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# Added Value of Optimizing Single Liquid Ring Vacuum Pump (LRVP) in Lumut Balai Geothermal Power Plant

Erwandi Yanto, Asep Mamat Rahmat Solihat, Miran Afriana, Dzuriat Khasani, Priatna Budiman, Hadi Suranto

Jl. Brigjen Dr H Noesmir No 3581, RT 54/ RW 06, Sukabangun Village, Sukarame District, Palembang-30151

erwandi.yanto@pertamina.com, asep.solihat@pertamina.com dkhasani@pertamina.com, miran.afriana@pertamina.com , priatnab@pertamina.com, hadi.suranto@pertamina.com

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## ABSTRACT

Non-Condensable Gas (NCG) is a natural component of geothermal fluids that it's not easy to condense by condensing process at the condenser. It has the ability to interfere with the heat transfer proses in the condenser by raising the temperature with the result that turbine isentropic efficiency isn't effectively working.

From the measurement, the average percentage ratio of NCG content to the total steam consumption in the Lumut Balai Geothermal Field area is 0.04% of the total steam consumption of 399 tons/55 MWe equivalent to 159.6 kg/h of NCG. The total content is relocated and dispersed to the environment by the Gas Removal System. The design capacity of Gas Removal System PLTP Unit 1 Lumut Balai using 1 x 100% Steam Jet Ejector and 2 x 50% Liquid Ring Vacuum Pump for 1.2% NCG of the total steam consumption at 55 MWe load equivalent to 4,660 kg/h NCG.

An assessment of the use of a 1 x 50% LRVP Gas Removal System is carried out to optimize the use of electrical energy consumption for its use. Design data using 1 x 50% LRVP can cover 2,330 kg/h of NCG while the actual production of NCG is 159.6 kg/h, meaning that only about 6% of the capacity of 1 x 50% LRVP is used. This assessment obtained the parameter-rated vacuum condenser pressure of 63 mbara at 55 MWe. The projection of revenue growth in using self-consumption energy and adding electrical energy to the grid amounted to USD 195,828 per annum, while the actual cost saving from January-May 2022 with the amount around USD 51,275.

## 1. INTRODUCTION

Geothermal Power Plant Unit 1 Lumut Balai was commercially operated on September 1, 2019 with an installed capacity of 55 MWe. The installed capacity contributes about 1.6% of the total peak load of South Sumatra's generation and can meet the needs of significant customers in Muara Enim Regency, South Sumatra Province. The total consumption of steam used to generate an average of 390 tons/hour is supplied from 9 production wells from 3 production clusters with a total mixed NCG gas of 0.04% of the average total weight.

Non-Condensable Gas (NCG) is exhaust gas from the processing and utilization of geothermal energy, which is no exception for PLTP Unit 1 Lumut Balai. NCG is naturally contained in the geothermal system and comes out together with the geothermal fluid. The value of the NCG content is one of the major factors to be considered before any geothermal energy utilization activity is carried out, this is because NCG can affect the economic value of the activity. The NCG contained in geothermal fluids will greatly affect the vacuum quality process that occurs in the condenser and affect the energy value that can be generated by a generator. The greater the value of the NCG content will cause the optimization of the vacuum quality in the condenser system to deteriorate so that it will cause the absorption of heat energy or the thermal efficiency of the turbine not to work optimally.

## 2. ISSUES AND CHALLENGES

In general, the content of NCG consists of carbon dioxide and hydrogen sulfide which types of gases cannot be condensed at the condenser temperature (Gases such as carbon dioxide and hydrogen sulfide co-exist with the natural steam and do not condense at the temperatures in the condenser (Dipippo,2016)). The NCG content of the geothermal fluid in the Lumut Balai Area consists of Hydrogen Sulfide ($H_2S$), $CO_2$ and others. This gas is difficult to condense and has the ability to act as a heat transfer heat transfer agent in the condenser with a blanketing mechanism. Unless the NCG are removed upstream of the turbine (which is currently not done in commercial plants), the NCG will accumulate in the condenser, thereby raising the backpressure on the turbine. This will cause a significant reduction in turbine power output (Dipippo,2016).

NCG in geothermal steam interfere with heat transfer in the condenser by forming a 'gas-blanketing' effect, which raises the condenser temperature and back-pressure on the turbine, reducing its output. NCG in geothermal steam interfere with heat transfer in the condenser by forming a 'gas-blanketing' effect, which raises the condenser temperature and back-pressure on the turbine, reducing its output.

