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Study of Implementation of Water Jet Ejector as a Gas Removal System for a Case Study of BPPT 3 MW Geothermal Power Plant

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ABSTRACT

Besides generation power, geothermal power plants also produce vast amounts of water. The water results from the condensation process in the condenser and the separation process of geothermal fluid and brine in the separator. This study investigates the implementation of water as the main driver of the gas removal system (GRS) with water jet ejector (WJE) or combination with the other GRS system. The current configuration for the GRS system uses the combination of SJE and LRVP. The SJE system uses motive steam so that the possibility of producing electricity decreases. A small-scale geothermal power plant 3 MW owned by BPPT located at Kamojang geothermal area is the focus of this case study. Three GRS system configurations, including a combination of WJE and LRVP systems, one-stage LRVP and two-stage LRVP system were investigated to know the potential water as a main driver GRS system. Based on three GRS system configurations, simulation of net power generation and techno-economic confirmed that the combination of WJE and LRVP could be implemented at a small-scale, 3 MW geothermal plant as a pilot project. The potential savings from motive steam is about 0.23 MW if the motive steam in SJE system converts to electricity production. The best result for net power generation and techno-economic is one-stage LRVP system.

1. INTRODUCTION

Indonesia has very large geothermal energy sources with a total potential of more than 28,000 MW. The installed geothermal power plant (GPP) capacity was 1,808.5 MW in the year 2017. The additional of GPP capacity is 250 MW, so the total GPP is 2,058.5 MW in the year 2018. By the end of the year 2018, Indonesia became the world's second-largest geothermal producer after surpassing the Philippines with total of 1,870 MW and has been further projected to become the world's largest geothermal producer after surpassing the United States with total of 3,450 MW in 2023 - the GPP capacity of 3,729.5 MW for case of total GPP of Philippines and US is not significantly increased. As per the Ministry of Energy and Mineral Resources in the energy development scenario, the GPP target up to 2025 is 7,242 MW. In 2025, the role of New Energy and Renewable Energy is at least 23% of total primary energy with a total plan of 45,044 MW (Nuryatin, 2018).

The Kamojang geothermal area was developed by Pertamina and has a very large potential of geothermal energy. Until now, the GPP operated in the Kamojang is about 300 MW, one of which is the small-scale geothermal 3 MW owned by BPPT. One type of GPP is the condensing turbine which has surplus water production. This water comes from condensation of steam and geothermal fluid separation (brine) in the separator. The results of observations in some GPPs indicated that 70% of condensation of the steam evaporated and some of it becomes adding water in the cooling tower, the 30% of remaining has been collected in the reinjection ponds together with brine and then injected into the reinjection well.

A GRS system is needed to maintain vacuum pressure in the condenser. The equipment commonly used as GRS system in the GPP is steam jet ejector (SJE), liquid ring vacuum pump (LRVP) and compressor. The existing GRS system configuration used in BPPT 3 MW GPP is a hybrid system which is a combination of SJE and LRVP, as shown in Figure 1.

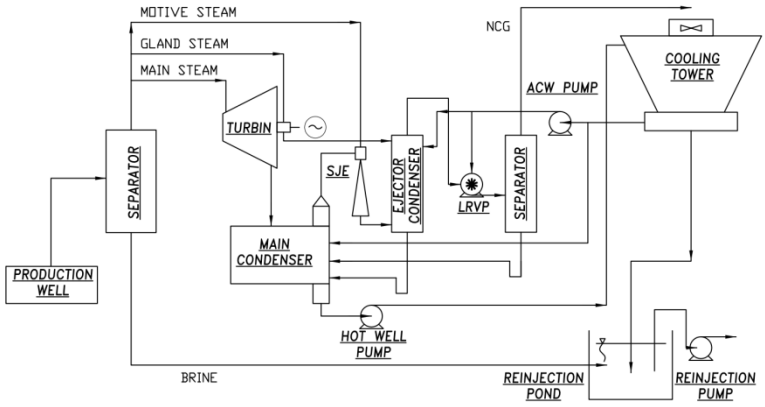


Figure 1: GRS type hybrid

The availability of water in the site, it is necessary to study and implementation GRS system by using water as the main driver of the GRS system as a substitute for SJE. This equipment is known as a water jet ejector (WJE). Using water also increases energy sustainability because it does not remove motive steam through SJE and increases electricity production if it is used to turn turbines. The NCG content in the Kamojang geothermal field is approximately 1.7% (Wahyuningsih and Sitorus, 2005). The typical NCGs are CO_2, H_2S, NH_3, CH_4, N_2, and C_2H_6, where CO_2 has an 85% portion of its composition (mass base) (Michaelides, 1982).

The laboratory-scale test of WJE has been done to confirm the potential of existing WJE in the market if used as GRS in the GPP. The WJE used in the laboratory scale test is from the jet pumps. This WJE originally has a function to draw water on the secondary side with main driver using water on the primary side. The WJE function to be tested is different when compared to WJE, which is used in GPP where on the secondary side used to draw gas containing NCG, steam and air. Based on the results of the laboratory-scale test of WJE, it can be confirmed that the existing WJE on the market can produce a low vacuum pressure as in condenser pressure on BPPT 3 MW GPP. The test results also show that the volume fraction (1.57% v/v) production is quite small because the WJE originally has a function to draw water and not ejecting the gas in the secondary side. By optimising the design and construction of WJE, it is expected to produce a much better volume fraction (Nuryadin, 2018).

