AIP Conference Proceedings

Optimization of flashing pressure separator and turbine thermal efficiency on mini-scale geothermal power plant at utilization exploration well

Cite as: AIP Conference Proceedings **2363**, 020018 (2021); https://doi.org/10.1063/5.0061069
Published Online: 23 November 2021

Herianto and Dewi Asmorowati

Optimization of Flashing Pressure Separator and Turbine Thermal Efficiency on Mini-Scale Geothermal Power Plant at Utilization Exploration Well

Herianto[a] and Dewi Asmorowati[b]

Petroleum Engineering Department, UPN "Veteran" Yogyakarta, Indonesia.

[a] Corresponding author: herianto_upn_ina@yahoo.com, [b] dewi.asmorowati@upnyk.ac.id

Abstract. In drilling geothermal exploration wells, sometimes a small capacity is obtained that produces a small amount of electrical energy. In some remote areas, the need for electricity is vital, because the distribution of electricity from the government sometimes does not reach these areas. For this reason, a mini-scale power plant with a capacity of fewer than 10 MWe is needed to meet the needs of electrical energy, especially in these areas. This research tries to make a mini-scale geothermal using two-phase exploration well data with a pressure of 11 bar, the temperature of 180 ºC, the mass flow of 100 kg/s, and drought of 23%. In this case study, the optimization of pressure separator flashing was carried out to obtain optimal energy. Based on the calculation results, the optimum separator flashing pressure is obtained at 4 bar where the 7 bar turbine inlet pressure produces 9.96 MWe with a thermal efficiency of 73%.

Keywords: Mini-scale power plant, Flashing Separator Pressure, Thermal Efficiency.

INTRODUCTION

Electrical energy is a very essential requirement for an area, but in reality, in Indonesia, there are still remote areas that lack electricity distribution. There are various sources for producing electricity, such as coal, solar power, geothermal energy, etc. In this study, the use of geothermal exploration wells was carried out to produce electrical energy. Geothermal Power Plant consists of various cycles that can be used, including single flash, double flash, binary cycle, or combined cycle. The utilization of geothermal exploration wells is done using a single-flash system where the phase used to drive turbines is steam. There are various scales of geothermal power-plants. Large-scale power plants generally produce electrical energy >30 MW, while mini-scale power plants produce <10 MW.

METHODOLOGY

The methodology used in this study is to model a mini-scale power plant with a single-flash system where only one separator is used to separate geothermal fluid. Obtaining optimal electrical energy production and thermal efficiency, flashing pressure variations are calculated on the separator at 3 bars, 4 bars, 5 bars, 6 bars, 7 bars, and 8 bars.

MINI-SCALE POWER PLANT

The mini-scale power plant in this study only utilizes one exploration well, one separator, one steam turbine, and one condenser. It is well-known as a single-flash where only one flashing process is performed. An overview of the mini-scale power plant can be seen in the image below:

3rd International Conference on Earth Science, Mineral, and Energy
AIP Conf. Proc. 2363, 020018-1–020018-7; https://doi.org/10.1063/5.0061069
Published by AIP Publishing. 978-0-7354-4154-5/$30.00

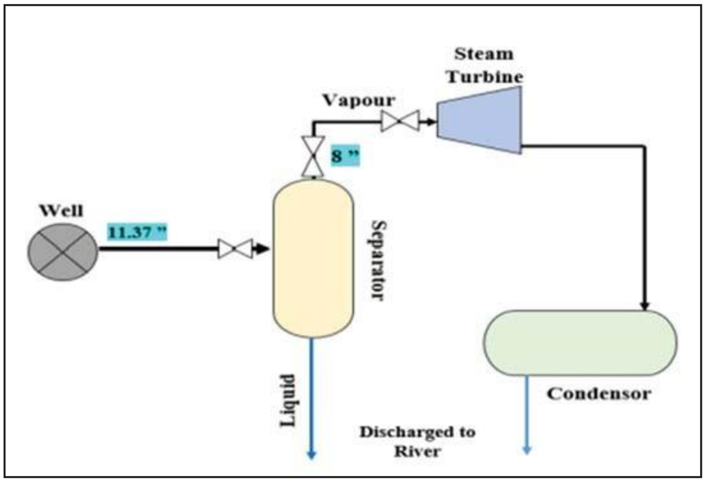

FIGURE 1. Diagram Flow of Mini-Scale Power Plant

THERMODYNAMIC ANALYSIS OF SINGLE-FLASH SYSTEM

The thermodynamic process that occurs in the geothermal fluid can be seen in Figure 2. Point 1 is the process of fluid from the well to the surface. This fluid flow produces temperature loss and pressure loss up to the separator shown at point 2. The brine outlet separator phase goes to the river, point 3. The flashing vapor phase enters the turbine inlet, point 4. After the steam turns the turbine, the steam will be condensed first in the condenser (point 5) before being discharged into the river.

