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INFLUENCE OF CONFIGURATION STEAM JET EJECTOR - LRVP ON GEOTHERMAL POWER PLANT 55 MW CAPACITY

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Abstract

The stability performance of geothermal power plants is maintained by the use of a gas exhaust system (*GRS)* to remove non-*condensable* gas (*NCG)* which is a natural element of steam. *NCG* will cause an increase in pressure in the condenser and affect the turbine power. Equipment commonly used in *GRS* is steam jet ejectors (*SJE)* and or liquid ring vacuum pump (*LRVP)*. The *GRS* stage variation and the *SJE-LRVP* configuration affected the ability of the *GRS* to handle *NCG* content variations. The first stage will be using *SJE* with 30%, 40%, and 60% capacity and the second stage will be used *SJE* 130% or *LRVP* 2x65% capacity. The simulation results using the Cycle Tempo 5.0 software showed the increase in *NCG* caused an increase in condenser pressure and caused a decrease power on the *GPP* system. The use of 2x65% *LRVP* on stage two generally shows the smaller influence on *GPP* power (or larger *GPP* output power) compared to 130% *SJE* usage except for *NCG* content values smaller or equal to 0.5%.

Keywords: Configuration, Gas Removal System, Steam Jet ejector, Liquid ring vacuum pump, Geothermal power plant.

1. Introduction

Overall the total geothermal potential for Indonesia reached 27,189 MW or equivalent to 11 billion barrels of oil. The amount of potential Indonesia is 40% of the total potential for the world. Geothermal potential for West Java is very large, equal to 5311 MW or 20% of the total potential of Indonesia. Mean that 8% of the world's geothermal potential is in West Java. The purpose of this research is to obtain the effect of SJE and LRVP performance on the main condenser pressure variations and their effect on the increase or decrease of the performance of the generating system using Cycle Tempo 5.0 from a GPP.

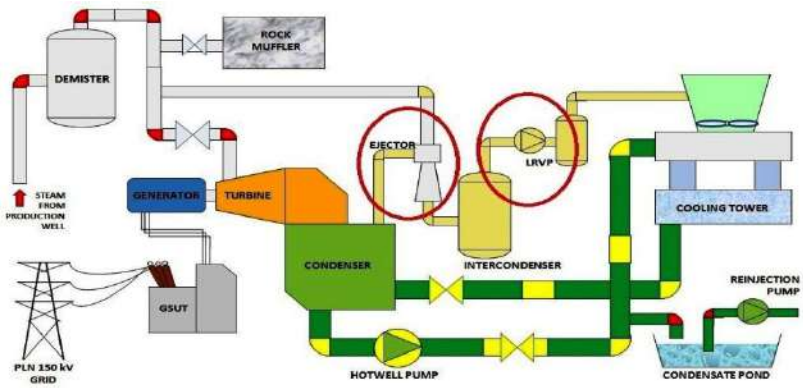

Fig. 1: Schematic GPP capacity 55 MW (Geodipa, 2015)

GRS is a tool used to trap non-condensable gas (NCG), any geothermal power plant uses a gas removal system (GRS) because it has the presence of NCG in the condenser that causes the rise of condenser pressure. To deal with this case used two main equipment, namely: steam jet ejectors (SJE) and liquid ring vacuum pump (LRVP). Both of these tools are commonly used in GPP, both of which can be used single or hybrid depending on the NCG concentration on the GPP and used on stage 1, stage 2 or stage 3.

2. NCG Flow pattern Configuration Scheme

With this two stage System design *GRS*, there are 14 configurations can be operated to depend on the % *NCG* at source of the steam. Configuration K (Configuration-1) and Configuration L (Configuration-2) will be simulated and compared the influence to the *GPP* Net Power Produced.

