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Analysis of Geothermal Wells with High Non-Condensable Gas (NCG) Content as an Alternative Energy Source to Reduce House Load on Indonesia's Geothermal Power Plant

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***Abstract* - Geothermal wells with a high Non-Condensable Gas (NCG) content still have a certain amount of heat and pressure energy. Geothermal Power Plant (GPP) power generation can be interrupted by high NCG. Energy in high NCG wells can be utilized to reduce house load on GPP to avoid disturbances in the overall GPP system. In this study, the existing condensate pump in the GPP uses an electric motor that supplies power from the house load. This article aims to see the opportunities for utilizing geothermal wells with high NCG as a driver of a back-pressure steam turbine. The back-pressure steam turbine will couple to the condensate pump that must inject the condensate into the injection well. The research methodology is collecting actual data from geothermal wells and condensate pump in the GPP. The analysis of data will focus on thermodynamics from the well to drive the condensate pump by using steam turbine back-pressure. The result of the study is that the steam flow rate needed to drive the condensate pump in the maximum condition is about 3.31 kg/s, and the actual steam flow rate from a high NCG well is about 4.53 kg/s. It indicates that the geothermal well can drive the condensate pump. It can reduce the house load of GPP to about 138.79 kW per hour or about 1215 MW per year.**

Keywords: Geothermal, Non-Condensable Gas (NCG), back-pressure steam turbine, condensate pump, thermodynamics.

I. INTRODUCTION

Indonesia is a country that has a variety of energy sources. One of the most used energy utilization is electrical energy. Electrical energy can be generated by converting energy sources into electrical energy with some technologies (Liun, 2011). Several types of power generation systems are classified based on the resources or fuel used. Conventional resources come from fossil fuels such as coal, oil, and natural gas (Overland, Juraev and Vakulchuk, 2022). Fossil energy sources produce emissions of carbon dioxide (CO_2), methane (CH_2), nitrous oxide (N_2O), and other gases which can cause climate change in the world. Other resources are new renewable resources such as hydropower, wind, biomass, solar, and geothermal (Kholiq, 2015).

Geothermal energy is one of the renewable energy sources from nature and can reduce Indonesia's dependence on fossil energy sources. Indonesia's geothermal potential is almost 28,100 MW spread over 265 locations throughout Indonesia. Currently, only around 2,130 MW is used to generate electricity for Geothermal Power Plants (GPP) (Asof, Pasra and Hidayat, 2014). Indonesia's electricity company targets a total installed capacity of GPP in Indonesia to be 3355 MW by 2030 (PLN Indonesia, 2020). This target can be achieved by constructing new plants or developing existing generating capacity by increasing energy efficiency.

Electrical energy in GPP can be produced by converting geothermal steam to a specific temperature and pressure using a steam turbine. Geothermal steam is produced naturally from within the earth and extracted to the surface via geothermal wells. The vapor content of the steam is mixed with several kinds of gas (Cen and Jiang, 2022). Some gases cannot be condensed or are commonly called Non-Condensable Gases (NCG) (Gokcen and Yildirim, 2008). NCG on Geothermal steam can still be used to generate electricity. The technology used to remove the NCG is Gas Removal System (GRS). GRS is a system that functions to remove NCG content in the condenser. The higher NCG content will affect several things. First, the effect of high NCG content will fail the equipment due to the corrosion attack. It was caused by H_2S and CO_2 (Banaś et al., 2007). Secondly, the higher the NCG which entered the turbine was, the higher the output pressure from the turbine. This condition is caused by the enthalpy of steam

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is still high due to there is the amount of steam that cannot be condensed (Sufyana, Akbar and Srigutomo, 2023). Gocken and Yilidirim in Kizildere had shown that 1% NCG could increase of 0,86% work loss at the turbine inlet (Gokcen and Yildirim, 2008).