Therefore, we need a system that can remove the NCG content from the condenser. System removal NCG steam jet ejector and liquid ring vacuum pump is a solutionc(Steam jet ejectors with after condensers and/or vacuum pumps are used for this purpose(Dipippo,2016)).

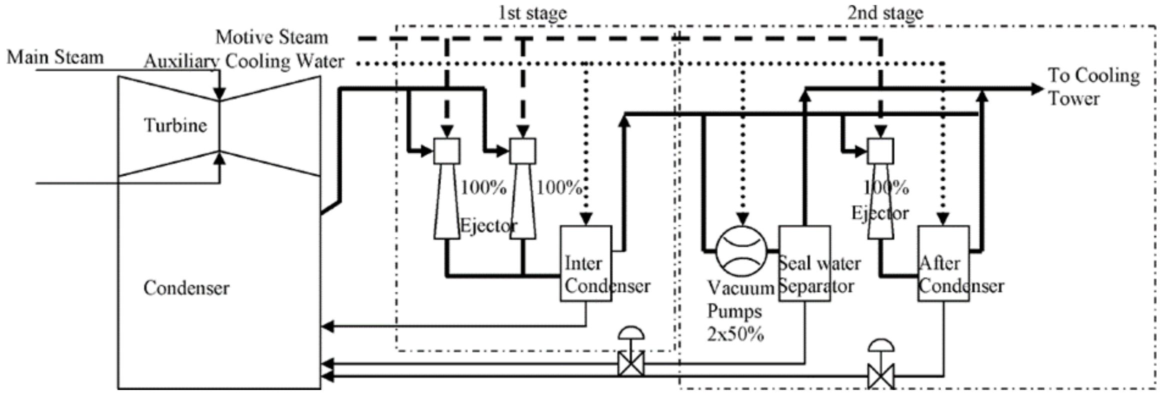


**Figure 1: Gas Removal system PLTP Unit 1 Lumut Balai**

Gas removal system is costly in geothermal systems because of elevated gas levels (Vorum and Fritzler, 2000). The power needed to extract the NCGs from the condensers and exhaust them to the atmosphere or an abatement system is supplied from the generated electricity; this seriously impairs the power generation performance (Duthie and Nawaz, 1989). The conventional gas removal systems used in geothermal power plants are;

1. Steam Ejector, steam jet ejectors, which are suitable for low NCG flows < 3%
2. Liquid Rings Vacuum Pump (LRVP)
3. Rotor dynamics, e.g. radial blowers, centrifugal compressors, which are mainly used for large flows of NCG (>3%),
4. Hybrid System (any combination of equipment above).

Liquid Rings Vacuum Pump (LRVP)

In principle, the vacuum pump is a compressor (compressing NCG) before distributing gas to the cooling tower. Seal water that comes from ACWP will be the separator between the compression chambers (the shaft of the vacuum pump that is not in the center). The inlet of the vacuum pump is a mixture of NCG and water. The water and NCG from the vacuum pump are first separated in the mini separator, where for the NCG it will be channeled to the fan cooling tower and the water will be channeled to the condenser. The seal water operation is equipped with a flow switch to ensure the availability of seal water during its operation. Flow seal water on Liquid Ring Vacuum Pump 40 m3/h for each of LRVP.