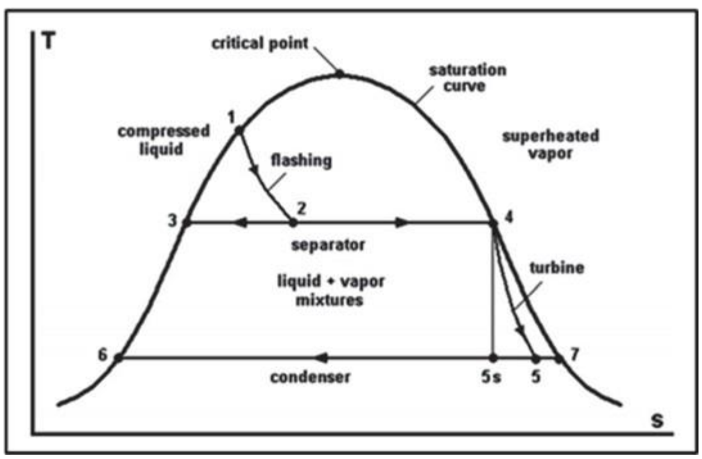

FIGURE 2. Temperature-entropy state diagram for single-flash plants (Dipippo, 2012)

Separator

The separator is an equipment where the flashing process occurs. Inside the separator, the vapor phase and the liquid phase will be separated and exit at different outlets. The vapor phase that has been separated from the liquid phase will evaporate to the top of the separator, while the liquid phase will flow towards the bottom outlet of the separator. The process of single-flash starts with geothermal fluid at point 1, where the process towards point 2 has the same enthalpy so that it can be written with:

$$h_1 = h_2 \tag{1}$$

The flashing process will produce two separate phases, the brine will go to the dump (point 3), and the steam will flow into the turbine. The dryness fraction of the separator is determined by:

$$X_2 = \frac{h_2 - h_3}{h_4 - h_3} \quad (2)$$

Steam Turbine

The turbine is an essential tool in a power plant, where the turbine will convert heat energy from the geothermal fluid into kinetic energy to produce electrical energy. One type of turbine in this industry is a steam turbine. Steam enters the turbine through the nozzle (Irianpoo, 2013). Inside the nozzle, the heat energy from steam is converted into kinetic energy, and the steam undergoes development. The vapor pressure when exiting the nozzle is smaller than when entering the nozzle, but conversely, the velocity of the vapor exiting the nozzle is more significant than when entering into the nozzle. Steam emitting from the nozzle is directed to the turbine blades, in the form of arches which is installed around the turbine wheels. Steam flows through the gap between the turbine blades is deflected towards the curve of the turbine blades. This change in steam velocity creates a force that drives and then turns the wheels and turbine shaft.

Turbine Power Calculation

The turbine power calculation is done by analyzing the balance on each separator and turbine. The results of the equilibrium balance calculation are used to find out the MWe produced using the equation:

$$We = \frac{m \; x \; (h4 - h5) \; x \; \text{eff}}{1000}, \text{mW} \quad (3)$$

Thermal Efficiency

Thermal efficiency is a measure that shows the performance of a device that performs thermal work processes. The value of thermal efficiency can be determined using the equation:

$$\eta t = \frac{h_4 - h_5}{h_4 - h_{5s}} \quad (4)$$

Water Treatment

The turbine outlet fluid will change phase from steam to mixed or condensate phase. This fluid will enter the condenser to change the phase into liquid. Just like the result of flashing water on the separator, the condenser output fluid will then be discharged into the river due to the absence of injection wells in this field.