The NCG content of the well at one of GPP in West Java, Indonesia has a value around 0–8 wt%. Usually, the NCG content of 0-2 wt% can flow in the turbine to generate electricity. In comparison, the NCG of the well with a value 6-8 wt% is not recommended to flow into the turbine. The existing Gas Removal System in the GPP is designed not to exceed NCG content of 3 wt%. One of the productions well with high NCG content in the GPP cannot be used to generate electricity. Steam is discharged into the atmosphere. The steam still contained an amount of energy that was wasted.

The effort of utilizing the waste energy from a high NCG well will be used as the driving force for the back-pressure turbine. Usually, the back-pressure turbine was used to produce lower-efficiency electricity and as a supporting equipment driver in the system.

The back-pressure turbine in the GPP is used as a driving force for the condensate pump that currently uses the electric motor, which is supported by a house load from the power plant. House load is a fixed load to support GPP for local load requirements. This fixed load will reduce the electrical of the overall power plant. Thus, it will be reduced the efficiency of the electric power system. Several kinds of research have been conducted on using steam turbines as the equipment's driving force.

Research which is related to the use of steam turbines as a driving force for pump systems was carried out by Zivkovic M et al. This research discussed the steam turbine that is used as a feed water pump drive on LNG vessels. The pump drives the fluid to the boiler.

Wanasinghe has done the analysis of the back-pressure steam turbine at Lakvijaya Power Station, Sri Lanka. The power of the back-pressure steam turbine was produced from the waste of the boiler. This research shows that using a back-pressure steam turbine as the driving force of the boiler-feed water pumps can reduce the electricity system. Using the back-pressure turbine as the pump driver can save the operation cost of about 0.46 to 2.72 million USD per year.

Another researcher has shown an opportunity to utilize some of the waste energy from the power plant. The waste energy during the unrestrained expansion in pressure reduction stations and used as a driver of the feedwater pump to the boiler (Selimli and Sunay, 2021). The method used is a back-pressure steam turbine as the feedwater pump drive. The analysis shows that there is an energy saving of 33.74%.

Other research regarding the utilization of excess steam in geothermal was carried out by Nandaliarasyad et al. in 2017. The activity of the analysis was the study of the GPP system. The system used the excess steam to drive the back-pressure steam turbine. It was used to generate electricity with the ORC (Organic Rankine Cycle) system. The electrical production was around 2.25 MW.

This article discussed the study of the energy potential of the high NCG content production well in the GPP. The high NCG content will be used to drive a backpressure steam turbine. There is potential to reduce the household of GPP by changing the electric motor of the condensate pump to a backpressure steam turbine as the driver. Hoping this analysis can be used as a reference to utilize high NCG content to support GPP production system.

II. RESEARCH METHODOLOGY

This research conducts at one of the geothermal power plants in Indonesia. The type of GPP installed is a single flash system with the dominant two-phase fluid. The dominant gas of NCG produced in production wells is CO_2 and H_2S. This research is quantitative type. The first method is literature study. This is to collect the article that related to geothermal well, NCG, centrifugal pump, steam turbine back-pressure and thermodynamic equations. The second method is collecting actual data from the field. This data consists of NCG rate, steam pressure, temperature, and steam flow rate from the well. The last method is the analysis of the data using the thermodynamic approach by helping the Microsoft excel program. The final solution of the analysis used the schematic diagram from the production well to the back-pressure steam turbine that is shown in Figure 1.

