ISSN No:-2456-2165

Study of Liquid Ring Vacuum Pump's Capacity to Reduce Motive Steam Consumption of Gas Removal System in Indonesia's Geothermal Power Plant 117 MW

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Abstract:- Gas Removal System (GRS) is vital in geothermal power plants since steam flows into the turbine and the condenser still has a certain amount of Non-Condensable Gas (NCG). The effect of the NCG will increase the pressure in the condenser so that it will affect the power generation performance of the Geothermal Power Plant (GPP). The types of equipment used in GRS are steam jet ejectors dan Liquid Ring Vacuum Pumps (LRVP). The existing configuration of GRS in this GPP uses a hybrid system for Train A and Train B, which consists of 2 stages for steam ejector and 1 stage for LRVP. This study aims to see the opportunities for motive steam reduction in the GRS by modifying the GRS configuration system using only 1 stage steam ejector and 1 stage LRVP on Train A and Train B. The research method used is to calculate the capacity of the LRVP based on data from the manufacturer and actual data processing in the field. The results of this study indicate that the LRVP capacity is still above the NCG flow rate. Therefore, it can still pull a certain amount of NCG from the condenser. Economically, the motive steam that can be saved from this modification is 11,724 kg/hr or equivalent to 3,26 MW generation.

***Keywords**:- Geothermal, Gas Removal System (GRS), Non-Condensable Gas (NCG)**,** Liquid Ring Vacuum Pump (LRVP), motive steam.*

I. INTRODUCTION

Geothermal energy is one of the renewable energy sources from nature and can reduce Indonesia's dependence on fossil energy sources. Based on the Handbook of Energy and Economics Statistics Indonesia in 2020, the total installed capacity of Geothermal Power Plants (GPP) in Indonesia is 2,13 GW compared with geothermal energy potential in Indonesia with a totalof 25,4 GW. Indonesia's Ministry of Energy and Mineral Resources Roadmap targets a total installed capacity of PLTP of 7780 MW by 2030. This target can be achieved by constructing new plants or developing existing generating capacity by increasing energy efficiency.

There are several types of Geothermal Power Plants (GPP): flash systems, dry-steam, binary cycle power plants and combined cycle[1]. GPP has a working principle like coal fire Power Plant, but the difference is that the source of the steam fluid in the coal fire PP comes from coal fuel that is burned in the boiler, while in GPP, the source of the steam fluid comes from heat from inside the earth. However, the geothermal fluid contains other gases commonly called Non-condensable Gas (NCG) like CO_2, H_2S, NH_3, N_2, CH_4, etc. Those NCG content can influence the performance of the power plant.

1% NCG content by weight can reduce power generation by 0.59% compared to steam without NCG[2]. Therefore, extracting NCG is essential to maintain the performance of geothermal power plants. In general, there are two main pieces of equipment for the Gas Removal System (GRS) to extract NCG; a steam jet ejector and a liquid ring vacuum pump[3].

Several studies on the optimization of gas removal systems have been carried out. Yamin W et al. conducted a study to increase the generator's efficiency by regulating the steam inlet on the steam jet ejector. Controlling the steam inlet on a steam jet ejector that adjusts to the generator load can reduce the use of steam equivalent to 0,7 MW [4]. A study conducted by Jayakalena F and Hermanto showed that the use of dual LRVP with a capacity 2x65% is more suitable compared to 130% steam jet ejector for NCG content of more than 0.5% weight in 55 MW geothermal power plant in Indonesia[5].

Another study is conducted to determine how effective the steam jet ejector is in producing vacuum and see the performance of the steam ejector at the Thermal Power Station in Vijawawada. The results of observations on the design of the steam jet ejector are that the smaller the entrainment ratio, the more air that can inhale, and shows that the more vacuum indicates the better condenser performance [6].

GRS is a design based on how much NCG is contained in the geothermal power plant. As in the previous research, both steam jet ejector and LRVP have their respective advantages. There is an opportunity to save the consumption of motive steam in the GRS by modifying the GRS configuration systemusing only 1 stage of steam ejector and

1 stage of LRVP on Train A and Train B. By maximizing LRVP based on operating condition data, steam supply can be saved because there is one steam ejector that is shut down for each train.

II. STUDY LITERATURE

A. Geothermal Power Plant

A single flash system is the most common type of geothermal power plant installed globally[7]. The working principle of this type of GPP is to convert 2-phase fluid from the well, namely a mixture of steam and liquid, which is then separated in a separator. The steam produced will be continued to the turbine while the hot water or brine produced will be injected into the injection well [8]. The turbine will produce mechanical energy, which is coupled with a generator to generate electrical energy. Maintaining vacuum pressure in the main condenser is necessary to maintain the power plant's performance. One way is to withdraw NCG using GRS. A diagram of the single flash system is shown in Figure 1.

B. Gas Removal System

Gas Removal System is vital in geothermal power plants, especially for systems that use turbines and condensers. Steam flow into turbine and condenser generally still has a certain amount of Non-Condensable Gas (NCG). The effect of the NCG will increase the pressure in the condenser, affecting the power generation performance of GPP[9].The gas removal system will withdraw the NCG in the condenser, which consists of a steam jet ejector and a liquid ring vacuum pump. The NCG from the condenser is a mixture of gas and steam. It can assume that the gas is in saturation with steam when the NCG is pulled out of the condenser. The mixture of gas and steam in NCG is dominated by gases such as CO_2 up to a composition of more than 95% of NCG[10]. To condense the vapor mixture in the NCG, inter-condenser and after-condenser are used to reduce the burden on the next stage of GRS because some of the steam has been condensed into water. These types of equipment can also reduce the content of steam discharged into the environment because the condensed steam will re-enter the main condenser.