Table 1: GRS Configuration Pattern on GPP 55 MW

No	Configuration	*Stage* 1	*Stage* 2
1	A	SJE 30%	SJE 130%
2	B	SJE 30%	1 LRVP 65%
3	C	SJE 40%	SJE 130%
4	D	SJE 40%	1 LRVP 65%
5	E	SJE 60%	SJE 130%
6	F	SJE 60%	1 LRVP 65%
7	G	SJE 30% + 40%	SJE 130%
8	H	SJE 30% + 40%	1 LRVP 65%
9	I	SJE 30% + 60%	SJE 130%
10	J	SJE 30% + 60%	2 LRVP 65%
11	K	SJE 40% +60%	SJE 130%
12	L	SJE 40% +60%	2 LRVP 65%
13	M	SJE 30%+40%+60%	SJE 130%
14	N	SJE 30%+40%+60%	2 LRVP 65%

For concentrations of NCG below 3% the configuration that allows use is configuration A, B, C, D, E, F, G, H and for concentrations on 3% the configuration that allows use is configuration I, J, K, L, M, N. The reason for using *SJE* at stage-1 is *SJE* stable performance, low cost component criteria, easy to operate, long life component, almost maintenance free, despite the consequences of vapor discharging. At stage-1 it does not use *LRVP* due to large in-house power considerations of *LRVP* on *GPP* and expensive component price, short component life.

3. SJE - LRVP Configuration

The variables studied include: NCG concentration in Steam content, NCG removal rate based on GRS configuration, mass vapor flow rate delivered to SJE, Power on LRVP, increased pressure caused by NCG concentration, and recent simulation of it and view its impact on the increase or decrease in performance at 55 MW GPP system capacity by using Cycle Tempo 5.0. With concentration of 3% NCG and 0.0973 bar condenser pressure. Two stages GRS will be evaluated. Stage-1 uses 40% and 60% SJE capacity. Stage 2 becomes Configuration 1 using LRVP 2x65% and Configuration 2 uses SJE 130%.

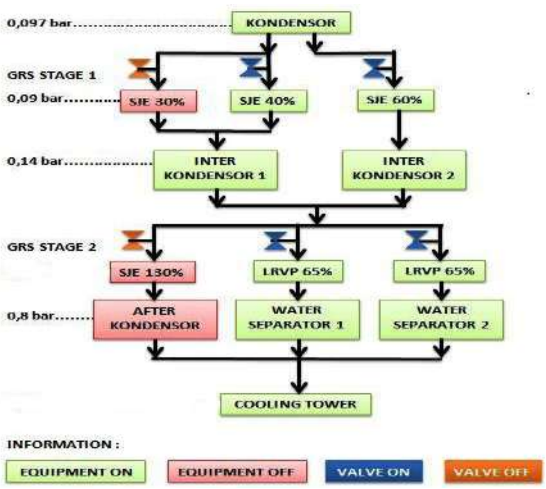

Fig. 2: NCG Flow Pattern Configuration 1

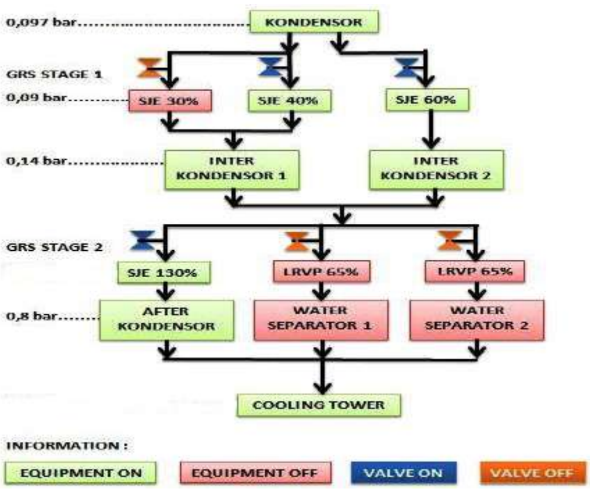

Fig. 3: NCG Flow Pattern Configuration 2

In Figure 2 showing at stage 1, the SJE will be at 0.09 bar suction pressure and 0.14 bar discharge pressure. After NCG and Steam mixed it will flow to Inter-condenser 1 and Inter-condenser 2. NCG will be sucked again by GRS stage 2 using 2x 65% LRVP capacity, and flowed to Separator Air 1 and Water Separator 2 at pressure of 0.8 bar for further flow to Cooling Tower. In Figure 3 shows the NCG 2 Flow Pattern Configurations, the phase 2 GRS will use a 130% SJE capacity with 0.14 bar suction pressure and will be discharged at a pressure of 0.8 bar in the after-condenser for subsequent flow to the Cooling Tower.