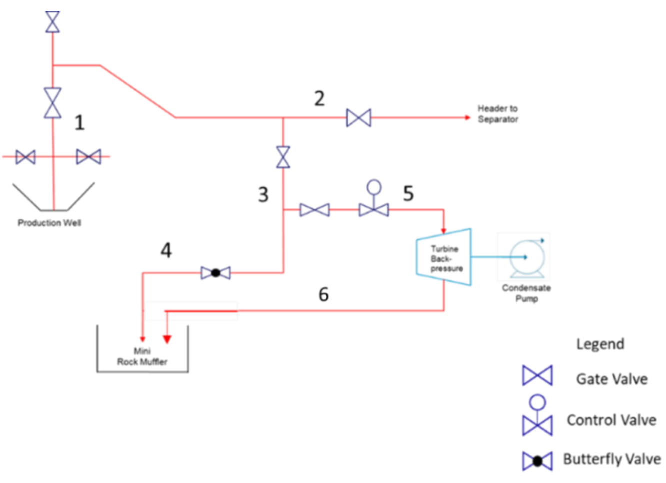

Figure 1: Schematic diagram of process

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The diagram in Figure 1 explains that Point 1 is the steam flow from production wells with high NCG content. Point 2 is the steam leading to the separator. Points 3 and 4 are the steam going to the mini rock muffler. Point 5 is the steam going to the back-pressure steam turbine that will drive the condensate pump. Point 6 is the outlet condition of the steam turbine that goes to the rock muffler (atmospheric conditions).

III. STUDY LITERATURE

The study literature comes from several journals and books. It discusses the principal work and type of geothermal power plant. It also explains Non-condensable Gas in GPP which influences the generation. The explanation and equation of the centrifugal pump and steam turbine are needed to conduct the analysis of this research.

Geothermal Power Plant

Generally, a flash system of GPP consists of two types. Single flash system and double flash system (El Haj Assad, Bani-Hani and Khalil, 2017). A single flash system is the most common type of geothermal power plant installed globally (Dincer and Ezzat, 2018). The working principle of the flash system is to convert two-phase fluid from the production well into the steam turbine. The difference between single-flash and double-flash system is the separator and steam flow into the turbine. The double flash system used dual separator. Each separator will flow the high-pressure and low-pressure steam into the turbine.

Figure 2 and 3 shows a diagram of the single and double flash system. The steam flowed from the production well. The steam will enter the separator that will separate the steam and brine. In the single flash system, the steam will continue to the turbine directly and the hot water or brine will be injected into the injection well (el Haj Assad, Bani-Hani and Khalil, 2017). While, in the double flash system, the steam from the first separator will enter the turbine and the other steam will enter the low separator. The turbine will produce mechanical energy coupled with a generator to generate electrical energy. After the steam is processed in the turbine, the low-pressure steam will enter the condenser and be condensed by cooling water from the cooling tower.

The steam that has condensed into water will be sent to the cooling tower. A pump will inject a certain amount of condensate water into the injection well. The temperature and entropy diagram of GPP can be described in Figure 4 as T-S diagram. This diagram indicates the phase of fluid from compressed liquid from the production well to the vapor condition in the turbine.

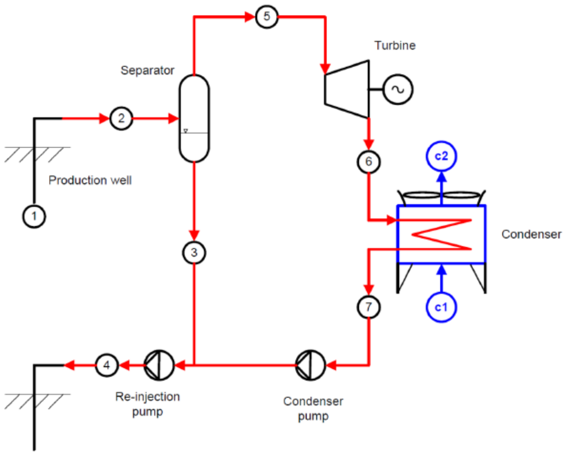

Figure 2: Single flash system in GPP (Valdimarson, 2011)