CASE STUDY

The design of this mini-scale power plant uses a well data on "X" Field with two-phase production fluid. The next production fluid will enter the separator for the flashing process. Fluid flow from the well to the separator is flowed using a pipeline with an inner diameter of 11.37 inches as far as 50 m. Fluid from the separator outlet to the turbine inlet is flowed using a pipe with a diameter of 6 inches as far as 100 m. Calculation of pressure loss and temperature loss of wells to the separator is done using HYSYS ASPEN software, while the heat loss to the pipe is considered to be non-existent because it is assumed that the use of an insulator with a thickness of 50.8 mm works perfectly. Fluid characteristic data for each nodal is obtained as the table below:

TABLE 1. Pressure Loss and Temperature Loss Data from Wells to Outlet Separator

Parameters		X-1
Pwh (bar)		11
Temperature (ºC)		180
Loss Through Well-Inlet Separator	**dP (bar)**	1
	dT (ºC)	3
Loss inside Separator	**dP (bar)**	1.5
	dT (ºC)	3
Loss Through Separator – Inlet Turbine	**dP (bar)**	1.5
	dT (ºC)	4

Based on the pressure loss and temperature loss data in table 1, the fluid characteristics of the manifold inlet, outlet manifold, separator inlet, separator outlet, and turbine inlet are obtained. The parameters at the well and inlet manifold are the average of the three wells. The following is a tabulation of the production fluid parameters in each section:

TABLE 2. Production Fluid Characteristics in Well to Outlet Separator

Parameters	Temperature (ºC)	Pressure (bar)	Mass Flow (kg/s)	Dryness (%)	Enthalpy (kJ/kg)	Fluid Phase
Well	180	11	100	23	1245.4	2 Phase
Inlet Separator	177	10	100	22.1	1205.86	2 Phase
Outlet Separator	174	8.5	18	100	2770	1 Phase (Vapour)
Inlet Turbin	170	7	18	100	2762.7	1 Phase (Vapour)

Optimization of Separator Flashing Pressure

Pressure optimization and temperature flashing are done to get the optimum conditions used so that the energy produced will be even greater. Doing the same steps as the example calculation above, note that the greater the flashing pressure used will produce higher dryness also. The calculation results for each flashing pressure condition are shown in the table below:

TABLE 3. Temperature, Energy Produced, and Thermal Efficiency in Different Separator Flashing Pressure

dP flashing (Bar)	X Separator (%)	dT Flashing (Ⱨ)	T at Turbine Inlet (Ⱨ)	Turbine Energy (MWe)	ηt (%)
3	23	10	170	9.9	71
4	24	16	164	9.96	73
5	25	22	158	9.93	74
6	26	29	151	9.7	76
7	27	37	143	9	79
8	28	47	133	8.2	83

The greater of flashing pressure, can be the smaller the turbine inlet temperature, where the temperature and pressure values are directly proportional. The relationship between flashing pressure and dT separator is in the graph is shown inFigure 3 :

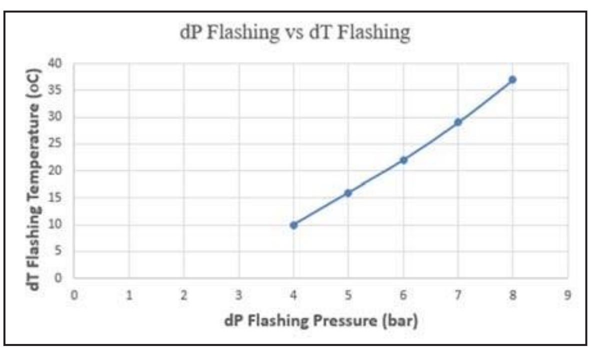

FIGURE 3. dP Flashing Versus dT Flashing

Optimum flashing pressure can be seen more easily on the graph of the relationship between dP flashing and MWe produced the following:

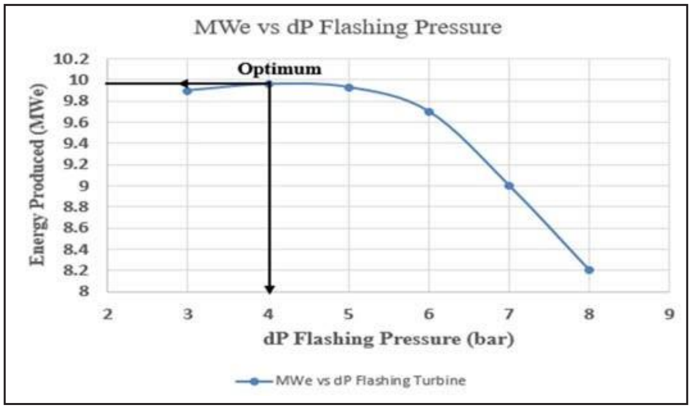

FIGURE 4. dP Flashing and Energy Produced Relation

Differences in flashing pressure will affect the separator temperature, so the relationship between the dT separator is obtained as follows:

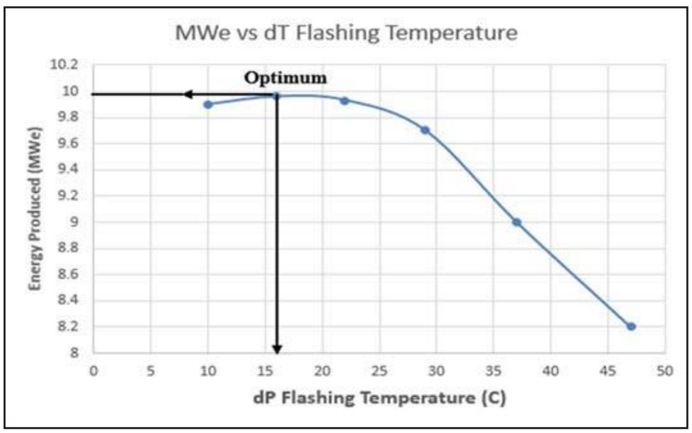

FIGURE 5. dT Flashing and Energy Produced Relation

Turbine Energy Calculation

The turbine energy produced can be done with an example calculation using 3 bar flashing pressure as follows:

Characteristics of well production fluids:

m = 100 kg/s

P = 11 bar

T = 180 ºC

From the data above, the enthalpy is determined using the steam table. Obtained enthalpy of 1241 kJ / kg.

1. Calculation of dryness on the separator

$$X_2 = \frac{h_2 - h_3}{h_4 - h_3} = \frac{1241 - 762.68}{2768.3 - 762.8} = 0.23$$

2. Mass flow steam outlet separator

$$mv = m_{total} \times X_{separator} = 100 \text{ kg/s} \times 0.23 = 23 \text{ kg/s}$$

3. Calculation of turbine energy

   h4 = turbine inlet enthalpy (P turbine inlet = 8 bar)

   h5 = enthalpy of turbine outlet (Poutlet = Pcondenser = 0.2 bar)

   After enthalpy is obtained using the steam table, the calculation of turbine energy is done by the formula (turbine eff = 0.75):

$$We = \frac{m\ x\ (h4 - h5)\ x\ \text{eff}}{1000}$$

$$= \frac{23\ x\ (2768.3 - 2193.8)\ x\ 0.75}{1000}$$

$$= 9.9\ \text{MW}$$

4. Thermal Efficiency

$$\eta t = \frac{h_4 - h_5}{h_4 - h_{5s}}$$

$$= \frac{2768.3 - 2357.5}{2768.3 - 2193.8}$$

$$= 71\%$$

The turbine inlet temperature will change if the flashing pressure on the separator is changed, thus affecting the thermal efficiency of the turbine. The relationship between thermal efficiency and dT in turbines showed in the figure below:

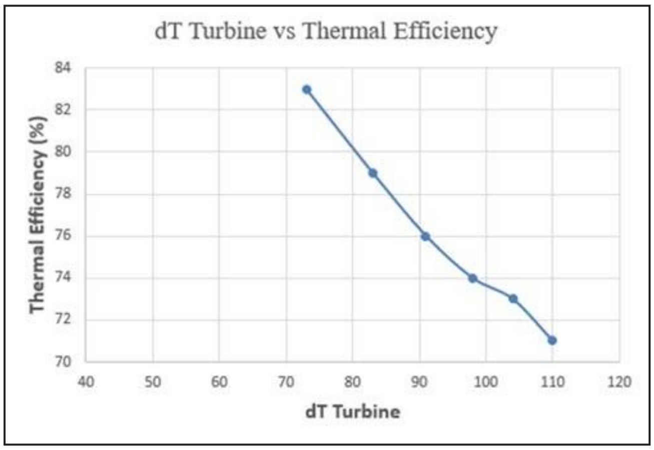

FIGURE 6. dT Turbine (^{o}C) Versus Thermal Efficiency Turbine (%)

RESULT AND DISCUSSION

This case study uses data from one exploration well in field X, which is a liquid-dominated reservoir with 23% dryness. This well has a pressure of 11 bar, a temperature of 180 ^{o}C, an enthalpy of 1245.4 kJ/kg, and a mass flow of 100 kg/s.

Production fluid flow is then flows to a separator as far as 50 m using a pipeline with an inner diameter of 11.37 inches and an insulator of 50.8 mm. Calculation of temperature loss and pressure loss from well to separator is done using Hysis software. Obtained a temperature loss of 3 ^{o}C and a pressure loss of 1 bar so that the fluid temperature inlet separator is 177 ^{o}C and pressurized 10 bar. The two-phase fluid then enters the separator for the flashing process. The flashing process inside the separator causes a pressure loss of 1.5 bar and a temperature loss of 3 ^{o}C. Steam flow from the separator to the turbine uses a 6-inch diameter pipe with a distance of 100 m.