WJE has a smaller efficiency compared to a commercial vacuum pump machine at higher pressures but has better performance at lower pressures based on the experimental results (Khaghani et al., 2013). The other experimental result shows that using different primary fluids (high density, low viscosity and low vapour pressure) that are water, NaI (aq) and liquid metal can create a high vacuum. Liquid metal at environmental temperatures, it shows the potential for oil-free vacuum pumps and has good performance at high operating temperatures. However, if focusing on entrainment, low-density fluid such as water is the best recommendation (Tang et al., 2016).

Study of excess steam in the Kamojang geothermal area shows that one-stage LRVP system produces net power generation greater than the hybrid system, one-stage SJE system, two-stage SJE system and two-stage LRVP system configurations (Prananto et al., 2018).

2. METHODOLOGY

2.1 The Availability of Water in Site

To find out the amount of water that can be used as the main driver of GRS, the easiest way is from PFD data of BPPT 3 MW GPP (Surana et al., 2013). By referring to the availability of water, as shown in Figure 2 and listed in Table 1, it can be predicted that the amount of WJE can be used.

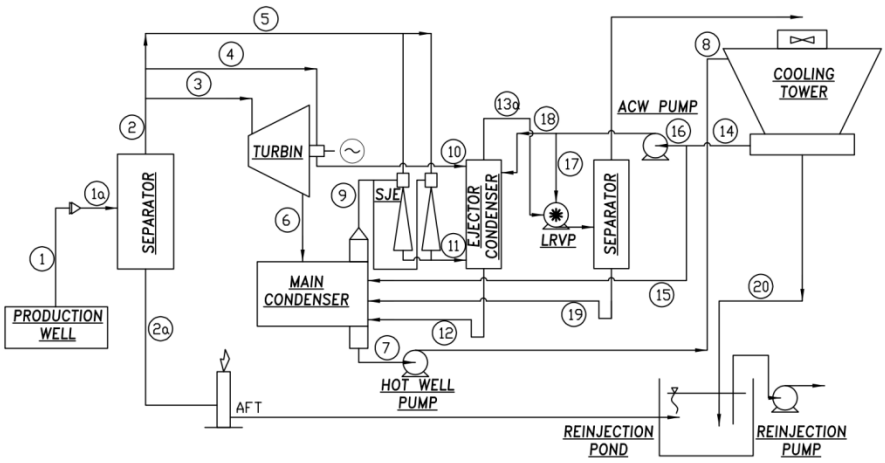


Figure 2: PFD data of BPPT 3 MW GPP

Table 1: Detail stream PFD data of BPPT 3 MW GPP

Stream Number	Pressure	Temperature	Steam Flow	NCG Flow	Water Flow	Air Flow
1	12	188	8.316	0.141	0	0
1a	7	165	8.316	0.141	0	0
2	6.5	165	8.233	0.140	0	0
2a	6.5	162	0	0	0.083	0
3	6.5	162	7.622	0.130	0	0

Stream Number	Pressure	Temperature	Steam Flow	NCG Flow	Water Flow	Air Flow
4	6.5	162	0.038	0.001	0	0
5	6.5	162	0,573	0.010	0	0
6	0.16	55.3	6.667	0.130	0.955	0
7	0.16	49	0	0	226.334	0
8	2.5	49	0	0	226.334	0
9	1	99.6	0.038	0.00064	0	0
10	0.16	49	0.021	0.130	0	0.004
11	0.4	55.3	0.594	0.139	0	0.004
12	0.16	35	0	0	69.664	0
13a	0.4	35	0	0.139	0	0.004
13b	1	35	0	0.139	0	0.004
14	1	30	0	0	219.073	0
15	1	30	0	0	149.7	0
16	1	30	0	0	69.373	0
17	1	30	0	0	0.303	0
18	1	30	0	0	69.07	0
19	0.16	35	0	0	0.303	0
20	1	30	0	0	0.924	0
21	1	30	0	0	1.007	0

Based on PFD data of BPPT 3 MW GPP and by removing the use of GRS type SJE, ejector condenser, using excess water from the cooling tower basin which ranged about 30% (this study was taken only 20%) of the condenser flow rate was not thrown away into reinjection ponds then the water flow rate that can be used for WJE is as follows (ρ_{water}= 997.25 kg/m^3):

$$\dot{m}_{water\ for\ WJE} = \dot{m}_{water\ to\ SJE} + \dot{m}_{water\ to\ CT} \quad (1)$$

$$\dot{m}_{water\ for\ WJE} = 114.34\ \text{kg/s}$$

$$\dot{V}_{water\ for\ WJE} = 412.75\ \text{m}^3/\text{h} = 0.115\ \text{m}^3/\text{s} = 6{,}879.13\ \text{lpm}$$

where $\dot{m}_{water\ for\ WJE}$, $\dot{m}_{water\ to\ SJE}$, $\dot{m}_{water\ to\ CT}$, $\dot{V}_{waterforWJE}$ are mass flow rate of water for WJE, the mass flow rate of water for SJE, the mass flow rate of water to the cooling tower, the volumetric flow rate of water for WJE, respectively.

The availability of the mass flow rate of water for WJE is about 114.34 kg/s or equal to 6,879.13 lpm. The available auxiliary pumps on the site are centrifugal type P-440 A/B (Q=250.6 m^3/h, H=10 m, P=11 kW) with electric motor drive. This pump can be used as an alternative to driving WJE if possible.

Besides water and auxiliary pumps data can be used, the data of gas ejected is also important to determine the amount and GRS configurations to be used. Based on PFD data of 3 MW GPP as indicated in Figure 2 and Table 1, it is assumed that NCG data are CO_2 equivalent, so the total rate of NCG ejected is about 0.155 kg/s or 558 kg/h.