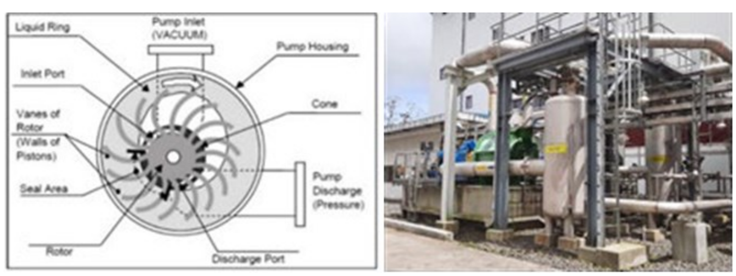


**Figure 2. Liquid Ring Vacuum Pump of Lumut Balai Power Plant Unit 1**

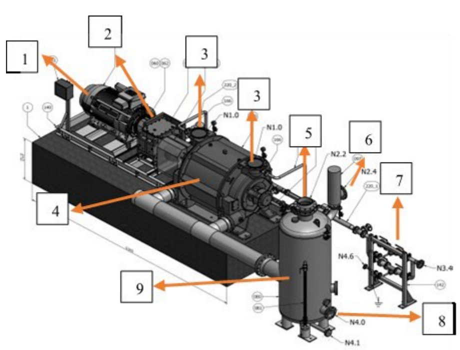


**Figure 3. Liquid Ring Vacuum Pump Internal Equipment**

Equipment of LRVP Lumut Balai Unit 1:
1. Motor
2. Gear Box
3. Inlet vacuum pump
4. LRVP (Liquid Ring Vacuum Pump)
5. Outlet NCG from mini separator to cooling tower
6. Pressure safety valve
7. Seal water
8. Outlet water from mini separator to condenser
9. Mini separator

**Table 1. Design data Liquid Ring Vacuum Pump**

| | | |
|---|---|---|
| 1 | *Type of liquid ring vacuum pump* | *Horizontal shaft, single stage, sealwater type* |
| 2 | *Number of pumps* | 2 x 50% |
| 3 | *Pump capacity per one pump* | 15200 m3/h (at inlet condenser) |
| 4 | *NCG inlet/outlet temperature* | 32°C/ 41°C |
| 5 | *NCG inlet/outlet press* | 0.157 bara/ 0,91 bara |
| 6 | *Motor output* | 460 KW |
| 7 | *One LRVP inlet flow rate* | 148.650 kg/h |
| 8 | *One seal water separator outlet flow rate* | NCG : 2.941 kg/h<br>Drain 35.095 kg/h |

Figure 2 & 3 shows the detail equipment installed in the LRVP which really similar with the usual standard of LRVP in power plant with the part such Motor, Gear Box, Inlet vacuum pump, LRVP (Liquid Ring Vacuum Pump) as the main pump to seal and separate the water from the gas, Outlet NCG from mini separator to cooling tower (Table 1. Pressure inlet 0.157 bara, outlet 0.91 bara and temperature inlet 32°C, outlet 41°C) , pressure safety valve, Seal water, Outlet water from mini separator to condenser mini separator.

## 3. ALTERNATIVE INNOVATION

### 3.1 Process

Normally, geothermal power plant unit 1 Lumut Balai is used to operate and run 2 LRVP (Liquid Ring Vacuum Pump) to remove NCG during generation of full load electricity (55 MWe), and after reviewing, considering the process and technical specification of 2 LRVP, the successful trials have been conducted by operating just single LRVP without neglecting full load electricity generation.