C. Steam Jet Ejector

A steam ejector is equipment used to convert the high-pressure energy of motive steam to kinetic energy to pull out gas fluid[11].A steam jet ejector's design will theoretically utilize high-pressure fluid to compress from low pressure to higher pressure[12]. There are no rotating components or power required in this equipment, so a steam jet ejector is a simple tool both in terms of operation and maintenance. This equipment needs lower capital costs than the LRVP [13]. The disadvantage of the steam jet ejector is that this tool requires a certain amount of steam to operate, which usually comes from steam before going to the turbine, so that it can reduce the thermal efficiency of a geothermal power plant. Steam ejector design consists of several parts, which describes in Figure 2. The essential components include a steam nozzle, suction chamber, supersonic diffuser, throat, and subsonic diffuser[14].Steam enters through the nozzles in section A where the steam velocity becomes very high until it reaches a speed of one mach due to the shape of the nozzle and the vapor pressure becomes very low. A gas that cannot be condensed from the condenser will be sucked into the suction chamber due to the vapor pressure, which becomes a vacuum. Furthermore, the mixture of steam and gas will enter the supersonic diffuser, where the pressure increases and the velocity decreases and enters the throat section. Then the mixture of steam and gas will exit through the subsonic diffuser, where the speed will decrease again and the pressure will increase, but not like the pressure at the steam inlet.

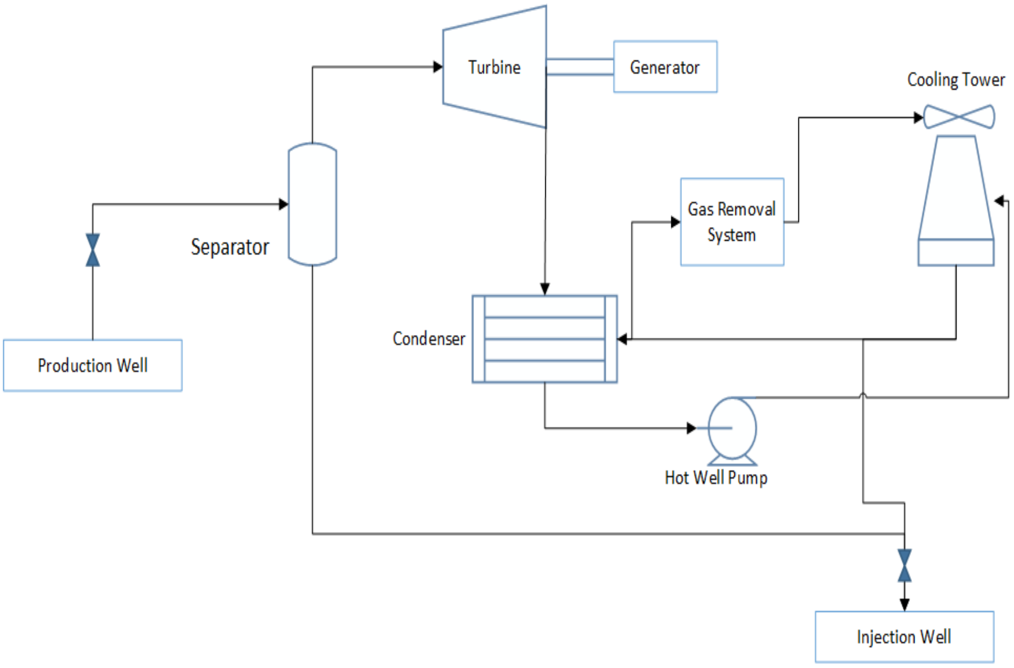

Fig. 1: Single flash geothermal schematic diagram

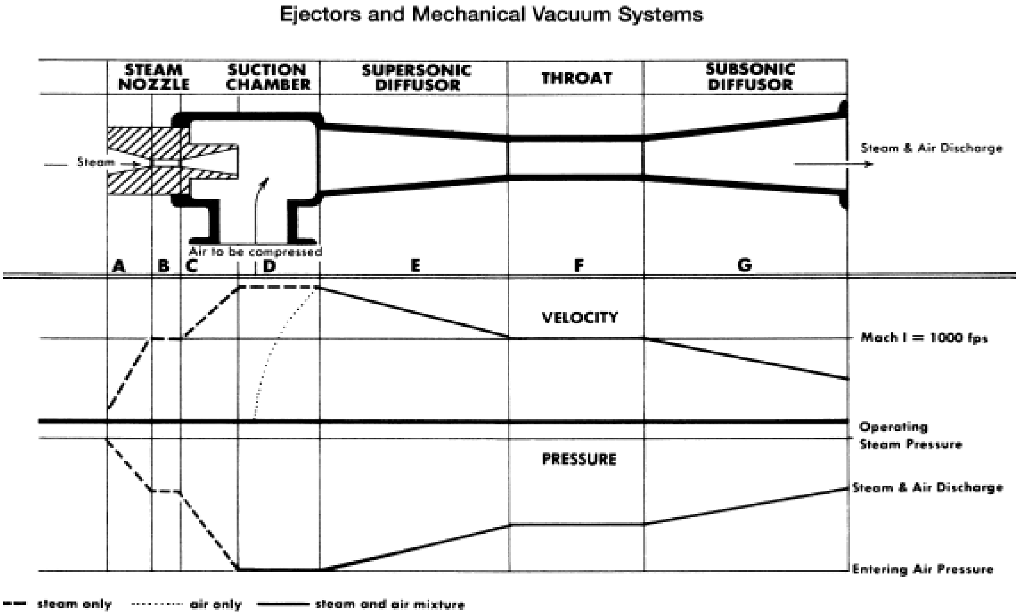

Fig. 2: Basic ejector components and diagram of energy conversion in nozzle and diffuser (Ingersoll-Rand Co.)