The using water as the main driver of the GRS system (WJE and LRVP) will result in increasing sustainability and production of electricity because of not using motive steam through SJE system. The potential for the production of electricity ($P_{electricity\ potential}$) can be calculated using Equation (2).

$$P_{electricity\ potential} = \frac{\dot{m}_{steam\ to\ SJE}}{\dot{m}_{steam\ to\ turbin}} x \dot{W}_{output\ electricity} \quad (2)$$

$$P_{electricity\ potential} = \frac{0.573\ {}^{\text{kg}}/_{\text{s}}}{7.622\ {}^{\text{kg}}/_{\text{s}}} x\ 3\ \text{MW}$$

$$P_{electricity\ potential} = 0.23\ \text{MW}$$

where $\dot{m}_{water\ for\ WJE}$, $P_{electricity\ potential}$, $\dot{m}_{steam\ to\ SJE}$, $\dot{m}_{steam\ to\ turbin}$, $\dot{W}_{output\ electricity}$ are mass flow rate of water for WJE, the mass flow rate of steam to SJE, the mass flow rate of steam to SJE, the power output of electricity, respectively.

2.2 Scale-up Based on the Results of Laboratory Scale Test

The available water to drive WJE or a combination with other GRS configurations is 412.75 m^3/h or 6,879.13 lpm. The scale-up design uses auxiliary pumps P-440 A/B with a total flow rate is about 2×250.6 m^3/h. Estimated scale-up of secondary fluid flow rate with assuming the secondary flow rate produced is the same as the test result ($\dot{V}_{secondary\ test\ result}$) at a working pressure of 0.16 bar can be calculated by Equation (3) (Nuryadin, 2018). The results of the scale-up the calculation for flow rate secondary scale up ($\dot{V}_{secondary\ scale\ up}$) that can be drawn from the 3 MW GPP system are:

$$\dot{V}_{secondary\ scale\ up} = \frac{\dot{V}_{water\ for\ WJE}}{\dot{V}_{regression\ result\ of\ primary\ fluid}} \times \dot{V}_{secondary\ test\ result} \quad (3)$$

$$\dot{V}_{secondary\ scale\ up} = \frac{6{,}879.13}{60} \times 0.79 = 90.33\ \text{lpm}$$

where $\dot{V}_{secondary\ scale\ up}$, $\dot{V}_{water\ for\ WJE}$, $\dot{V}_{regression\ result\ of\ primary\ fluid}$, $\dot{V}_{secondary\ test\ result}$ are volumetric flow rate of secondary scale-up, the volumetric flow rate of water for WJE, volumetric flow rate regression result of primary fluid, the volumetric flow rate of the second test result, respectively.

The volume fraction of the design scale up ($\%_{volume\ scale\ up}$) can be calculated using Equation (4).

$$\%_{volume\ scale\ up} = \frac{\dot{V}_{secondary\ scale\ up}}{\dot{V}_{water\ for\ WJE}} \quad (4)$$

$$\%_{volume\ scale\ up} = \frac{90.33}{6.879{,}13} = 0.0131 = 1.31\%$$

where $\%_{volume\ scale\ up}$, $\dot{V}_{secondary\ scale\ up}$, $\dot{V}_{water\ for\ WJE}$, are percent volume scale-up, the volumetric flow rate of secondary scale-up, volumetric flow rate regression result of primary fluid, the volumetric flow rate of the second test result, respectively.

Based on PFD data of BPPT 3 MW GPP that NCG must be ejected is 0.155 kg/s or 558 kg/h. To meet these data, it is necessary to estimate the amount of WJE scale-up design results and the water requirements used. Table 2 shows the results of calculation of WJE needs of scale-up design results and water requirements used.

Table 2: The results of WJE needs and water requirements

No	Parameters	Value	Unit
1	Total available of water	412.75	m^3/h
2	NCG ejected for 3 MW	558	kg/h
3	Total WJE needs	88.65	pc
4	Rounded off	**89**	pc
5	Total pump needs(P-440 A/B)	146.59	pc
6	Rounded off	**147**	pc
7	Total water needs	**36,735.5**	m^3/h

3. GRS ANALYSIS, NET POWER GENERATION AND TECHNO-ECONOMIC

Existing GRS used on BPPT 3 MW GPP is a hybrid system (the combination of SJE and LRVP). In this study, the WJE system will be used as the main candidate or combination with the other of GRS.

3.1 The Availability of Water in Site

To get optimal GRS selection, some alternative GRS configuration is proposed in this study. The hybrid system is used as a comparison only in this study. Based on the results of scale-up from the laboratory scale test of WJE, it will require a considerable amount of water and also the number of pumps (Nuryadin, 2018). Therefore, the GRS configuration used in this study is a combination of WJE and LRVP, one-stage LRVP and two-stage LRVP. The selected GRS configuration, as shown in Figures 3 to 5, use water as the main driver of GRS. Based on the PFD of BPPT 3 MW GPP, the condenser pressure works at 0.16 bar.