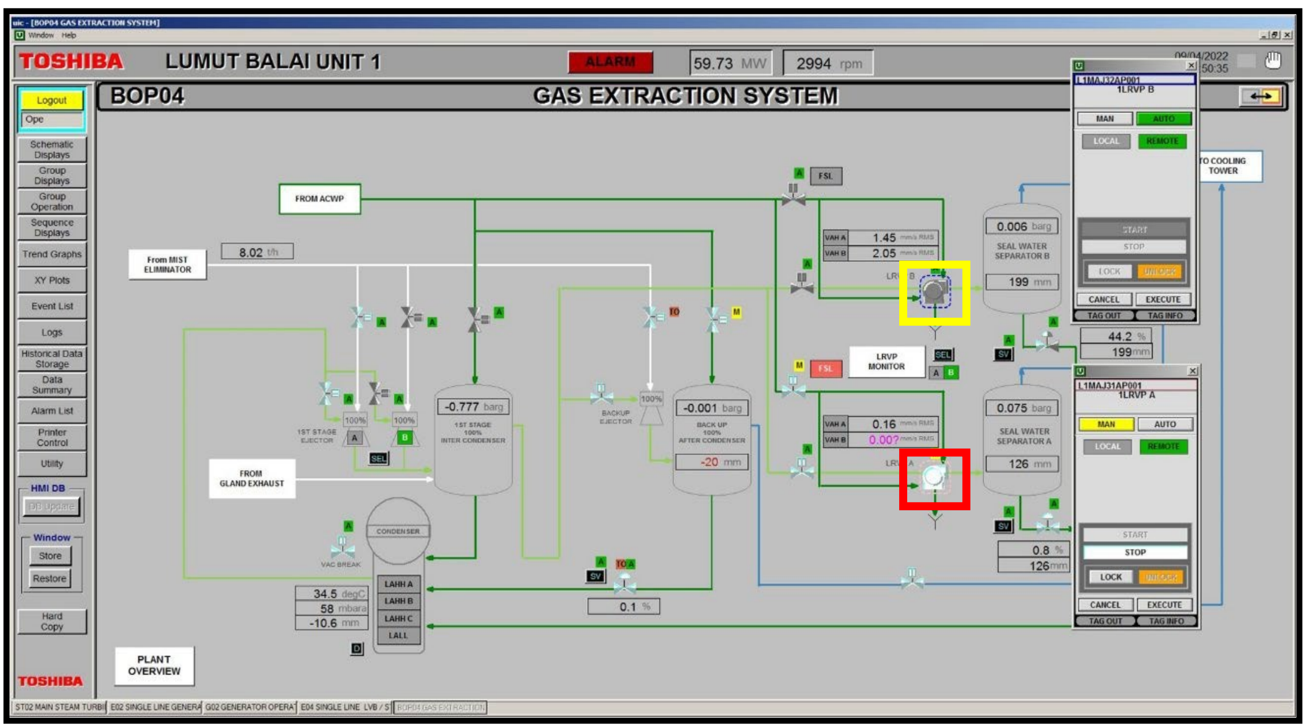


**Figure 4. Window display of Gas Extraction System Lumut Balai GPP Unit 1**

Notes:

: Operating LRVP-B

: Non-operating LRVP-A

Figure 4 refers to gas extraction mechanism in geothermal power plant using compression mechanism of NCG before releasing the gas into the cooling tower to disperse in the atmosphere. Due to the least concentration of NCG (lower than 0.05%), the double working vacuum pump (LRVP) usage could be overworked, then single LRVP considered to be efficient enough in extracting the gas into the cooling tower without neglecting the electricity generation and optimum gas extraction as well.

**Table 2. Flow Data Process of Liquid Ring Vacuum Pump Seal Water Separator**

| *Liquid Ring Vacuum Pump Seal Water Separator* | *Guarantee point* | *Constant output* | *Back up ejector inservice* |
|---|---|---|---|
| *Seal water temperature* | 24°C | 29.1°C | - |
| *2nd stage suction pressure atLRVP inlet flange* | 0.150 bara | 0.228 bara | - |
| *2nd stage suction temperature* | 29°C | 34.2°C | - |
| *2nd stage NCG flow rate (100%)* | 4.660 kg/h | 8.543 kg/h | - |
| *2nd stage air flow rate* | 689 kg/h | 658 kg/h | - |
| *2nd stage water vapour flow rate* | 828 kg/h | 1.169 kg/h | - |
| *Seal water separator discharge pressure* | 0.97 bara | 1.01 bara | - |

Table 2 shows the mechanism of seal water separator inside the vacuum pump with the standard requirement of working fluid parameter enter the chamber. The 2nd stage NCG flow rate should be 4.660 kg/h as the guarantee point and 8.543 kg/h for the constant output.

### 3.2 Monitoring data power from digital power meter

During the simulation of single LRVP operation, the monitoring of power consumption in each LRVP has been monitored to ensure the operation conducted as per program.


**Figure 5. Power Data Reading of LRVP A (left) and LRVP B (right) from Digital Power Meter (DCS)**

Based on the monitoring power data of Figure 5, LRVP-A (left side) is set to be turned off without any energy consumption, whereas LRVP-B on the right side is running with fully capacity of generation as usual.

### 3.3 Logic Runback Forced for Single LRVP-A

Due to isolate the communication between 2 LRVP, the logic of LRVP A should be forced to close for safety procedure, the blocking logic of runback has conducted based on the figure 6 below.