4. Calculation of SJE steam consumption.

The gas in this case NCG can be captured by an SJE, with a very varying capacity. Relate to NCG to be handled. The Heat Exchanger Institute (HEI), sponsored a test to predict the NCG handling capacity of the suction pressure and discharge pressure handling capacity. The results of the test were published in 1951 and incorporated into the HEI Standard for SJE as entrainment ratio curves.

The HEI procedure for using curves does not simplify and standardize load calculations for SJE. This procedure can have several disadvantages such as the absence of NCG-specific heat and the specific heat ratio of the correlation, as well as the neglect of the SJE dimension. But this weakness is compensated by the simplicity of the method. To model some also different conditions.

The determination of the NCG massed to flow rate and the suction and exhaust pressure on the SJE is the most flexible procedure for determining the amount of vapor required to operate the SJE. This curve can change the NCG at any temperature in DAE (dry air entrainment) which is the main parameter to determine the steam consumption of the steam release stage. DAE means the constituent composition of a substance, which in this case DAE consists of steam H2O and NCG in a particular composition.

If the NCG to be extracted from the SJE system is a mixture of steam and other gases, This should be done separately and then added to get the DAE value, then the first step is to calculate the vapor equivalent value, the NCG equivalent value and Finally the DAE is the sum of the two values.

The first step is to convert the vapor extracted from the condenser to an equivalent of 70°F. This is done by using correction factors of the weight ratio of entrainment molecules and temperature.

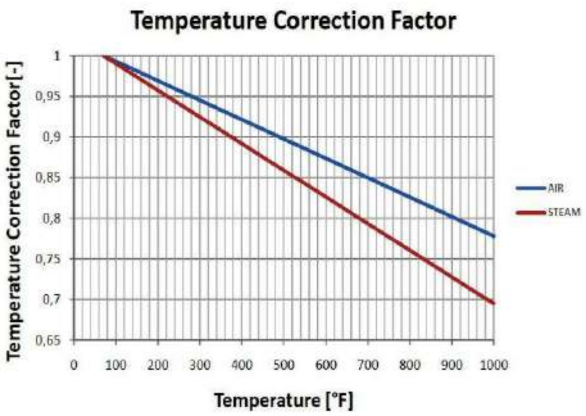

Fig. 4: ***Temperature correction Factor*** **(HEI, 2000)**

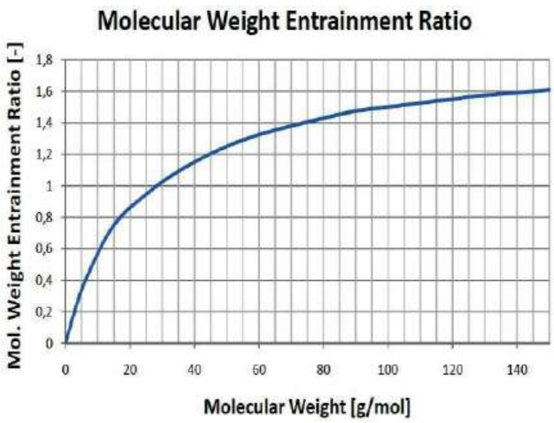

Fig. 5: ***Molecular Weight Entrainment Ratio*** **(HEI, 2000)**

For temperature correction it is necessary to compare the temperature of the entrainment to determine the equivalent air flow. This can be done using the Figure of, entering the graph with a steam temperature at °F and cutting the steam line to obtain the correction factor value of the y-axis. Correcting after the temperature values it is necessary to calculate the weight entrainment ratio value of the figure of, using the molecular weight of water (vapor) 18.02, and entering the graph from x-axis to curve, is performed to read the entrainment weight. The value of the y-axis.

Then the steam into the equivalent air is calculated by:

$$DAE_{h2o} = \frac{\dot{m}_{h2o}}{TCF_{h2o} * WER_{h2o}} \quad (1)$$

The non-condensable gases in this case the NCG is assumed to consist of 100% CO2 in fact the CO2 content of the measurement data is about 98%. For then the NCG equivalent calculation, the procedure according to HEI is similar to the vapor equivalent calculation, Only in this which case is necessary first to fix the weight of CO2 into the NCG equivalent using Figure molecular weigh entrainment ratio and then fix the temperature of NCG using °F equivalent by using the temperature correction factor of the Image temperature correction factor.