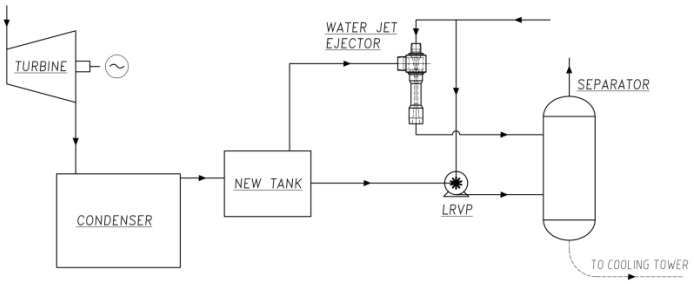


Figure 3: GRS of WJE and LRVP system

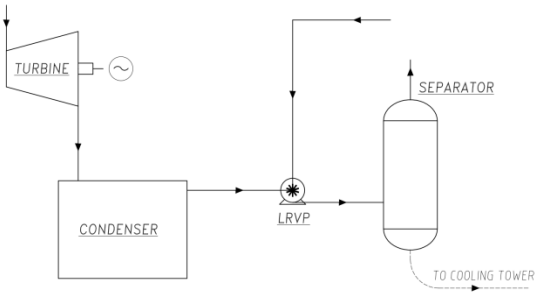


Figure 4: GRS one-stage LRVP system

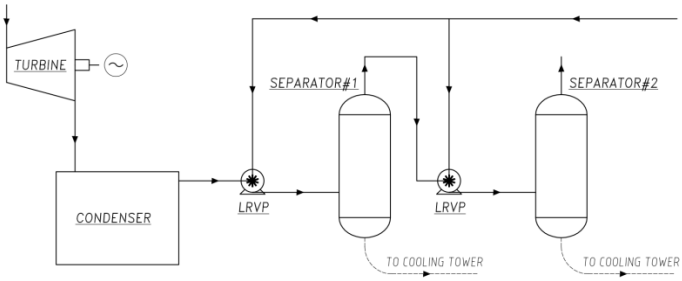


Figure 5: GRS two-stage LRVP system

To simplify the calculation, data assumption and constant parameters for GRS are used in simulation and modelling. Data assumption can be seen in Table 3. The thermodynamic analysis was conducted and refer to Moran et al. (2003).

Table 3: Data assumptions and constant parameters

No	Constant parameter	Unit	Value
1	Total steam flow rate	kg/s	8.233
2	NCG content	%	1.7
3	Steam flow rate to inlet turbine	kg/s	7.622
4	Pressure inlet turbine	bar	6.5
5	Molecular weight NCG (CO_2)	kg/kmol	44
6	Molecular weight air	kg/kmol	28.96
7	Molecular weight steam/water	kg/kmol	18
8	Cp water	kJ/kg·K	4.19
9	Cp CO_2	kJ/kg·K	0.85
10	Cv CO_2	kJ/kg·K	0.66

11	Gas constant (R)	kJ/kmol·K	8.314

3.2 Simulations of Net Power Generation

The calculation results from the selected GRS configuration will produce different net power generation. GRS, which gives the best net power generation selected as GRS recommended in this study. In general, net power generation ($\dot{W}_{net}$) can be defined as the net power produced ($\dot{W}_{output\ electricity}$) minus the total parasitic load power used ($\dot{W}_{parasit\ load}$). Equation (5) shows the formula for net power generation.

$$\dot{W}_{net} = \dot{W}_{output\ electricity} - \dot{W}_{Parasitic\ load} \tag{5}$$

where $\dot{W}_{net}$, $\dot{W}_{output\ electricity}$, $\dot{W}_{Parasitic\ load}$, are net power generation, net power produced, total parasitic load power, respectively. All of the power plants required parasitic load, including also in BPPT 3 MW GPP. The parasitic load data collected can be seen in Table 4.

Table 4: Existing data parasitic load

No	Item	Qty	Power kW	Total Power kW	Note
1	Hot well Pumps	2	55	110	Electric motor
2	LRVP	1	15	15	Electric motor
3	Auxiliary Pumps	1	11	11	Electric motor
4	Cooling Tower Fan	2	22	44	Electric motor
5	Reinjection Pump	1	11	11	Electric motor + Diesel
6	Fire water main pump	1	15	15	Electric motor + Diesel
7	Fire water jockey pump	1	1	1	Electric motor
8	Rotary screw compressor	1	11	11	Electric motor
	Total Parasitic Load			**218**	

Simulations of net power generation need to use assumption data. The assumption data used in this study is based on the data in the site, as shown in Table 5.

Table 5: Assumptions data for simulation of net power generation

No	Item	Qty	Power kW	Total Power kW	Note
1	Hot well Pumps	2	55	110	Electric motor
2	GRS selected	1	?	?	Simulation result
3	Auxiliary Pumps	1	11	11	Electric motor
4	Cooling Tower Fan	2	22	44	Electric motor

The parasitic load power used for net power generation simulation is as in Equation (6).

$$\dot{W}_{parasitic\ load} = \dot{W}_{GRS} + \dot{W}_{HW\ pumps} + \dot{W}_{Aux\ pumps} + \dot{W}_{CT\ fan} \tag{6}$$

where $\dot{W}_{parasitic\ load}$, $\dot{W}_{GRS}$, $\dot{W}_{HW\ pumps}$, $\dot{W}_{Aux\ pumps}$, $\dot{W}_{CT\ fan}$ are parasitic load power, GRS power, hot wells pumps power, auxiliary pumps power, cooling tower fan power, respectively.

3.3 Analysis of GRS Simulation and Modelling Results

The flow rate of NCG, steam and air from the condenser (0.16 bar) to a new tank (0.08 bar) can predict use Equations (7) and (8) with assuming compressible isothermal flow (Coker, 2007). Based on the schematic GRS of WJE and LRVP system in Figure 3, the results of GRS simulation where the condenser pressure is 0.16 bar and the new tank is 0.08 bar are as follows:

$$G = 2.484\, x10^{-4} d^2 \left[\left(\frac{\rho_1}{K_{Total}+2\ln\left(\frac{p'_1}{p'_2}\right)}\right)\left(\frac{(p'_1)^2-(p'_2)^2}{p'_1}\right)\right]^{0.5} \quad (7)$$

where G, ρ_1, p'_1, (p'_2) are mass flow rate, the density of upstream, pressure of upstream, pressure of downstream, respectively. Equation (8) is used to calculate K_{Total}. After K_{Total} the total value of NCG flow rate can be calculated using Equation (7).

$$K_{Total} = f_D \frac{L}{D} + \sum K_f (pipefittings + valves) \quad (8)$$

where f_D, L, D, K_f are Darcy factor, pipe length, pipe diameter, friction value of pipe fittings and valves, respectively.