D. Liquid Ring Vacuum Pump

The Heat Exchange Institute defines a *liquid ring vacuum pump* as a rotary positive displacement pump that uses a liquid as the principle in compressing gases. The compressed gas is carried out by a liquid that forms a ring[15]. The NCG that enters through the inlet will then be compressed and forwarded to the pump outlet. This NCG has been mixed with liquid, and to separate the gas and liquid, the vacuum pump outlet will go directly to the separator. After being separated in the separator, the gas will continue to the cooling tower while the water will be recirculated to the LRVP. The suction pressure on the vacuum pump has a value below atmospheric pressure or can be called a vacuum condition [16]. Rotation of the impeller on the pump will make the fluid ejected out due to centrifugal force and form a liquid ring. Due to the eccentricity of the impeller to the casing, a crescent-shaped space is formed. As the impeller rotates, an area on the suction port sucks the NCG through the suction port. On the opposite side of the suction port, the NCG is compressed in a smaller area and pulled out the NCG through the discharge port [17]. The operating principle of the liquid ring pump is illustrated in Figure 4.

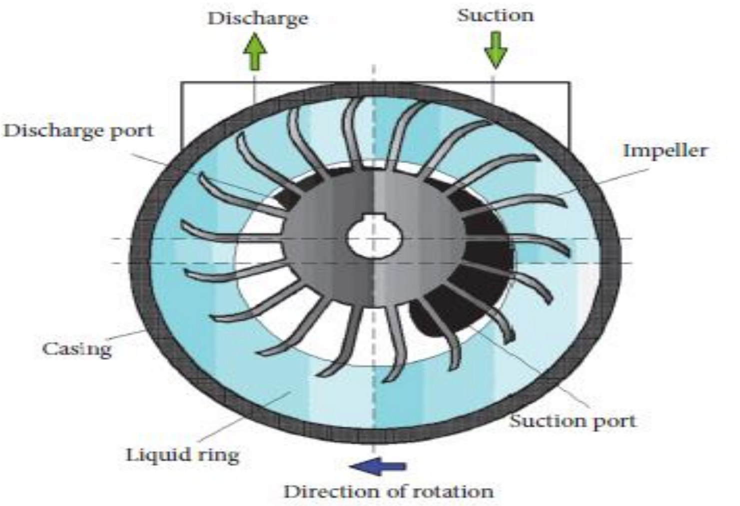

Fig. 1: Operating principle of Liquid Ring Vacuum Pump [17]

The application of LRVP is limited by the vapor pressure of the seal water because it will affect the ability of LRVP to perform compression. Seal water on this LRVP is one of the critical parameters that must be maintained from pressure and temperature. Seal water temperature is very influential on the magnitude of the suction pressure on the LRVP and the capacity of the gas to be drawn. This is because the higher the seal water temperature, the higher the vapor pressure and the higher energy consumption will be needed. With the high vapor pressure, the vacuum pressure at the suction of the LRVP is also limited because it must be above the vapor pressure. The lower temperature of seal water will also prevent cavitation; it will extend the pump's life[18]. Figure 5 describes the effect of seal water temperature on the suction pressure of the vacuum pump.

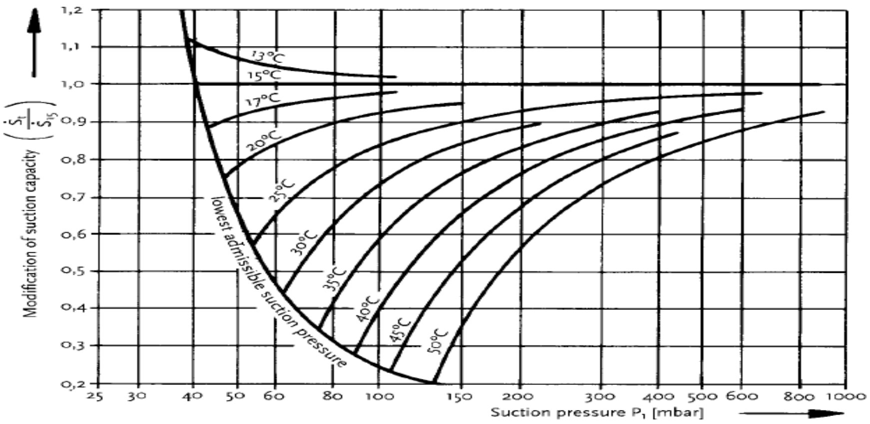

Fig. 5: Graph of the effect of Seal Water temperature on suction pressure and capacity factor *(Liquid ring vacuum pumps, compressor and systems handbook)*

The suction flow in the LRVP is determined by the volume available to the pump and the impeller rotation theoretically. The volume inside the pump not only contains a liquid mixture of gas and steam that is sucked in, but the other part contains a liquid ring so that the capacity of the gas and steam mixture that can be sucked in is reduced and can be referred to as a correction factor according to Dalton's law. The equation used to determine the volume capacity of gas is referred to as equation 1 as the explanation from Helmut Banwarth.

$$S_{eff} = S_k \frac{p_A - p_S}{p_A - p_k} \qquad (1)$$

S_{eff}: effective suction capacity

p_A: suction pressure of the pump

p_s: saturated vapor pressure of the operating liquid at the operating temperature

p_k: saturated vapor pressure of the operating liquid under conditions given in the catalogue (at 15°C)