Then the CO2 airs equivalent is calculated by:

$$DAE_{CO2} = \frac{\dot{m}_{CO2}}{TCF_{CO2} * WER_{CO2}} \quad (2)$$

Finally the total steam equivalent is the addition of DAE steam and DAE NCG values.

$$\mathrm{DAE} = \mathrm{DAE}_{CO2} + \mathrm{DAE}_{H20} \quad (3)$$

Once DAE is determined, it is necessary to calculate the amount of vapor required to suck NCG from the condenser, this is done by using the ratio of air to vapor, which determines the amount of vapor required to remove a certain amount of NCG. Under certain pressure conditions. This pressure condition is related to the steam mass flow rate entering the SJE, the SJE NCG suction pressure and the SJE release pressure.

The ratio of NCG to steam is obtained from the graph shown in the figure of air to steam ratio, the input data is the compression ratio (CR), and the expansion ratio (ER) defined as:

$$\mathrm{CR} = \frac{P_{dis}}{P_{suc}} \quad (4)$$

$$\mathrm{ER} = \frac{P_{ms}}{P_{suc}} \quad (5)$$

For this case it is important to note that in the event of pressure velocity mass flow rate entering the *SJE*, *SJE NCG* suction pressure and *SJE* release pressure. Each then stage has the same compression ratio, and the expansion ratio is the same as well.

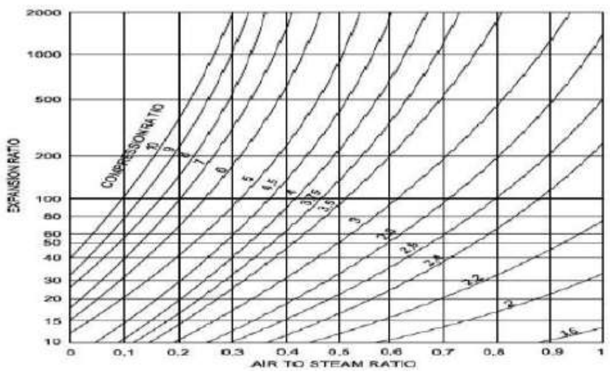

Fig. 6: ***Air to Steam Ratio*** **(HEI, 2000)**

Eventually the consumption of steam (SC) for each stage in SJE is defined as

$$\mathrm{SC} = \frac{\mathrm{DAE}}{\mathrm{AS}} \quad (6)$$

Pressure into SJE (motive steam) and condenser will affect the compression and expansion ratio, thus modifying the ratio of air to vapor and steam consumption. These parameters can greatly affect the amount of vapor consumed at each stage of the SJE system.

When non-condensable gases are removed from the condenser, some vapors are also carried out along with the NCG, as they are mixed in the condenser. The suction pressure on the SJE is at least 0.01 bars lower than the condenser pressure assuming a constant pressure drop between the condenser and the GRS system. (Pálsson, 2010). The design parameters are:

- The steam mass flow rate entering the turbine is 101,44 kg/s.
- Percentage of NCG at 3%.
- SJE or Psuc suction pressure of 0.09 bar.
- SJE or Pdis out pressure of 0.14 bar.

Temperature interconnected 38°C.In determining the required power an LRVP can work required some design parameters in suction pressure, discharge pressure, mixed mass flow rate, inter-condensor temperature and NCG concentration. To calculate the electrical energy requirements required to turn on one LRVP the following formula is used (Siregar, 2004):

$$W_{lrvp} = \left[\frac{\gamma}{\gamma - 1}\right] * \frac{\dot{m}_{mix} * R * T_{mix}}{\eta_{lrvp} * M_{mix}} * \left[\left(\frac{P_{dis}}{P_{suc}}\right)^{1-\frac{1}{\gamma}} - 1\right] \quad (7)$$

5. SIMULATION

The simulation is done in two configurations with the help of software cycle tempo 5.0. After obtaining a manual calculation of the concentration of NCG, and steam consumption wasted in SJE and then incorporated into the simulation. Configuration 1 modeled the stage 1 GRS (SJE 40% and SJE 60%). On stage 2 uses LRVP 2x65% Capacity.