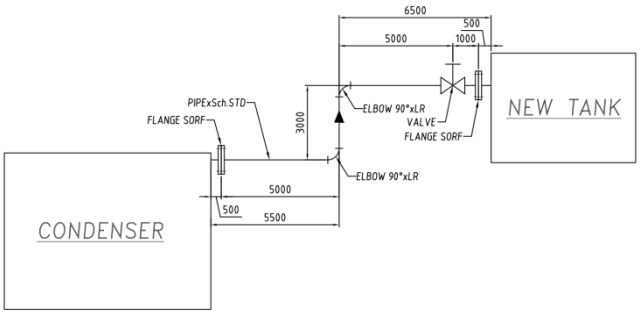


Figure 6. Assumptions for piping installation from the condenser to the new tank.

Table 6: The result of the total flow rate of NCG from the condenser to the new tank

No	Pipe Diameter	K_{Total}	G (kg/s)
1	4"xSch. STD	13.029	0.0977
2	6"xSch. STD	7.9136	0.276
3	8"xSch. STD	5.686	0.548
4	10"xSch. STD	4.362	0.958

Based on Figure 6 and the results of Table 6, it shows that the K_{Total} value significantly indicates a close relation to the total flow rate of NCG that removes from the condenser to the new tank.

To calculate GRS power ($\dot{W}_{GRS}$), WJE and LRVP system uses Equation (9).

$$\dot{W}_{GRS} = \dot{W}_{WJE} + \dot{W}_{LRVP} \quad (9)$$

where $\dot{W}_{GRS}$, $\dot{W}_{WJE}$, $\dot{W}_{LRVP}$ are GRS power, WJE power, LRVP power, respectively.

To calculate WJE power ($\dot{W}_{WJE}$) then Equation (10) is used, while to calculate the LRVP power ($\dot{W}_{LRVP}$) then Equation (11) is used.

$$\dot{W}_{WJE} = FI\ 1 \times (PI\ 2 - P_{atm}) \quad (10)$$

where $\dot{W}_{WJE}$, $FI\ 1$, $PI\ 2$, P_{atm} are WJE power, volumetric flow rate to WJE, secondary pressure resulted by WJE, atmospheric pressure, respectively.

$$\dot{W}_{LRVP} = \left[\frac{y}{y-1}\right]\frac{\dot{m}_{CO_2}.R.T_{CO_2}}{\eta_{LRVP}.M_{CO_2}}\left[\left[\frac{p_d}{p_{suc}}\right]^{1-\frac{1}{y}} - 1\right] \quad (11)$$

where $\dot{W}_{LRVP}$, y, $\dot{m}_{CO_2}$, R, η_{LRVP}, M_{CO_2}, p_d, p_{suc} are LRVP power, Cp CO_2 divided by Cv CO_2, NCG flow rate assumption for CO_2, gas constant, LRVP efficiency equal to 0.8, the molecular weight of CO_2, LRVP discharge pressure, LRVP suction pressure, respectively.

Table 7: The result of calculation LRVP power ($\dot{W}_{LRVP}$)

Parameter $\dot{W}_{LRVP}$	Value	Unit
cp CO_2	0.85	kJ/kmol·K

Parameter $\dot{W}_{LRVP}$	Value	Unit
cv CO_2	0.66	kJ/kmol·K
y	1.29	
$\dot{m}_{CO_2}$	0.153	kg/s
R (gas constant)	8.314	kJ/kmol·K
T_{CO_2}	322	K
η_{LRVP}	0.8	
M_{CO_2}	44	
$1-\frac{1}{y}$	0.224	
P_d	1	bar
P_{suc}	0.08	bar
$\left[\frac{p_d}{p_{suc}}\right]^{1-\frac{1}{y}}$	1.759	
$\dot{W}_{LRVP}$	39.56	kW

Table 8: The result of calculation WJE power ($\dot{W}_{WJE}$)

Parameter $\dot{W}_{WJE}$	Value	Unit
FI 1	412.75	m^3/h
FI 1	0.1147	m^3/s
PI2	200,000	Pa
P_{atm}	101,325	Pa
$\dot{W}_{WJE}$	11,313.29	W
$\dot{W}_{WJE}$	11.31	kW

Based on the results of calculations in Tables 7 and 8, and using Equation (9), the $\dot{W}_{GRS}$ of WJE and LRVP system is 50.87 kW. Details of calculations can be seen, as shown in Table 9.

Table 9: The result of $\dot{W}_{GRS}$ WJE and LRVP system

Parameter $\dot{W}_{GRS}$	Value	Unit
$\dot{W}_{LRVP}$	39.56	kW
$\dot{W}_{WJE}$	11.31	kW
$\dot{W}_{GRS} = \dot{W}_{WJE} + \dot{W}_{LRVP}$	50.87	kW

The next configurations besides using GRS of WJE and LRVP system is that using a one-stage LRVP system. Based on the schematic configuration of the one-stage LRVP system in Figure 4, the GRS simulation results with a condenser pressure of 0.16 bar will be discussed.