III. RESEARCH METHODOLOGY

This research will be conducted at one of the geothermal power plants in Indonesia, which has an installed capacity of 117 MW in one of its units. The type of the GPP installed is a single flash system with the dominant two-phase fluid. The dominant gas of NCG produced in production wells is CO2 and H2S. This type of quantitative research uses actual data processing methods in the field, which refers to equations and formulas derived from several journals and books. This research focuses more on studying configuration changes in the existing design of the Gas Removal System. The data that need to be collected are NCG Flow rate, motive steam flow rate, existing LRVP Suction pressure, Inter-condenser outlet pressure, and seal water temperature. After collecting the operational data and specifications of the GRS equipment, the next step is to calculate the capacity factor of LRVP with variations in seal water temperature. The capacity of gas sucked by LRVP can be calculated with the capacity factor that has been determined, referring to LRVP performance curve. The next step is to validate the total NCG flow rate from operational data with the total NCG flow rate of LRVP after modification of Gas Removal System. Figure 6 explains the flow diagram of the research.

A. Equipment Specification

The system of GRS in this power plant uses a hybrid system. The hybrid system uses steam jet ejectors and liquid ring vacuum pump. In this GPP, the steam jet ejector consists of two stages. The specification of that equipment is shown in table 1 and table 2.

Table 1: Specification of steam jet ejector

No	Stage	Capacity	Value (kg/hr)	Remark
1	First	Motive Steam	5561	Train A/B
		NCG	14900	Train A/B
2	Second	Motive Steam	5862	Train A/B
		NCG	14900	Train A/B
3	First	Motive Steam	8610	Train C
		NCG	14900	Train C
4	Second	Motive Steam	10253	Train C
		NCG	14900	Train C

Table 2: Specification of LRVP

Manufacturer	Nash Gardner Denver
Model	N904L22-2HY3-Z
Capacity	8195 m^3/hr
Suction Pressure	-0,828 bar g to -0,024 bar g
Discharge Pressure	0,01 bar g
Type of Pump	Centrifugal Pump
Operating Rotation	484 rpm
Number of stages	one
Size (suction x discharge)	10” x 8”

B. *Existing Configuration of GRS*

The existing GRS design of this GPP used a hybrid type of vacuum system on Train A&B and condensing steam ejector type vacuum system on Train C. Hybrid combines two stages of steam ejectors, and the third stage is a vacuum pump. Train A and Train B are used for regular operation, but if there is maintenance or another activity, Train C will be used as a backup. Figure 7 describes the schematic diagram for the existing design of GRS.

C. *ModificationConfiguration of GRS*

The modification of this hybrid is that the system only uses the first-stage steam ejector and liquid ring vacuum pump as the second stage of GRS on Train A and Train B. Therefore, the motive steam needed for the second stage ejector can be removed. The difference between the modified design and the existing one is the presence of a block valve between the outlet inter-condenser and inlet second-stage ejector to stop NCG flow from the first-stage ejector into the second-stage ejector. It also needs a block valve between the outlet after-condenser to the LRVP to stop NCG flow from the second stage ejector to the LRVP. An additional block valve upstream of the second stage steam ejector is to stop the motive steam flow. In addition, this modification also requires the installation of a pipe from the inter-condenser outlet directly into the LRVP. If the NCG is too high, the second stage of the steam ejector can be operated again, and the system is back to the existing hybrid system. Figure 8 describes the schematic diagram of the design modification.