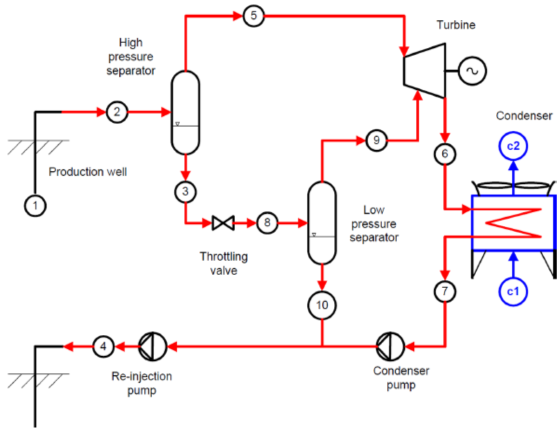

Figure 3: Double flash system in GPP (Valdimarson, 2011)

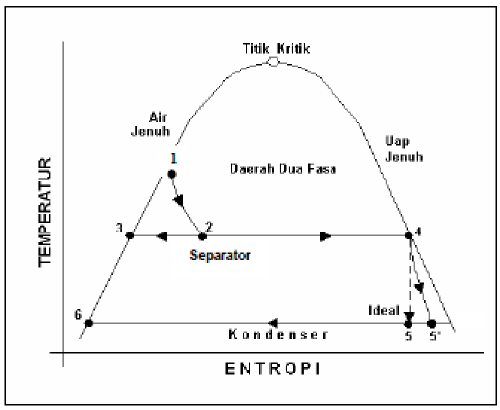

Figure 4: T-S diagram of GPP Single Flash Cycle (Saptadji M, 2019)

Non-Condensable Gas

Non-Condensable Gas (NCG) is a type of gas that cannot be condensed in a geothermal vapor mixture. The effect of NCG entering the turbine with the geothermal steam mixture will increase the pressure in the condenser or reduce the vacuum level in the condenser so that it will reduce the power generated from the turbine. In general, in a geothermal power

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plant system, the NCG content in the condenser will be pulled out by the Gas Removal System (GRS). The gas and steam mixture in NCG in geothermal steam consists of gases such as CO_2, H_2S, NH_3, and CH_4, with CO_2 predominant (Yildirim Ozcan and Gokcen, 2009).According to the first research conducted by Khalifa and Michaelides (1978) regarding the effect of NCG on geothermal power plants, the presence of 10% NCG content in geothermal steam will reduce 25% the total net generation when compared to geothermal steam without NCG.

Steam Turbine

The turbine is used to convert heat energy into mechanical energy. Applications of turbine utilization are for generating systems connected to generators so that they can produce electrical energy. In addition, turbines can also be used to drive pump engines instead of electric motors. Steam turbines used to drive processes are usually required to operate at a different speed range than turbines used to drive electric generators, which run at nearly constant speeds (Bahadori and Vuthaluru, 2010) Steam turbines use steam as their main energy source. The turbine consists of several parts such as casing, blades, rotor, inlet, outlet, seal, diaphragm, and others (Sabri et al., 2020). The steam turbine rotor has a series of road blades in a row. In its installation, a series of fixed blades and a series of road blades are installed alternately. The heat energy in the steam is first converted into kinetic energy by the nozzle; then, this high-speed steam hits the road blades on the turbine rotor, which eventually causes the rotor to rotate. The steam turbine used to generate electric power will be influenced by several factors, such as the amount of steam flow, steam pressure, and temperature (Chao and Yongjian, 2021). The greater the flow, temperature, and steam pressure, the greater the power the turbine generates. In general, the power generated by a steam turbine can be known through steam pressure and temperature, a function of enthalpy and steam mass flow rate. Equation 1 shows how turbine power is produced. Equation 2 shows how to find out the power of the turbine as a pump driver by adding the efficiency of the turbine (Selimli and Sunay, 2021).