To calculate the one-stage LRVP power system ($\dot{W}_{one\ stage\ LRVP}$) then Equation (11) is used. To calculate the GRS power ($\dot{W}_{GRS}$) one-stage LRVP system then Equation (12) is used. Table 10 shows the details calculation of one-stage LRVP power system ($\dot{W}_{one\ stage\ LRVP}$).

$$\dot{W}_{GRS} = \dot{W}_{one\ stage\ LRVP} \quad (12)$$

Table 10: The results of the calculation of the one-stage LRVP power system ($\dot{W}_{one\ stage\ LRVP}$)

Parameter $\dot{W}_{LRVP}$	Value	Unit
cp CO_2	0.85	kJ/kmol·K
cv CO_2	0.66	kJ/kmol·K
y	1.29	
$\dot{m}_{CO_2}$	0.155	kg/s
R (gas constant)	8.314	kJ/kmol·K

Parameter $\dot{W}_{LRVP}$	Value	Unit
T_{CO_2}	322	K
η_{LRVP}	0.8	
M_{CO_2}	44	
$1-\frac{1}{y}$	0.224	
P_d	1	bar
P_{suc}	0.16	bar
$\left[\frac{p_d}{p_{suc}}\right]^{1-\frac{1}{y}}$	1.506	
$\dot{W}_{LRVP}$	26.70	kW
$\dot{W}_{GRS} = \dot{W}_{onestageLRVP}$	26.70	kW

Based on the results of calculations in Table 10 and using Equation (12), $\dot{W}_{GRS}$ *one-stage* LRVP system is 26.70 kW. The last configuration in this study is the two-stage LRVP system. Based on the schematic configuration of the two-stage LRVP system in Figure 5, the GRS simulation results with a condenser pressure of 0.16 bar will be discussed.

To calculate the two-stage LRVP power system ($\dot{W}_{two\ stages\ LRVP}$), Equation (12) is used. Table 11 shows the details calculation of two-stage LRVP power system ($\dot{W}_{two\ stages\ LRVP}$).

Table 11: The results of the calculation of the two-stage LRVP power system ($\dot{W}_{two\ stages\ LRVP}$)

Parameter $\dot{W}_{LRVP_1}$	Value	Unit
cp CO_2	0.85	kJ/kmol·K
cv CO_2	0.66	k/kmol·K
y	1.29	
$\dot{m}_{CO_2}$	0.0775	kg/s
R (gas constant)	8.314	kJ/kmol·K
T_{CO_2}	322	K
η_{LRVP}	0.8	
M_{CO_2}	44	
$1-\frac{1}{y}$	0.224	
P_d	1	bar

P_{suc}	0.16	bar
Parameter $\dot{W}_{LRVP_1}$	Value	Unit
$\left[\frac{p_d}{p_{suc}}\right]^{1-\frac{1}{y}}$	1.506	
$\dot{W}_{LRVP_1}$	13.350	kW
Parameter $\dot{W}_{LRVP_2}$		
cp CO_2	0.5	kJ/kmol·K
cv CO_2	0.66	kJ/kmol·K
Parameter $\dot{W}_{LRVP_2}$		
y	1.288	
$\dot{m}_{CO_2}$	0.0775	kg/s
R (gas constant)	8.314	kJ/kmol·K
T_{CO_2}	322	K
efficiency LRVP	0.8	
M_{CO_2}	44	
$1-\frac{1}{y}$	0.224	
P_d	1	bar
P_{suc}	0.16	bar
$\left[\frac{p_d}{p_{suc}}\right]^{1-\frac{1}{y}}$	1.506	
$\dot{W}_{LRVP_2}$	13.350	kW

To calculate GRS power ($\dot{W}_{GRS}$) two-stage LRVP system then Equation (13) is used.

$$\dot{W}_{GRS} = \dot{W}_{LRVP_1} + \dot{W}_{LRVP_2} \quad (13)$$

Based on the results of calculations in Table 11 and Equation (13), $\dot{W}_{GRS}$ two-stage LRVP is 26.70 kW.

Existing hybrid system (SJE and LRVP) power calculation used to comparison with the selected GRS configurations discussed in this study. Schematic hybrid system configuration can be seen in Figure 3. Because of SJE uses the motive steam as a driver, to calculate the SJE power ($\dot{W}_{SJE}$) is used the equivalent of the motive steam if it converts to produces the electricity. The equation (2) discussed before shows that SJE power ($\dot{W}_{SJE}$) used is equal to 225.53 kW. The LRVP power ($\dot{W}_{LRVP}$) used based on the actual nameplate in the site is 15 kW.

The GRS power ($\dot{W}_{GRS}$) used for the hybrid system is the sum of the SJE power ($\dot{W}_{SJE}$) and the LRVP power ($\dot{W}_{LRVP}$). Equation (14) is used to calculate the GRS power.

$$\dot{W}_{GRS} = \dot{W}_{SJE} + \dot{W}_{LRVP} \quad (14)$$

Based on Equation (14), the existing hybrid system power used is 240.53 kW. The calculation results show that the existing hybrid system uses GRS power ($\dot{W}_{GRS}$) which is the biggest of the selected GRS configuration in this study.

4. RESULT AND DISCUSSION

4.1 Net Power Generation

Existing net power generation for hybrid system needs to be calculated to determine the actual conditions and also as a comparison with the other GRS configuration used in this study. Based on Equations (5) and (6), the net power generation can be calculated. Table 12 shows the parasitic load data for the hybrid system.

Table 12: Parasitic load data for the hybrid system

No	Item	Qty	Power kW	Total Power kW	Note
1	Hot well Pumps	2	55	110	Electric motor
2	SJE + LRVP	1	240.53	240.53	SJE + LRVP
3	Auxiliary Pumps	1	11	11	Electric motor
4	Cooling Tower Fan	2	22	44	Electric motor

The net power generation produced from the existing hybrid system is 2.594 MW. Table 13 shows details calculation of net power generation produced by the hybrid system.

