and 5.43% at the low pressure separation. 3.15% is lost at the high pressure steam expansion part and 5.44% at the low pressure expansion unit. 21.05% are destroyed in the condenser, 0.72% and 15.77% are the waste brine from condensing steam and low presser separator respectively. Finally the remainder is 45.22%, which is the fraction of the initial exergy that the plant turns to power. Table 2, illustrates important parameters at major stages of power plant at optimal pressure.

In reality, the waste fluids should only be accepted as exergy lost in geothermal power plant applications if this exergy can not be made useful for other applications such as space and district heating, greenhouse, pool heating or aquaculture. The other approach to waste fluid is reinjection. Reinjection of the used geothermal brine is a legal obligation in the USA and other developed countries [8]. There are some important points concerning the reinjection process. For example, brine must be reinjected in a suitable place for reheating. When the geofluid has returned to its original reservoir, it should have reached the original temperature and pressure. Thus the reservoir is replenished with water, and the exploitation gets as close to being renewable as possible.

Ideally the heat in the rejected geofluid should be utilized in a cascade of applications, each making the most of the available heat, before the fluid is reinjected into the reservoir. A reservoir can be limited by the natural inflow of heat or the natural inflow of water. If the natural inflow of heat is sufficient, then the reservoir will not cool down. In most cases the reinjection will create a cold plume around the reinjection well, and the lifetime of the project is limited to the time it takes for this plume to grow into the production wells.

Reinjection will always solve the limited water inflow problem. To avoid of well clogging problem, possible need for filtering the brine before reinjection should be taken into account. If the waste fluid is reinjected to the reservoir carefully, it will contribute to preserving the pressure and temperature of the resource. In that case, this process should not be considered as an exergy destruction process.

Quality of steam at LP separation	10.3%
Mass flow rate after LP separation	53 kg/s
Quality of steam at HP separation	14.5%
Mass flow rate after HP separation	87 kg/s
Quality of steam at HP turbine exit	90.6%
Quality of steam before LP turbine	94.2%
Power output (net) at HP part	21318
Power pot put (net) at LP part	36755
Total net power produced by plant	54005 KW
Power used by pump	2496 KW
Power used by compressor	1512 KW
Overall first law efficiency	9.4%
Overall second law efficiency	45.2%

Table 1: Optimum values of analysis.

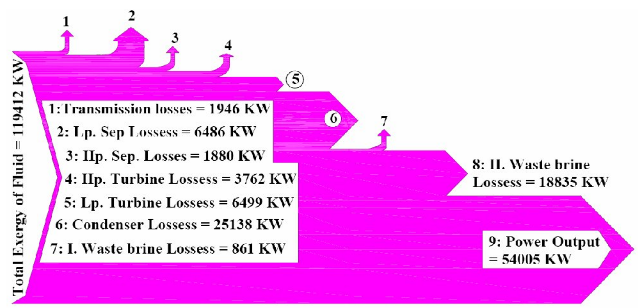

Figure 3: Grassman presentation of the overall exergy flow.

State	Enthalpy kj/kg	Mass flow kg/s	Energy kW	Energy rate %	Temperature °C	Exergy rate kW	Exergy rate %
0	960	600	576000	100	170 [9]	119412	100
1	960	600	576000	100	155	117466	93.4
2	2748	87	155556	27	151	68122	57.1
3	2459	87	25143	4.4	97	43042	36.1
4	2539	140	132786	23.1	97	71671	60
5	2230	140	43260	7.5	45.8	28417	23.8
6	191.7	140	285362	49.5	45.8	887	0.74
7	639	513	164673	28.6	151	53948	45.2
8	639	513	164673	28.6	97	47465	39.7
9	2670	53	107643	18.7	97	25138	21.1
10	41.9	2161	278358	48.3	10	188	0.16
11	405	460	107640	18.7	97	18835	15.8

Table 2: Important parameters at major stages of power plant at optimal pressure.

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5 CONCLUSION

Analysis of the double–flash geothermal power plant was done using energy and exergy concepts for Sabalan, Iran. Reservoir enthalpy and mass flow rate for geothermal fluid are 960 kj/kg and 600 kg/s respectively. EES software was used to model the plant. Optimization was done to maximize the net power output of the plant. Optimum pressure value for HP_separation is 5.5 bar, and for LP_separation is 0.9 bar. With these optimum pressure values the net power output of the plant is 54005 KW_e. HP_turbine produces 21318 KW_e and the remaining 36755 KW_e comes from LP_turbine. Pumps and compressor will use 2496 KW_e and 1512 KW_e respectively.

The exergy analysis of Sabalan geothermal power plant has pointed out the locations and quantities of exergy losses, wastes and destructions in the different processes within the plant. The exergy analysis was found to be very helpful tool where the thermodynamical solutions (energy analysis) is not sufficient. It increases the accuracy of the analysis and makes it possible to determine the key parameters of processes. The locations with largest exergy destruction are the condenser, the low pressure turbine, the low pressure separator and waste brine with 21.05%, 5.44%, 5.43% and 15.77% of total exergy destruction in the plant.

The reason for high exergy loss in condenser is due to heat transfer from the turbine exhaust steam to the environment via cooling water. In geothermal (and conventional) power plants, the waste heat of the condenser should be recovered if it is possible and economy allows. Some low-temperature applications could be added to this system for heat recovery. Another important location for exergy destruction in the plant is the low pressure turbine. This is also evident from the low second law efficiency of the second turbine-generator system. The main reason for this result is low temperature and pressure values at the second turbine inlet [8]. Waste brine discharged from the power plant has important energy and exergy content. The energy and exergy rates of the waste brine have been calculated as 107640 kW and 18835 kW, respectively. These values represent 18.7% and 15.8% of the total energy and exergy flow from the reservoir, respectively. The waste geothermal fluid must be carefully reinjected to the reservoir to ensure sustainability.

From the results, the following conclusions have been drawn:

1. The total exergy available from production wells at Sabalan power plant has been calculated to be 119 MW.
2. The overall exergy efficiency for the power plant is 45.2% and the overall energy efficiency is 9.4% in both cases with respect to the exergy from the connected wells, assuming an environment temperature of 15ºC.
3. The exergy lost in the transmission system amounting to 2 MW should be taken into account when the site for the power plant is selected. It seems to be one of the parameters in the site selection and decision making.
4. The rejected water from the low pressure separator with mass flow rate of 460 kg/s and temperature of 97°C, can be beneficial to be used as a heat source for a district heating system for the population in the Sabalan area (winter temperature around -5ºC).
5. A detailed exergy analysis and plant optimization studies should be done using actual operating condition, based on real plant data. Exergy analysis should be incorporated in future designs of geothermal plants.

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