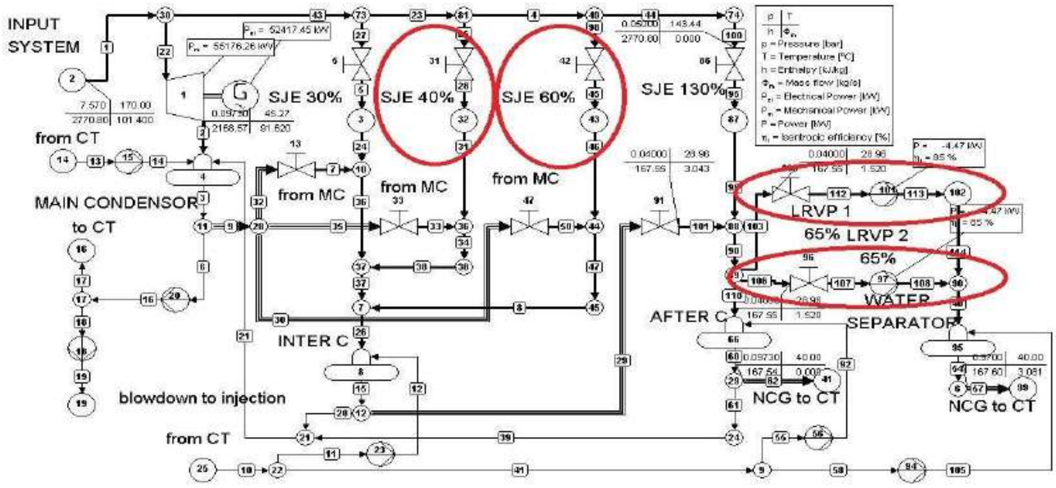

Fig. 7: Simulation results at NCG 3% in configuration 1

Configuration-2 modeled the stage 1 GRS (SJE 40% and SJE 60%). On stage 2 using (SJE 130%) everything is on.

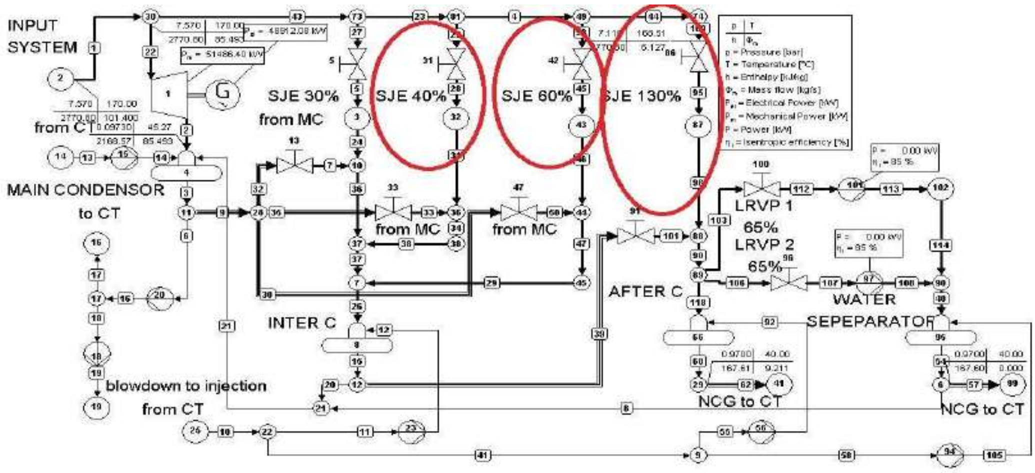

Fig. 8: Simulation results at NCG 3% in configuration 2

The simulation result shows at table 2.

Table 2: Simulation results for Configuration 1 and Configuration 2.

No	NCG (%)	M Uap	M NCG	P In (bar)	ΔP condensor (bar)	P condensor (bar)	Power System (MW) LRVP ON SJE OFF	Power System (MW) SJE ON LRVP OF
1	0,0	1,000	0,000	7,570	0,0000	0,0945	58,305	58,305
2	0,5	0,995	0,005	7,570	0,0005	0,0950	57,317	56,721
3	1,0	0,990	0,010	7,570	0,0009	0,0954	56,332	55,146
4	1,5	0,985	0,015	7,570	0,0014	0,0959	55,343	53,570
5	2,0	0,980	0,020	7,570	0,0018	0,0963	54,369	52,013
6	2,5	0,975	0,025	7,570	0,0023	0,0968	53,390	50,458
7	3,0	0,970	0,030	7,570	0,0028	0,0973	52,417	48,912
8	3,5	0,965	0,035	7,570	0,0032	0,0977	51,458	47,384
9	4,0	0,960	0,040	7,570	0,0037	0,0982	50,495	45,858
10	4,5	0,955	0,045	7,570	0,0041	0,0986	49,548	44,349
11	5,0	0,950	0,050	7,570	0,0046	0,0991	48,596	42,842
12	5,5	0,945	0,055	7,570	0,0051	0,0996	47,648	41,345
13	6,0	0,940	0,060	7,570	0,0055	0,1000	46,715	39,864