Table 13: Net power generation produced by the hybrid system

No	Item	Unit	SJE &LRVP
1	Cooling Tower Fan	kW	44
2	Hot well Pumps	kW	110
3	SJE + LRVP	kW	240.53
4	Auxiliary Pumps	kW	11
5	Total power consumption	kW	405.53
		MW	0.406
6	Output power generator	MW	3
7	**Net power generation output**	MW	**2.594**

Net power generation produced by WJE and LRVP system also needs to be calculated to determine its performance in this study. Based on Equations (5) and (6), the net power generation can be calculated. Table 14 shows the parasitic load data for WJE and LRVP system.

Table 14: Parasitic load data for WJE and LRVP system

No	Item	Qty	Power kW	Total Power kW	Note
1	Hot well Pumps	2	55	110	Electric motor
2	WJE + LRVP system	1	50.87	50.87	Calculation result
3	Auxiliary Pumps	1	11	11	Electric motor
4	Cooling Tower Fan	2	22	44	Electric motor

Net power generation produced by WJE + LRVP system is 2.784 MW. Table 15 shows the details of net power generation produced by WJE and LRVP system.

Table 15: Net power generation produced by WJE + LRVP system

No	Name	Unit	WJE+LRVP
1	Cooling Tower Fan	kW	44
2	Hot well Pumps	kW	110
3	WJE + LRVP system	kW	50.87
4	Auxiliary Pumps	kW	11
5	Total power consumption	kW	215.87

		MW	0.216
6	Output power generator	MW	3
7	**Net power generation output**	MW	**2.784**

Net power generation produced by one-stage LRVP system also needs to be calculated to determine its performance in this study. Based on Equations (5) and (6), the net power generation can be calculated. Table 16 shows the parasitic load data for one-stage LRVP system.

Table 16: Parasitic load data for one-stage LRVP system

No	Name	Qty	Power kW	Total Power kW	Note
1	Hot well Pumps	2	55	110	Electric motor
No	Name	Qty	Power kW	Total Power kW	Note
2	One-stage LRVP	1	26.70	26.70	Calculation results
3	Auxiliary Pumps	1	11	11	Electric motor
4	Cooling Tower Fan	2	22	44	Electric motor

The net power generation produced by one-stage LRVP is 2.808 MW. Table 17 shows the details of net power generation produced by one-stage LRVP system.

Table 17: Net power generation produced by one-stage LRVP system

No	Name	Unit	One-stage LRVP system
1	Cooling Tower Fan	kW	44
2	Hot well Pumps	kW	110
3	One-stage LRVP system	kW	26.70
4	Auxiliary Pumps	kW	11
5	Total power consumption	kW	191.70
		MW	0.192
6	Output power generator	MW	3
7	**Net power generation output**	MW	**2.808**

The last configuration for this study is the two-stage LRVP system. Net power generation two-stage LRVP system need to be calculated to determine their performance in this study. Based on Equations (5) and (6), the net power generation can be calculated. Table 18 shows the parasitic load data for two-stage LRVP system.

Table 18: Parasitic load data for two-stage LRVP system

No	Name	Qty	Power kW	Total Power kW	Note
1	Hot well Pumps	2	55	110	Electric motor
2	Two-stage LRVP system	1	26.70	26.70	Calculation results
3	Auxiliary Pumps	1	11	11	Electric motor
4	Cooling Tower Fan	2	22	44	Electric motor

The net power generation produced by two-stage LRVP system is 2.808 MW. Table 19 shows the details of net power generation produced by two-stage LRVP system.

Table 19: Net power generation produced by two-stage LRVP system

No	Name	Unit	Two-stage LRVP system
1	Cooling Tower Fan	kW	44
2	Hot well Pumps	kW	110
3	Two-stage LRVP system	kW	26.70
4	Auxiliary Pumps	kW	11
5	Total power consumption	kW	191.70
		MW	0.192
6	Output power generator	MW	3
7	**Net power generation output**	MW	**2.808**

4.2 Techno-Economic

The payback period is a method used to calculate when a turnover is achieved. By knowing the potential savings, investment and maintenance costs, the payback period can be calculated. Table 20 shows the results of the calculation of the payback period for WJE + LRVP system.

Table 20: The results of the calculation of the payback period for WJE + LRVP system

Parameter *payback period* (WJE+LRVP system)	Value	Unit
Potential savings (without SJE) of 1 year	1,975,654.68	kWh
Total parasitic load of 1 year	1,891,055.46	kWh
Total savings for one year	84,599.23	kWh
Price for 1 kWh	1,400	IDR
Total savings	118,438,920.05	IDR
Assumption on WJE+LRVP system investment costs	140,000,000	per MW
	420,000,000	3 MW
Assumption1 year maintenance cost	30,000,000	IDR
Payback period	4.75	years

The life cycle cost analysis (LCCA) method calculates the estimated cost in the n^{th} year in the present value. Table 21 shows assumption data for LCCA of WJE + LRVP system.

Table 21: Assumption data for LCCA of WJE + LRVP system

The LCCA assumption (WJE+LRVP system)	Value	Unit
Economic life cycle	5	year
Investment cost	420,000,000.00	IDR
The first year of total saving	118,438,920.05	IDR
First year maintenance costs	30,000,000.00	IDR
Rate of increase in total savings	5	%
Rate of increase in maintenance costs	3	%
Discount rate	15	%

Cash flow for the n^{th} year estimation in the present value, it can be seen in Table 22 for WJE + LRVP system.