Calculations on this single-flash start by finding the enthalpy value at the separator inlet using the steam table. The inlet and outlet enthalpy values are assumed to be the same, so the separator outlet enthalpy. The separator pressure is used to determine the liquid outlet enthalpy separator and steam enthalpy outlet separator. After getting the enthalpy value, the dryness calculation inside the separator is then performed. Dryness is used to find the value of steam mass flow and liquid outlet separator. The dryness differences in the separator will affect the mass flow of steam that results from flashing. Next, the turbine inlet enthalpy is calculated based on the pressure used while the turbine outlet pressure is assumed to be the same as the condenser pressure used, which is 0.2 bar.

The variation of the flashing pressure in this calculation is intended to determine the effect of the different values of the flashing pressure and to obtain optimum electrical energy. Based on the calculation results, the greater the flashing pressure used will produce higher dryness. The increased value of dryness is due to the higher flashing pressure used. The liquid fraction in the separator can also change the phase into steam so that the steam fraction is higher than liquid fraction. At 3 bar flashing pressure, where the turbine inlet pressure is 8 bar, dryness is 23% and can produce 9.9 MWe of energy. The use of 4 bar, turbine inlet pressure 7 bar, the dryness obtained is 24% with the resulting energy of 9.96 MWe. The decrease in energy produced starts when using a flashing pressure above 4 bars even though the dryness produced is greater. As in the 5-bar flashing pressure, the energy produced is 9.93 MWe. A flashing pressure of 6 bars produces energy of 9.7 MWe. The energy produced when using 7 bar of flashing pressure is 9 bar and when using 8 bar only produces 8.2 bar. The decrease in electrical energy is caused by efficiency in the turbine.

Compared with the six flashing pressure conditions, the optimum condition is obtained at 4 bar flashing pressure where the separator dryness is 24%, the energy produced is 9.96 bar, and the thermal efficiency that occurs is 73%.

CONCLUSION

The conclusions that can be drawn from the results of this study are:

1. Pressure loss generated along the flow from the wellhead to the separator inlet is 1 bar and temperature loss is 3 ^{o}C.
2. Inside the separator, the pressure loss that occurs is 1.5 bar with a temperature loss of 3 ^{o}C.
3. The greater the flashing pressure used, the greater the separator dryness will be.
4. The optimum condition is 4 bar flashing pressure with 24% dryness, producing energy of 9.96 MWe and thermal efficiency of Turbine 73%.
5. Reduction in energy produced under flashing pressure conditions at Separator two phase above 4 bar is due to turbine efficiency. The temperature at the turbine inlet is too low so that the enthalpy at the turbine inlet will also be smaller.

REFERENCES

[1] Assad, M. E., Bani-Hani, E., & Khalil, M. (2017). Performance Of Geothermal Power Plants (Single, Dual, And Binary) To Compensate For Lhc Cern Power Consumption: Comparative Study. Geothermal Energy.

[2] Baihaqi, R. T., & Sinulingga, H. P. (2017). Tekanan Flashing Optimal Pada Separator,. Prosiding Seminar Nasional Fisika (E-Journal).

[3] Jamaludin, & Kurniawan, I. (N.D.). Analisis Perhitungan Daya Turbin Yang Dihasilkan Dan Efisiensi. Kusuma, G. A., Mangindaan, G., & Pakiding, M. (2018). Analisa Efisiensi Thermal Pembangkit. Jurnal Teknik Elektro Dan Komputer Vol 7 No 2.

[4] Saptadji, N. M. (2009). Teknik Panasbumi. , Istitut Teknologi Bandung.

[5] Sarmago, W., & Ho, P. (2001). An Innovative Approach To Treating Geothermal Power Generating. Proceeding Of The 5th Inaga Annual Scientific Conference & Exhibitions. Yogyakarta.

[6] Schochet, D. N. (2000). Case Histories Of Small Scale Geothermal Power Plants. Proceedings World Geothermal Congress. Kyushu-Tohoku: Ormat International, Inc.

[7] Yudiantoro, I., & Nuraeni, I. (2018). Evaluasi Potensi Produksi Sumur Panas Bumi Menggunakan Data Uji. Jurnal Migasian, Vol. 2 No. 1 : 22-28.