Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Modeling of the Single and Double Flash Cycles and Comparing Them for Power Generation in Sabalan Geothermal Field, Iran

Behnam RADMEHR[1], Saeid JALILINASRABADY[2]

[1]Geothermal Power Plant Project, Meshgin Shahr, Iran

[2]Kyushu University, Fukuoka, Japan

Radmehr.beh@gmail.com[1], jalili@kyudai.jp[2]

Keywords: Single Flash, Double Flash, Geothermal Power Plant, Efficiency, Iran.

ABSTRACT

The results from three exploration wells and the successful discharge test of them led Renewable Energy Organization of Iran (SUNA) to consider further production drilling in the geothermal resource area in North West Sabalan, Iran, as well as options for early development. In total, eleven exploration wells including production and re-injection wells have been drilled in five well pads in the area so far. However, four of the new production wells were discharged by air lifting and using steam from nearby wells and the flow from those wells was tested successfully.

The main objectives of this study are: 1. Evaluation of power generation potential of newly drilled wells. 2. Thermodynamic modeling of single and double flash cycles and comparing them to determine optimum parameters of each cycle. 4. Determination of the first and second law efficiencies and the productivity of geothermal fluid for single flash as well as for double flash systems. The Engineering Equation Solver (EES) was used for developing and analyzing mathematical models of energy flows.

1. INTRODUCTION

Currently, the final steps of bidding for installation of a demonstration pilot 5 MWe power plant at Sabalan Geothermal Field are being completed. The demonstration pilot power plant is considered to be installed on well NWS-4 of this field.

Single flash cycle with steam condensing turbine will be used as energy conversion system at the power plant. Using single flash system will result in discarding a significant volume of energy in the form of brine from the separator, due to low quality of produced two-phase fluid. However, the data from three other wells in same field are available and while the wellhead pressure of these wells are relatively high (>10 bar-a), therefore using the energy content of saturated water discarded from separator through the second flash process is considered in this study. Figure 2 shows the simple process flow diagram of a double flash system, the production fluid is separated to steam and brine through the separator, the high pressure steam is directed to the turbine and brine leaving the primary separator is led to the flasher in order to generate additional steam, at a lower pressure than the primary steam.

This paper presents the theoretical framework and mathematical formulations on both single and double flash cycles, compares the power output of two cycles, the steam productivity and the system performances of two development scenarios.

2. SUMMARY OF THERMAL DESIGN OF THE PROPOSED SYSTEM

The thermodynamic design of the proposed system has been established in EES software. The results from well testing of three wells of NWS-6, NWS-7 and NWS-10 in the Sabalan field were used to evaluate the initial values to perform more accurate analysis. The initial data obtained from well testing for the wells are shown in Table 1:

Table 1: The enthalpy and mass flow rates of wells NWS-6, NWS-7 and NWS-10 at 10 bar-a wellhead pressure

Wells	Enthalpy (kj/kg)	Mass flow rate (kg/s)
NWS-6	1150	58
NWS-7	1100	60
NWS-10	1140	56

2.1 Single Flash Cycle

The subscript numbers refer to state locations on Figure 1.

The fraction and flow rate of the steam and brine can be defined by mass and heat balance of the separator as follows:

$$\dot{m}_1 x_1 = \dot{m}_2 x_2 + \dot{m}_3 x_3 \quad (1)$$

$$\dot{m}_1 h_1 = \dot{m}_2 h_2 + \dot{m}_3 h_3 \quad (2)$$

where the $\dot{m}$ and h are the mass flow and enthalpy of the stream at their specified state on the system, respectively. The subscript numbers denote the state position of each stream at Figure 1.

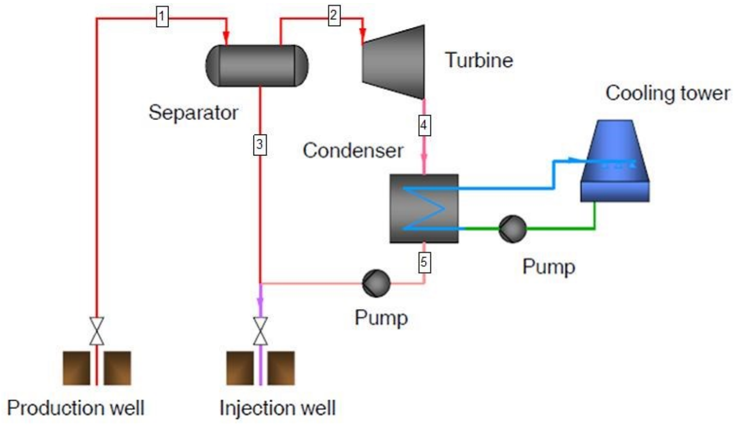

Figure 1: The process flow diagram of single flash cycle.