Table 22: Cash flow in the year of occurrence WJE + LRVP system

Year	Investment costs, IDR	Total savings, IDR	Maintenance costs, IDR	Total annual cash flow, IDR	Present value total annual, IDR
0	420,000,000.00	0	0	420,000,000.00	420,000,000.00
1	0	118,438,920.05	30,000,000.00	88,438,920.05	76,903,408.74
2	0	124,360,866.05	30,900,000.00	93,460,866.05	70,669,842.01
3	0	130,578,909.36	31,827,000.00	98,751,909.36	64,930,983.38
4	0	137,107,854.82	32,781,810.00	104,326,044.82	59,648,754.73
5	0	143,963,247.56	3,765,264.30	110,197,983.26	54,787,873.56
	Net Present Value of life cycle cash flow, IDR				(93,059,137.59)

Same as with WJE + LRVP system, the one-stage LRVP system will also be calculated for the payback period. By knowing the potential savings, investment costs and maintenance costs, the payback period can be calculated. Table 23 shows the results of the calculation of the payback period for one-stages LRVP system.

Table 23: The results of the calculation of the payback period for the one-stage LRVP system

Parameter of payback period (one-stage LRVP system)	Value	Unit
Potential savings (without SJE) of 1 year	1,975,654.58	kWh
Total parasitic load of one year	1,679,286.88	kWh
Total savings for one year	296,367.81	kWh
Price for 1 kWh	1,400	IDR
Total savings	414,914,930.64	IDR
Assumption on LRVP investment costs	160,000,000.00	per MW
	480,000,000.00	3 MW
Assumption1 year maintenance cost	30,000,000.00	IDR
Payback period	1.25	years

Table 24 shows assumption data for LCCA of one-stage LRVP system.

Table 24: Assumption data for LCCA of one-stage LRVP system

The LCCA assumption (one-stage LRVP system)	Value	Unit
Economic life cycle	5	years
Investment cost	480,000,000.00	IDR
The first year of total saving	414,914,930.64	IDR
First year maintenance costs	30,000,000.00	IDR
Rate of increase in total savings	5	%
Rate of increase in maintenance costs	3	%
Discount rate	15	%

Cash flow for the n^{th} year estimation in the present value can be seen in Table 25 for one-stage LRVP system.

Table 25: Cash flow in the year of occurrence one-stage LRVP system

Year	Investment costs, IDR	Total savings, IDR	Maintenance costs, IDR	Total annual cash flow, IDR	Present value total annual, IDR
0	480,000,000.00	0	0	480,000,000.00	480,000,000.00

1	0	414,914,930.64	30,000,000.00	384,914,930.64	334,708,635.34
2	0	435,660,677.18	30,900,000.00	404,760,677.18	306,057,222.82
3	0	457,443,711.04	31,827,000.00	425,616,711.04	279,849,896.30
4	0	480,315,896,59	32,781,810.00	447,534,086.59	255,879,066.52
5	0	504,331,691.42	33,765,264.30	470,566,427.12	233,954,679.97
	Net Present Value of life cycle cash flow, IDR				(930,449,500.96)

The last configuration is two-stage LRVP system will also be calculated for the payback period. By knowing the potential savings, investment costs and maintenance costs, the period payback can be calculated. Table 26 shows the results of the calculation of the payback period for the two-stage LRVP system.

Table 26: The results of the calculation of the payback period for the two-stage LRVP system

Parameter of payback period (two-stage LRVP system)	Value	Unit
Potential savings (without SJE) of 1 year	1,975,654.68	kWh
Total parasitic load of one year	1,679.286.88	kWh
Total savings for one year	296,367.81	kWh
Price for 1 kWh	1,400	IDR
Total savings	414,914,930.64	IDR
Assumption on LRVP investment costs	190,000,000.00	per MW
	570,000,000.00	3 MW
Assumption1 year maintenance cost	30,000,000.00	IDR
Payback period	1.48	years

Table 27 shows assumption data for LCCA of two-stage LRVP system.

Table 27: Assumption data for LCCA of two-stage LRVP system

The LCCA assumption (two-stage LRVP)	Value	Unit
Economic life cycle	5	years
Investment cost	570,000,000.00	IDR
The first year of total saving	414,914,930.64	IDR
First year maintenance costs	30,000,000.00	IDR
Rate of increase in total savings	5	%
Rate of increase in maintenance costs	3	%
Discount rate	15	%

Cash flow for the n^{th} year estimation in the present value can be seen in detail in Table 28 for two-stage LRVP system.

Table 28: Cash flow in the year of occurrence two-stage LRVP system

Year	Investment costs, IDR	Total savings, IDR	Maintenance costs, IDR	Total annual cash flow, IDR	Present value total annual, IDR
0	570,000,000.00	0	0	570,000,000.00	570,000,000.00
1	0	414,914,930.64	30,000,000.00	384,914,930.64	334,708,635.34
2	0	435,660,677.18	30,900,000.00	404,760,677.18	306,057,222.82

3	0	457,443,711.04	31,827,000.00	425,616,711.04	279,849,896.30
4	0	480,315,896.59	32,781,810.00	447,534,086.59	255,879,066.52
5	0	504,331,691.42	33,765,264.30	470,566,427.12	233,954,679.97
	Net Present Value of life cycle cash flow, IDR				(840,449,500.96)

5. CONCLUSION AND FUTURE WORK

The study of water use as the main driver of GRS in GPP was completed in this study. By using water as the main driver of GRS, there is no steam motive that is wasted through SJE so that it can increase sustainability and the potential become electric power if it rotates turbines. Motive steam that is wasted through SJE if converted into electricity production (0.23 MW) is equivalent to the use of existing parasitic load power (0.218 MW). WJE can be used on small-scale GPP 3 MW when combined with LRVP. Using only WJE system will need a large amount of water. The use of LRVP is better than WJE because it uses far less water, but LRVP has rotating components, so it is not as reliable as WJE, which does not have moving components. From the selection of GRS in this study, the type of one-stage LRVP is the one that produces the highest net power generation. Techno economically, the most recommended GRS is the LRVP type one-stage.

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