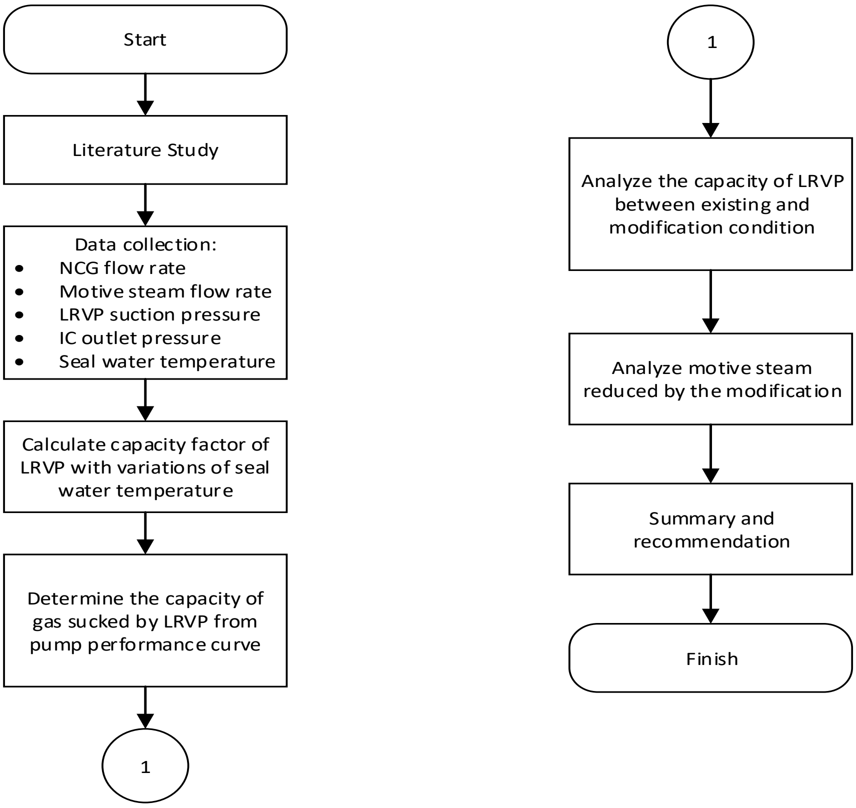

Fig. 6: Flow diagram of Research

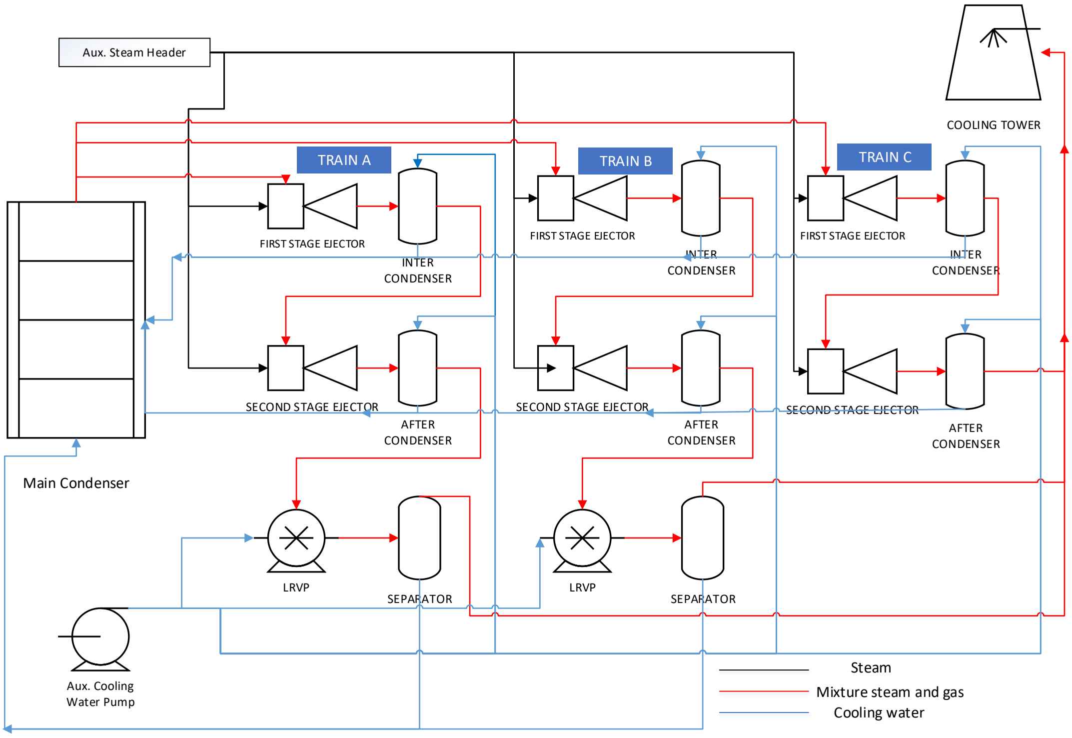

Fig. 7: Existing Configuration of Gas Removal System

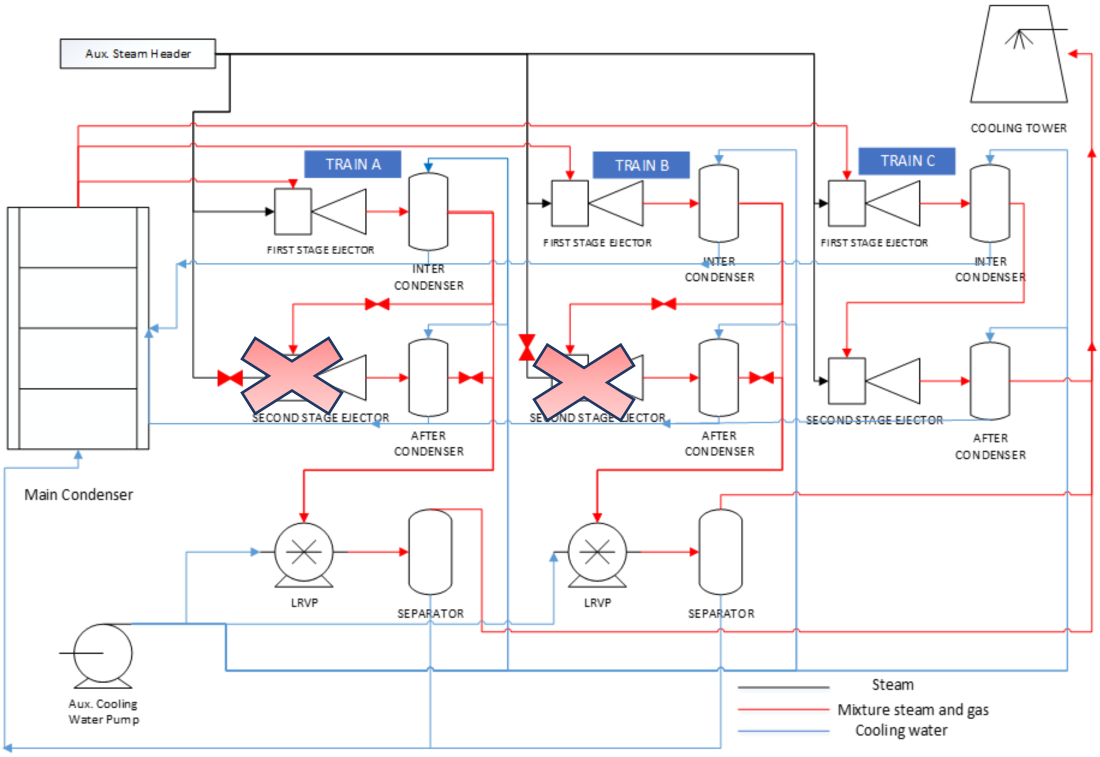

Fig. 8: Modification design of Gas Removal System

IV. RESULT AND DISCUSSION

A. Non-Condensable Gas Condition

The Non-Condensable Gas (NCG) total data is collected from average operation data each month from 2017 to 2021. The data was from the flow transmitter in the downstream main condenser into the steam ejector. NCG total is a mixture of steam and gas collected from the main condenser. Figure 9 shows the NCG flow rate operation data for 2017 – 2021. NCG flow rate has ranged from 2,09 – 2,38 kg/s.