The turbine power production is:

$$\dot{W}_{turb} = \dot{m}_2(h_2 - h_4) \tag{3}$$

$$\eta_{turb} = \frac{h_2 - h_4}{h_2 - h_{4s}} \tag{4}$$

where h_4 and h_{4s} are the enthalpy values at the turbine exit for actual and isentropic processes, respectively.

For the condenser, $\dot{Q}_{cond}$ the heat rejected by cooling water is:

$$\dot{Q}_{cond} = \dot{m}_2(h_4 - h_5) \tag{5}$$

The mass flow of cooling water can be defined by:

$$\dot{m}_{CW} = \frac{\dot{Q}_{cond}}{(h_8 - h_7)} \tag{6}$$

where h_7 and h_8 are the enthalpy of cooling water at the inlet and outlet of the condenser.

The power consumed by cooling water pump, $\dot{W}_{cwp}$ can be calculated by:

$$\dot{W}_{cwp} = \dot{W}_{cwp,isentropic} . \eta_{pump} \tag{7}$$

$$\dot{W}_{cwp,isentropic} = v_{cw} \Delta p_{pump} \tag{8}$$

The energy conversion (or first law) efficiency for a heat engine operating cyclically between two thermal energy reservoirs is:

$$\eta_{1law} = \frac{\dot{W}_{net}}{\dot{Q}_{in}} \tag{9}$$

$$\dot{Q}_{in} = C_p \dot{m}_1(T_1 - T_{CW1}) \tag{10}$$

where $\dot{W}_{net}$ is the power delivered to the network and $\dot{Q}_{in}$ is the corresponding heat transfer to the engine per cycle. T_{CW1} is the temperature of the cold water entering the condenser from the cooling tower.

The exergetic (or second law) efficiency of the cycle based on the two phase fluid exergy input to the plant can be calculated as:

$$\eta_{II-Law} = \frac{\dot{W}_{net}}{E_1} \tag{11}$$

$$E = \dot{m}(h - h_0 - T_0(s - s_0)) \tag{12}$$

where T_0 is the environment (dead state) temperature, h and s are the enthalpy and the entropy of the geothermal fluid at the specified state, respectively, and h_0 and s_0 are the corresponding properties at the restricted dead state, respectively.

2.2 Double Flash Cycle

With employing a throttling valve at stage 3 and a secondary low pressure separator at stage 3 of Figure 1, a double flash system can be designed as shown in Figure 2.

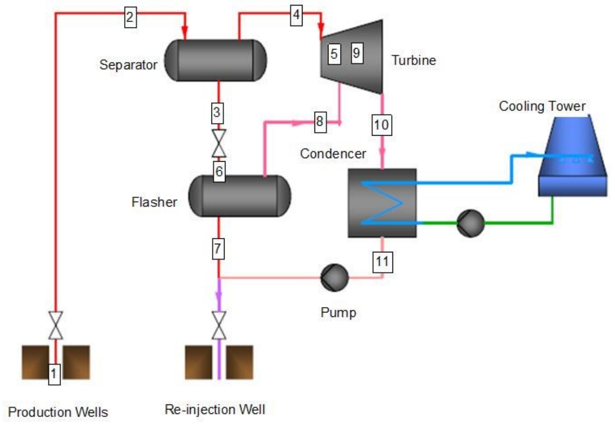

Figure 2: The process flow diagram of double flash cycle.

It is assumed that the turbine is a dual-admission, single-flow machine where the low pressure steam is admitted to the steam path at an appropriate stage so as to merge smoothly with the partially expanded high-pressure steam. Other designs are possible; for example, two separate turbines could be used, one for the high-pressure steam and one for the low-pressure steam. In this case, the turbines could exhaust to a common condenser or to two separate condensers operating at different pressures.

The processes are best described in a thermodynamic temperature-entropy diagram as shown in Figure 3. The hot separated brine at the saturation liquid state (point 3) is flashed by means of a throttle valve and produces a low-pressure mixture of steam and brine. The flashing process is isenthalpic, therefore (the subscript numbers refer to state locations on Figure 2.):