$$W_t = \dot{m}_t(h_{in} - h_{out}) \qquad (1)$$

$$W_t = \frac{W_p}{\eta_t} \qquad (2)$$

Steam turbines are divided into two types based on the type of condensation, namely back-pressure turbines, and condensing turbines. The steam turbine back-pressure type is a turbine that does not require condensation at the outlet. The working principle of the back-pressure turbine is steam with a specific temperature, and pressure will enter the inlet of the turbine. The steam will be converted into mechanical energy, and then steam with a lower temperature and pressure will flow into the atmosphere or to the following process (Zhao et al., 2021). The advantage of this type of turbine is its simple configuration because it does not require a condenser and cooling water system. It also has lower installation costs than the condensing type. The condensing turbine is a type of turbine that requires a condenser in its working system. The condenser is connected directly to the outlet of the turbine. Steam with lower pressure will be condensed in the condenser, and the resulting steam, with a liquid phase, will flow to the cooling tower to be cooled and flow back to the condenser. With a working system like this, the efficiency of the condensing type steam turbine will be higher than the back-pressure type steam turbine (Mrzljak et al., 2022).

Centrifugal Pump

Centrifugal pumps use a continuous energy addition system by increasing the fluid velocity on the inlet side of the pump over the outlet side. Based on the structure of the pump, the fluid will experience a reduced speed before heading to the discharge side. There are two main parts of a centrifugal pump. The impeller converts energy from the drive system into velocity energy in the form of an impeller which will generate centrifugal force. This impeller's suction side makes the speed very large so the pump can suck the fluid in. The volute is the structural part of a centrifugal pump that converts kinetic/velocity energy into pressure energy (Qazizada, Sviatskii and Bozek, 2016). Equation 3 explains how the centrifugal pump power can be generated by calculating the density of the fluid, the flow rate of the fluid, and the difference in the head from the initial position to the destination position of the fluid.

$$W_P = \frac{\rho.g.Q.H}{\eta_p} \qquad (3)$$

IV. DATA COLLECTING

All data used in this research is from actual measurements on the site. The data consists of production well condition and condensate pump. The production well data was measured several times yearly from 2017 to 2022. It consists of pressure, flow rate, temperature, and NCG contents. While the condensate pumps data was conducted from the latest performance test that was done in 2019. Table 1 describes the average data of production well. The average pressure, flow rate, and steam temperature are about 5.45 barg, 4.53 kg/s and 157.88 ^{o}C. The average value of NCG content in the steam is 7.39 wt%. Table 2 describes the performance test result of the condensate pump. The pump's flow rate and Total Differential Head (TDH) varied. The highest flow rate of the pump is 184.16 m^3/hr with TDH 135.66 m.

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Table 1: Average of production well data per year

Tahun	Pressure	Flowrate	Temperature	NCG
	barg	kg/s	°C	wt%
2017	7.10	5.70	167.01	8.04
2018	7.37	4.98	171.56	6.38
2019	4.81	4.29	150.64	7.38
2020	4.48	4.58	152.69	6.85
2021	4.24	3.56	150.08	8.49
2022	4.73	4.07	155.32	7.19
Average	**5.45**	**4.53**	**157.88**	**7.39**

Table 2: Condensate pump performance test results

Flowrate	TDH	Efficiency
m^3/hr	meter	%
184.16	135.66	70%
170.47	139.45	69%
151.41	143.60	67%
142.27	145.61	67%
129.02	147.68	65%
100.85	149.09	59%
76.32	150.21	49%

V. RESULT AND DISCUSSION

This research studies the potential of steam with high NCG content to drive back-pressure steam turbine that is coupled to a condensate pump. The amount of condensate that the pump must deliver varies based on the needs in the field. Flow rate, head differential, and pump efficiency were obtained from Table 2. Each flow rate of condensate needs different shaft pump power.

The pump shaft power required to deliver a certain amount of condensate can be calculated using equation 3. The density of condensate is 1000 kg/m^3. The pump shaft power shall be driven by the steam turbine back-pressure. Therefore, it needs to calculate the power of steam turbine back-pressure.