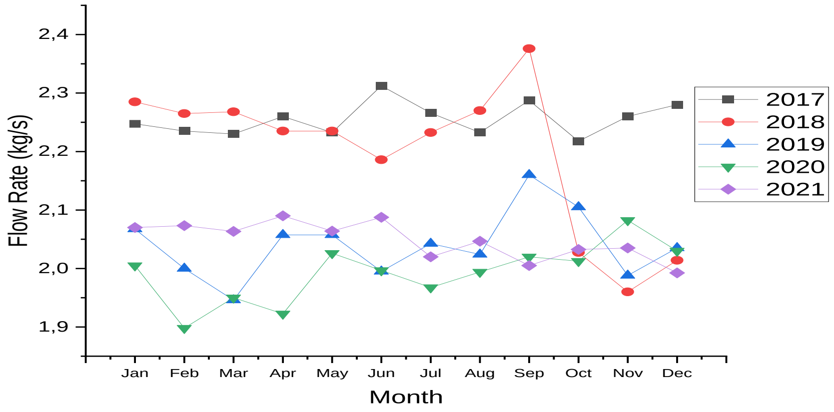

Fig. 9: NCG total flow rate

B. *Seal Water of LRVP*

Seal water temperature is one of the factors affecting the maximum gas that can be absorbed. The pump capacity factor has been calculated using the pump capacity calculation method referred to Helmut Banwarth journal. The method of capacity factor is calculated from the suction pressure and vapor pressure of seal water. From the calculation results, it is known that the higher the seal water temperature, the lower the capacity factor of the NCG that can be absorbed. The higher temperature of the seal water, the more likely the seal water will require a larger volume of space in the pump. Data on seal water temperature was obtained from January to December 2021 by averaging each month, as shown in Figure 10. The vapor pressure was obtained from the assumption water in saturation pressure 1 barg. Figure 11 describes the effect of seal water temperature on the capacity factor of LRVP suction.

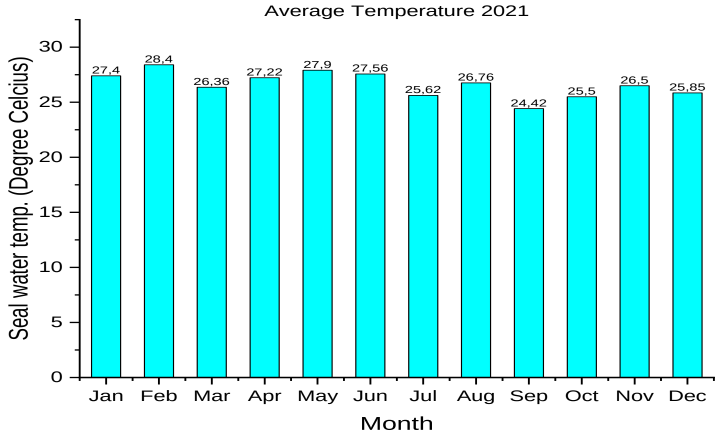

Fig. 10: Seal water temperature average data in 2021

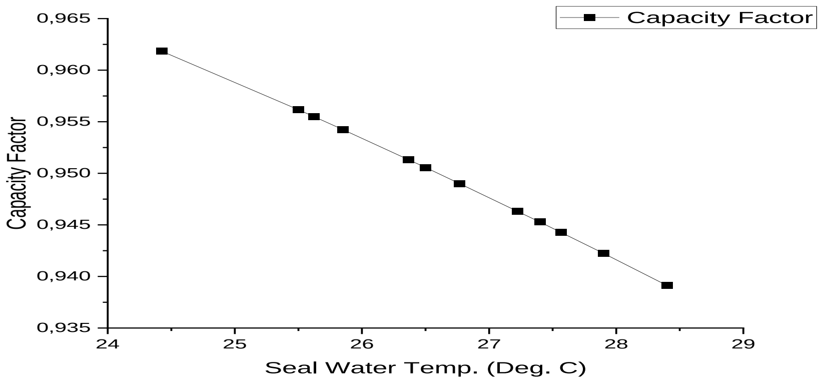

Fig. 11: Effect of seal water temperature on capacity factor

C. LRVP Performance Curve

The gas capacity that the LRVP can inhale can be seen from the pump performance curve. The pump performance curve refers to the factory's shop and inspection test document in 2008. From the manufacturer curve, the condition of operating seal water is about 15^{o}C. The actual data of seal water temperature is obtained from the average operating temperature during 2021, as described in Table 3. Therefore, the performance curve will be different from the original curve from the manufacturer since the capacity factor of gas sucked is also changed. Figure 12 shows the performance curve. From the pump performance curve, the factor that affects the capacity of gas being sucked is the suction pressure of the LRVP. In addition, the seal water temperature also affects the LRVP capacity according to the theory in journals and previous research.