$$h_3 = h_6 \tag{11}$$

The low-pressure steam mass flow, $\dot{m}_8$ is found from

$$\dot{m}_8 = \dot{m}_6 x_6 \tag{12}$$

where the mass fraction of the mixture at state 6, can be calculated from

$$x_6 = \frac{(h_6 - h_7)}{(h_8 - h_7)} \tag{13}$$

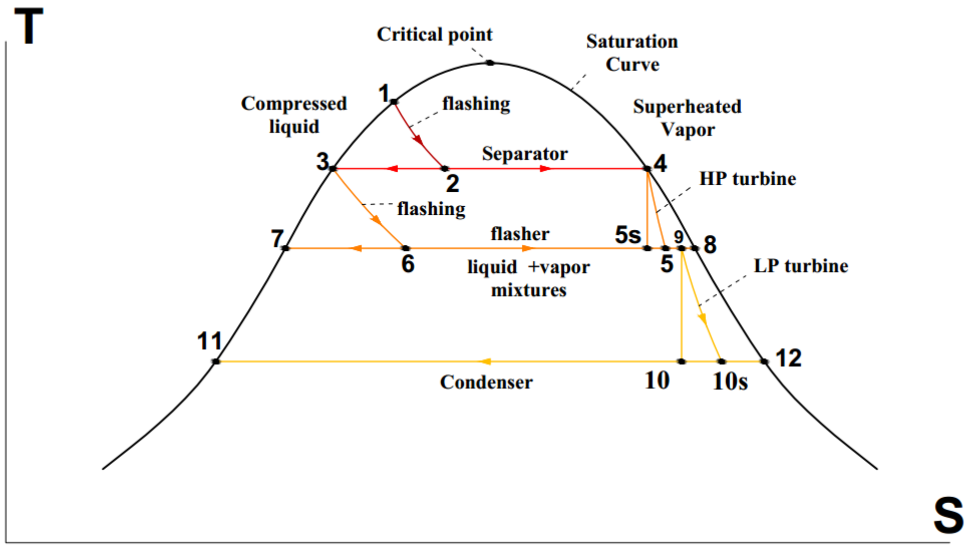

Figure 3: Temperature-entropy process diagram for double-flash plant with a dual admission turbine.

The low-pressure steam from the flasher is admitted to the steam path, and joins the partially expanded high-pressure steam at state 5. With reference to Figure 3, the partially expanded steam is at state 5, the low-pressure steam is at state 8 (saturated vapor), and the mixed steam, ready to enter the low-pressure turbine stages, is at state 9, thus:

$$\dot{m}_9 = \dot{m}_8 + \dot{m}_5 \tag{14}$$

$$\dot{m}_9 h_9 = \dot{m}_8 h_8 + \dot{m}_5 h_5 \tag{15}$$

With the assumption of using a dual-admission, double-flow turbine, the HP-stages and LP-Stages of the turbine may be analyzed according to the methodology used for the single-flash turbine, namely:

$$\dot{W}_{HPT} = \dot{m}_4 (h_4 - h_5) \tag{16}$$

$$\dot{W}_{LPT} = \dot{m}_9 (h_9 - h_{10}) \tag{17}$$

Adopting the Baumann rule (Dippipo, 2007), the isentropic efficiencies of a high pressure turbine, η_{HPT} and a low pressure turbine, η_{LPT} are calculated from

$$\eta_{HPT} = \eta_{td} \times \left[\frac{x_4 + x_5}{2} \right] \tag{18}$$

$$\eta_{LPT} = \eta_{td} \times \left[\frac{x_9 + x_{10}}{2} \right] \tag{19}$$

where the dry turbine efficiency, η_{td} may be conservatively assumed to be constant at 85%.

The net power output of a double flash system is calculated by summing up the power output of the turbines (HP turbine and LP turbine) and subtracting auxiliary power consumption for the cooling-water pumps, compressors for NCG removal and the cooling tower fans.

3. RESULTS AND DISCUSSION

3.1 Single Flash Cycle

The thermodynamic design of the system has been established in EES. For geothermal fluid, the thermodynamic properties of water are used.

The following plant operating parameters are used for the thermal design:

$p_{sep} = 9$	Separator pressure - [bar-a]
$p_{cond} = 0.1$	Condenser Pressure - [bar-a]
$\eta_{turb} = 85$	Turbine isentropic efficiency - [%]
$\eta_{pump} = 50$	Pump isentropic efficiency - [%]
$T_{db} = 10$	Wet-bulb temperature - [°C]

All pressure and heat transfer losses are neglected. The results show that the net output power of the single flash is 13500 kW with first low efficiency of 12.9% where the second law efficiency of the single flash cycle was estimated to be 27 % with reference to the total exergy from the connected wells (51000 kW). The electric productivity of geothermal fluid was calculated as 21.78 kWh/ton.