6. ANALYSIS

After performing manual calculations for the NCG mass to flow rate, and mass to flow rate of steam-driving consumption of the SJE, then from the calculation, after collecting all the calculation results from the increase of each NCG 0,5% from NCG 0% to NCG 6%.

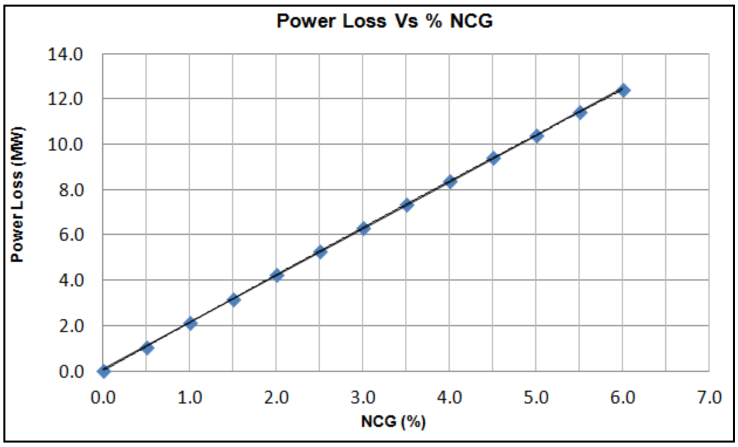

Fig. 9: The power loss to the increased of NCG

% NCG has very significantly influence on the system power loss. From the results obtained from Figure 9 shows the loss of power in the GPP system due to losses caused by GRS stage 2 installed capacity of SJE 130%, at the opening of GRS stage 1 (SJE 40% and SJE 60%) up to 12.617 MW maximal at concentration increases to 6%. With NCG 3 %, the system will be 6.423 MW reduced power. The power loss is approximately 2 MW per 1% increased NCG.