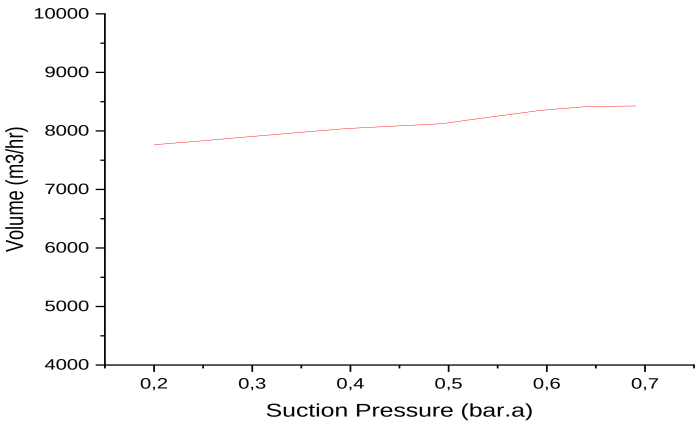

Fig. 12: LRVP performance curve from manufacturer

In this study, the suction pressure LRVP with the existing design is obtained directly from the operation data; the data used is from the last year, taken every week in every month. At the same time, the suction pressure data for design modifications were obtained from the inter-condenser outlet on stage 1, which was also taken from the data in 2021. Based on Figure 13, the capacity of gas that can be sucked in in the existing condition is 7580,11 m^3/hr, while in the modified condition, it is 7298,04 m^3/hr. It shows that the lower the suction pressure, the lower the gas suction capacity of the pump. In addition, by using the average temperature data in Figure 14, you can see the gas suction capacity using the maximum temperature in 2021. The gas capacity that can be inhaled with the existing design is 7577,22 m^3/hr, and the modified design is 7196,31 m^3/hr.

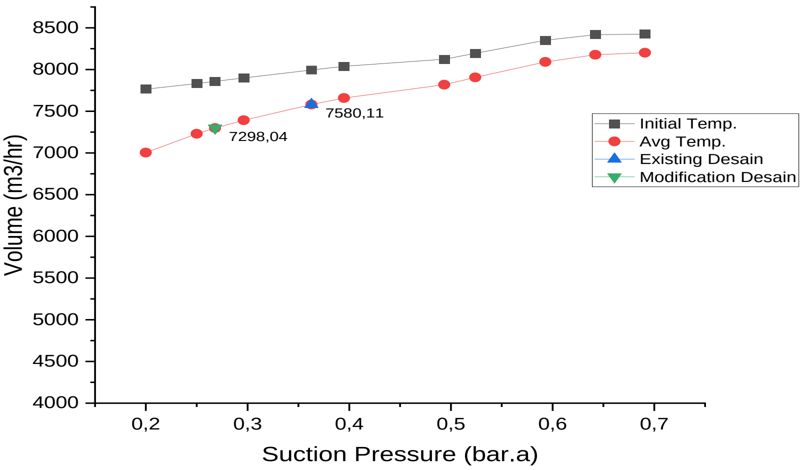

Fig. 13: LRVP performance curve on average temperatures

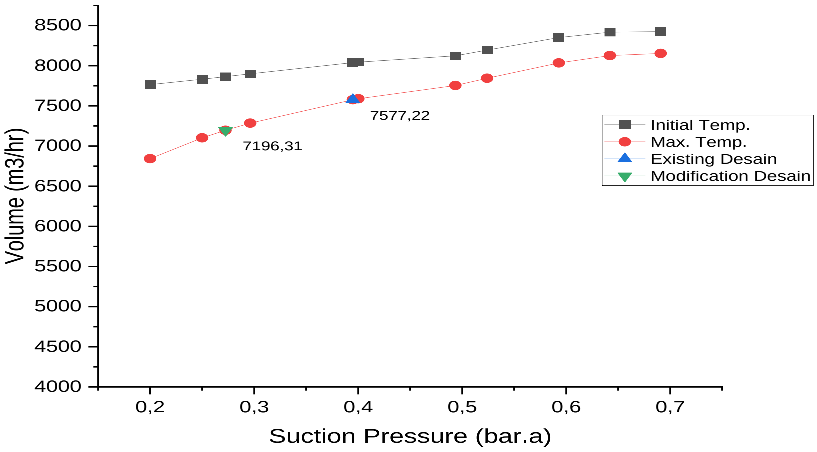

Fig. 14: LRVP performance curve with max temperature

The NCG mixture's density can be determined using the ideal gas equation formula. The average molarity value obtained from company data is 33 mol wt. From the gas ideal equation, the density of the NCG mixture is 1,11 kg/m^3. By knowing the density of the NCG mixture, the amount of gas flow rate that can be sucked by LRVP both from existing and modified conditions can be known. The value in Table 3 is indicated for a capacity of 1 LRVP, whereas the regular system of the GPP uses two trains in the system, namely Train A and Train B, therefore the LRVP capacity can be multiplied by two.

Table 3: Summary of NCG Flow Rate Sucked by LRVP

Existing		Modification	
Average Temp	Maximum Temp	Average Temp	Maximum Temp
2,33 kg/s	2,33 kg/s	2,25 kg/s	2,21 kg/s

D. Motive Steam Saving

Based on the modified GRS configuration, there will be a certain amount of steam that can be saved. This condition is due to the motive steam needed by the second stage ejector in both Train A, and Train B does not need to be consumed. The total value of motive steam that can be saved on the second stage ejector on Train A and Train B based on the design specifications is 11724 kg/hr, equivalent to 3,26 MW. However, this modified design requires capital costs to purchase materials such as pipes, fittings, valves, and construction services. Based on economic calculations, the total investment in this modification costs about 350.000 USD. By looking at the investment and steam costs that can be saved, the payback period is 50 days.