The power of turbine back-pressure can be calculated using equation 2. The efficiency of the turbine back-pressure used is assumed to be 70% based on literature studies in journal (Selimli & Sunay, 2021). Table 3 describes the result of pump shaft power and turbine power from each condensate flow rate. From Table 3, the shaft power needed to flow the maximum condensate is 97.15 kW. It needs 138.79 kW of turbine power.

The steam turbine back-pressure power is also calculated from the steam flow rate and enthalpy. Pressure and temperature drop from the well to the turbine are ignored because the pipe length is insignificant and is still in one area. The data of the turbine inlet is shown in Table 1. On the turbine outlet side, the pressure value is an atmospheric pressure of 1 barg because the steam will be discharged directly into the atmosphere. The temperature of the outlet turbine is about 120 °C. The enthalpy is determined by average pressure and temperature steam data from 2017 to 2022 in Table 1. The Enthalpy inlet turbine is 2758.6 kJ/kg, and the enthalpy outlet is 2716.61 kJ/kg. The calculation of the steam flow rate needed to enter steam turbine back-pressure is referred to equation 1.

The total steam flow rate needed for the maximum turbine power is about 3.31 kg/s. The value is less than the average steam flow rate from the high NCG well on the GPP based on Table 1 which has a value of about 4.53 kg/s. It indicated that the energy of high NCG well is enough to provide the mass flow rate of turbine.

The flow rate of high NCG well is safe to operate the pump. The value of the steam flow rate needed for each condition is shown in figure 5.

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Table 3: Condensate pump shaft and turbine power

Pump Flowrate (m^3/hr)	Pump Shaft Power (kW)	Turbine efficiency %	Turbine Power (kW)
184.16	97.15	70	138.79
170.47	64.71	70	92.45
151.41	59.19	70	84.56
142.27	56.39	70	80.56
129.02	51.87	70	74.10
100.85	40.93	70	58.47
76.32	31.21	70	44.58

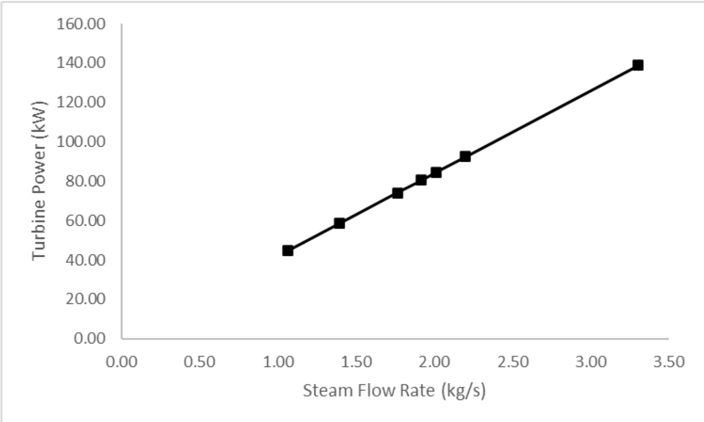

Figure 5: Steam turbine performance curve

VI. SUMMARY

Wells with high NCG content can affect the overall GPP system. The energy utilization method for the well-used in this study uses a back-pressure steam turbine. The energy generated by using a back-pressure steam turbine is used to drive the condensate pump.

Based on analysis of thermodynamics, the steam flow rate of high NCG production well can be used to generate power on turbine back-pressure. The flow rate is sufficient to drive the condensate pump. The condensate pump needs about 138.79 kW or equal to 3.31 kg/s at maximum condition while the high NCG well provides 4.53 kg/s of steam flow rate. It proves that the high NCG well can be used as condensate pump driver.

There will be a certain amount of house load that can be saved. The existing condensate pump is driven by an electric motor that needs a maximum power of 138.79 kW and minimum power of 44.58 kW. With this study, it is possible to save about a maximum of 1215 MW per year and a minimum of 390 MW per year by using steam turbine back-pressure as a replacement of the motor. This amount of energy can increase the overall efficiency of the GPP and use for electricity in Indonesia.

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