3.2 Double Flash Cycle

The operating parameters described above for the single flash and the initial flasher pressure of 4 bar-a, are used for the thermal design. The optimized pressures for the separator and flasher will be presented in section 3.2.1

The results show that the net power output of the plant with using double flash cycle has increased up to 22500 kW where the high pressure turbine output is 4500 kW and the output from low pressure turbine is 19000 kW. The first law efficiency of the plant and the electric productivity of the geothermal fluid are calculated as 30% and 35 kWh/ton, respectively, the overall exergy efficiency of the double flash cycle was found to be 43.5% with reference to the total exergy from the connected wells (51000 kW).

<u>3.2.1 Optimization of Double Flash Cycle</u>

The optimization process for a double-flash plant is more complicated than for a single-flash plant because of the extra degree of freedom in the choice of operating parameters. For each choice of separator pressure (or temperature), there will be a range of possible flasher pressures (or temperatures), one of which will yield the highest power output. Over the spectrum of separator pressures, there will be corresponding flash pressures that yield the best output. Among this array of results there will be a single overall best optimum point. The pressures that yield maximum total net power output have been calculated and selected as optimum separation pressures. According to calculations, optimum pressure value for the separator (high pressure (HP) separation) is 8.5 bar, and for the flasher (low pressure (LP) separation) is 1.8 bar (see Figure 4).

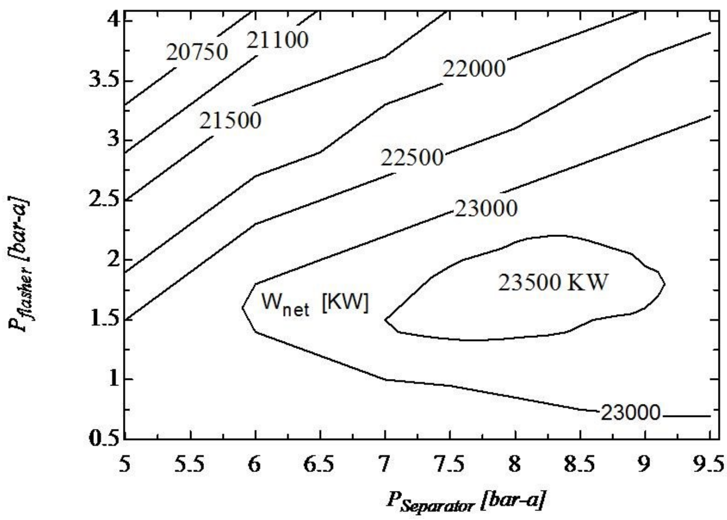

Figure 4: Pressure optimization of separator and flasher in double flash cycle.

4. CONCLUSION

Using a single flash plant in Sabalan geothermal field (NW Iran) will result in discarding a significant volume of energy in the form of brine from separator. Thermodynamic models of single and double flash cycles were developed and analyzed using the Engineering Equation Solver (EES) to perform the calculations based on the data from discharge test results of three wells in Sabalan geothermal field. The net power output of single flash and double flash cycles and the first law and second law efficiencies of two cycles were calculated. Optimization was conducted to determine the optimum pressures of the sparator and flasher in double flash cycle.

From the results, the following conclusions have been drawn:

1. The net power output of the single flash is 13,500 kW where this value for the double flash cycle was estimated to be 22,500 kW.
2. The first law efficiency of the single flash and double flash cycles were calculated to be 12.9 % and 30%, respectively.
3. The second law efficiency of the single flash and double flash cycles with reference to the total exergy from the connected wells were calculated to be 27 % and 43.5%, respectively.
4. Optimum pressure values for the separator and flasher in double flash cycle were found to be 8.5 and 1.8 bar-a, respectively.

REFERENCES

Dippipo, R., 2007: Geothermal Power plants. 490 pp. website, http://books.elsevier.com/companions>

DiPippo, R., Marcille, D.F: Exergy analysis of geothermal power plants. Geothermal Resources Council Transactions 8, (1984), 47–52.

El-Wakil, M.M., 1984: Power plant technology. McGraw-Hill, Inc., USA, 859 pp.

F-Chart Software 2004: Engineering Equation Solver (professional version 7.209). Web page https://www.fchart.com/

Kotas, T.J., 1995: The exergy method of thermal plant analysis. Krieger Publishing Co. Ltd, Florida, USA, 327 pp.

Páll Valdimarsson, 2005: Lectures on High Temperature Geothermal Energy Utilization. UNUGTP, Iceland. Lecture notes

SKM, 2005: NW-Sabalan geothermal feasibility study. SUNA and Sinclair Knight Merz (SKM), internal report, 95 pp

Wark, K.J.: Advanced Thermodynamics for Engineers. McGraw-Hill, New York, (1995).