V. CONCLUSIONS

This study concludes that LRVP capacity can be maximized from the current operational data by looking at the performance curve and based on operational data from the GPP. It can be seen from the LRVP suction capacity in the modified design with the value of 4,5 kg/s (multiplied by two) for average temperature and 4,42 kg/s (multiplied by two) for maximum temperature. Those are still above the maximum NCG flow rate from 2017 to 2021 at about 2,37 kg/s in September 2018. In addition, the circulating cooling water system is also crucial because the seal water temperature can affect the suction capacity of the LRVP. As mitigation, when one day the NCG flow rate value becomes high and exceeds the capacity of the modified GRS, the GRS configuration can be returned to the existing design, which is to reactivate the second-stage ejector on train A or train B. However, the study in this research still has many gaps that need to be filled. Therefore, there is still an opportunity to conduct further studies, for example, by looking at which configuration is more optimal between train A, train B, and train C. This study also can be completed with the software of process simulations.

REFERENCES

[1.] IRENA, Takatsune Ito, and Carlos Ruiz, *Geothermal power: Technology brief*. Abu Dhabi, 2017. [Online]. Available: www.irena.org

[2.] H. Moon and S. J. Zarrouk, “EFFICIENCY OF GEOTHERMAL POWER PLANTS: A WORLDWIDE REVIEW,” 2012.

[3.] P. Ediatmaja, P. S. Darmanto, and D. T. Maulana, “Performance Evaluation of Geothermal Power Production Using EES (Case Study Ulumbu Geothermal Power Production Unit 4 East Nusa Tenggara, Indonesia),” Apr. 2021.

[4.] W. Yamin, I. G. B. N. Makertihartha, and J. Rizkiana, “Evaluation on Energy Efficiency Improvement in Geothermal Power Plant with The Application of Load-based Gas Removal System and Cooling Water Pump Control System,” *Jurnal Rekayasa Proses*, vol. 14, no. 1, Jun. 2020, doi: 10.22146/jrekpros.54656.

[5.] F. Jayakelana and A. Hermanto, “INFLUENCE OF CONFIGURATION STEAM JET EJECTOR-LRVP ON GEOTHERMAL POWER PLANT 55 MW CAPACITY,” 2017.

[6.] V. Sairam and G. Satyanarayana, “Feasibility Study of Replacing Steam Ejector with Liquid Ring Vacuum Pump (LRVP) in 210 MW Plant of Vijayawada Thermal Power Station (V.T.P.S),” 2014.

[7.] I. Dincer and M. F. Ezzat, “Renewable Energy Production,” in *Comprehensive Energy Systems*, vol. 3–5, Elsevier Inc., 2018, pp. 126–207. doi: 10.1016/B978-0-12-809597-3.00310-2.

[8.] M. el Haj Assad, E. Bani-Hani, and M. Khalil, “Performance of geothermal power plants (single, dual, and binary) to compensate for LHC-CERN power consumption: comparative study,” *Geothermal Energy*, vol. 5, no. 1, Dec. 2017, doi: 10.1186/s40517-017-0074-z.

[9.] C. K. Simatupang Orka, F. Putra, C. Hamonangan Simatupang, A. Dawud Hidayaturrobi, H. Melati Permatasari, and F. Junanda Putra, “Successful High NCG Wells Optimization in Salak Geothermal Field to Maintain Unit 4 Full Generation,” Aug. 2017. [Online]. Available: https://www.researchgate.net/publication/336686237

[10.] J. Bonafin, C. Pietra, A. Bonzanini, and P. Bombarda, “CO2 emissions from geothermal power plants: evaluation of technical solutions for CO2 reinjection,” European Geothermal Congress 2019 Den Haag, 2019.

[11.] K. Pranav, H. K. Ranjan, and M. P. Singh, “A Study and Analyze of an Ejector in Steam Power Plant,” 2014. [Online]. Available: www.ijemr.net

[12.] Ap. reddy, “CFD ANALYSIS OF STEAM EJECTOR WITH DIFFERENT NOZZLE DIAMETER,” 2017.

[13.] B. Nuryadin, P. Setyo Darmanto, and I. Made Astina, “Experimental Study of Water Jet Ejector for Geothermal Power Plant,” Mar. 2018.

[14.] S. Nugroho and C. Citrahardhani, “CFD Analysis of Nozzle Exit Position Effect in Ejector Gas Removal System in Geothermal Power Plant,” 2015.

[15.] J. C. Richardson and J. Devinney, “Optimization of Hybrid Noncondensable Gas Removal System for a Flash Steam Geothermal Power Plant,” 2014.

[16.] D. Strušnik, M. Marčič, M. Golob, A. Hribernik, M. Živić, and J. Avsec, “Energy efficiency analysis of steam ejector and electric vacuum pump for a turbine condenser air extraction system based on supervised machine learning modelling,” *Applied Energy*, vol. 173, pp. 386–405, Jul. 2016, doi: 10.1016/j.apenergy.2016.04.047.

[17.] S. Huang, J. He, X. Wang, and G. Qiu, “Theoretical Model for the Performance of Liquid Ring Pump Based on the Actual Operating Cycle,” *International Journal of Rotating Machinery*, vol. 2017, 2017, doi: 10.1155/2017/3617321.

[18.] Q. S. Feng, L. F. Chen, X. H. Wang, Y. N. Le, and J. Zheng, “Application and Analysis of water ring vacuum pumps reform Based on Characteristic Curve,” in *IOP Conference Series: Materials Science and Engineering*, Sep. 2019, vol. 592, no. 1. doi: 10.1088/1757-899X/592/1/012094.