Figure 10 shows the influence of % NCG to the Power of GPP System

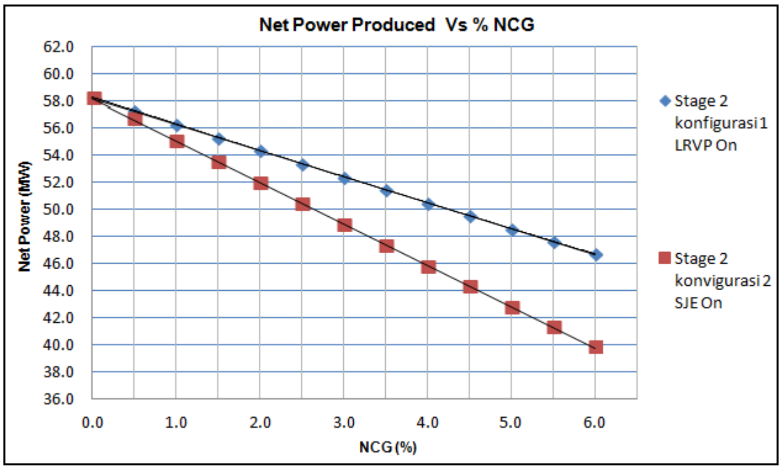

Fig. 10: Net Power Produced to the increase in NCG

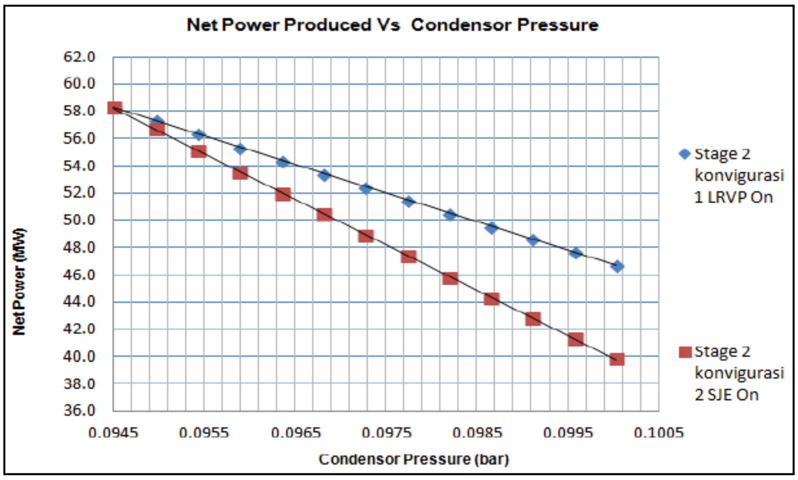

Fig. 11: Net Power Produced to the increase in NCG

With a mixed mass vapor flow rate of 104,4 kg/s and 1 % NCG, Configuration-1 can generate power of 56.332 MW and Configuration-2 produces 55.146 MW of power. Configuration-1 is better at saving power in the in-house power of GPP using LRVP 2x65% capacity of discharging consequences, This can be seen when the concentration of NCG increases to 6% system power produces 46,715 MW. Configuration-2 is worse in saving power in the in-house power of GPP, because it uses SJE 130% with the consequence of discharging the steam to suck the NCG present in the condenser. This can be seen when the concentration of NCG increased to 6% system power output 39.864 MW. When the concentration of NCG above 0.5%, then the use of LRVP is better compared to SJE.

7. CONCLUSION

1. GPP system modeling can be simulated using software cycle tempo 5.0 by adjusting the input parameters that exist on the technical specifications of existing equipment in software cycle tempo 5.0.
2. The simulation of Configuration 1 and Configuration 2, configuration 1 is better at saving power for GPP systems capacity of 55 MW in the face of 3% NCG concentration.
3. For NCG less than 0.5% using Configuration 1 on stage 2 is better in system performance than using configuration 2 on stage 2.
4. For NCG concentrations greater than 0.5% using configuration-1 on stage 2 save more powers than using configuration 2 on stage 2.
5. For every 0.5% NCG concentration increase using configuration-1 is better in performance of GPP system than configuration 2.
6. For NCG concentrations of 0.5%-6%, the use of LRVP in stage 2 is better in system performance compared to using SJE.

8. NOMENCLATURE

DAE_{h2o} : Dry air constituents from H_2O [kg/s]
DAE_{co2} : Dry air constituents from CO_2 [kg/s]
h. : Entalpi [kJ/kg]
$\acute{m}_{co2}$: Mass flow rate of CO_2 [kg/s]
$\acute{m}_{h2o}$: Mass flow rate of steam [kg/s]
$\acute{m}_{ncg}$: Mass flow rate of NCG [kg/s]
$\acute{m}_{mix}$: Mass flow rate of NCG and steam [kg/s]
M_{ncg} : Mole mass NCG [kg/kmol]
M_{h2o} : Mole mass steam [kg/kmol]
M_{mix} : Mole mass NCG and steam [kg/kmol]
P_{cond} : Condenser pressure [bar]
P_{IC} : Inter condenser pressure [bar]
P_{ms} : Push Pressure of steam jet ejector [bar]
P_{suc} : Inside Pressure of steam jet ejector [bar]
P_{dis} : Outside Pressure of steam jet ejector [bar]
R : The ideal gas constants [J/mol K]

S : Entropi [kJ/kg.K]
T_{co2} : Temperature [°F]
T_{h2o} : Temperature [°F]
T_{mix} : Mix temperature of interkondensor [°K]
TCF_{h2o} : Temperature correction factor of steam [-]
TCF_{co2} : Temperature correction factor of NCG [-]
WER_{co2} : The carrying mass ratio in CO_2 [-]
WER_{h2o} : The carrying mass ratio in H_{2O} [-]
W_{Pompa} : Power pump [kW]
W_{Turbin} : Power steam turbin [MW]
W_{Sistem} : Power system [MW]
η : efisiensi [%]
γ : Gamma: Cpgas/Cvgas [-]
GPP : Geothermal Power Plant.
SPP : Solar Power Plant.
WPG : Wind Power Generation.

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