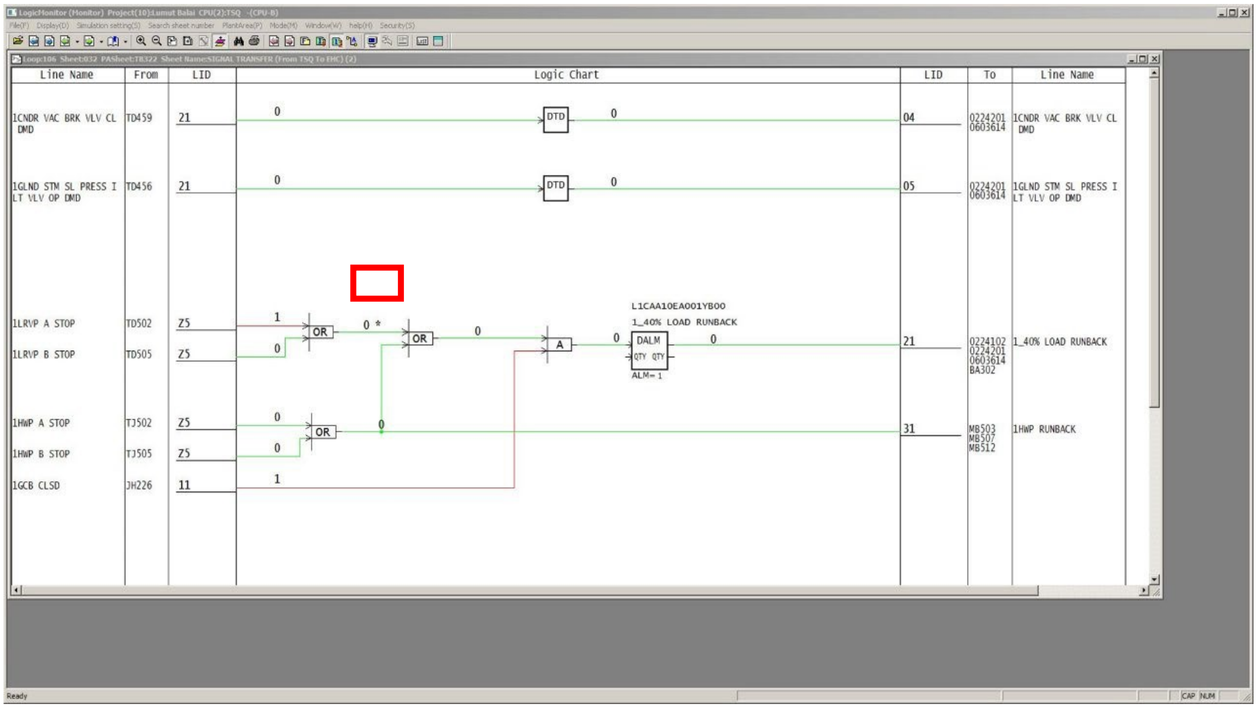


**Figure 6. Logic Runback Forced for LRVP-A**

The indication of "0*" means the communication signal between 2 LRVP has been blocked where LRVP-B is continue to run and operate to extract NCG into the cooling tower.

## 4.RESULT

In 2022, PGE in the Lumut Balai area will operate 1 x 100% Ejector and 1 x 50% LRVP which was previously 1 x 100% Ejector and 2 x 50% LRVP by taking into account the value of the NCG to Weight Ratio, with this saving 1 x power consumption. 50% of the LRVP, which will then be channeled to the network to increase the selling value of the export of electricity and reduce the cost of importing electricity from the PLTP Unit 1 Lumut Balai.

**Table 3. Comparison of Energy Consumption with 1 and 2 Liquid Ring Vacuum Pump**

| PARAMETER | 2 LRVP | 1 LRVP | UNIT |
|---|---|---|---|
| | **April 30, 2021** | **April 8, 2022** | |
| DAILY POWER DELIVERY IN AVERAGE (GROSS) | **59.33** | **59.44** | MW |
| DAILY POWER DELIVERY IN AVERAGE (NETT) | **56.17** | **56.75** | MW |
| ENERGY CONSUMPTION (HOUSELOAD) | **75,923.00** | **64,530.00** | kWh |
| DAILY POWER HOUSE LOAD CONSUMPTION | **3.16** | **2.69** | MW |

Based on the data, the most significant efficiency of energy consumption has been reached successfully, and eventually this will be the best practices to reduce cost and optimize the single LRVP running while the other one is set to be standby for backing up needs. The daily power house load consumption has significantly decrease from 3.16 MW into 2.69 MW.

## 5. TECHNICAL EVALUATION

Based on engineering study, PLTP Unit 1 Lumut Balai applies a hybrid system in processing NCG with a capacity of not less than 1.2% of the average weight of steam consumption. The hybrid system (two stages) applied to PLTP Unit 1 Lumut Balai consists of the following components:

- 2 x 100% Steam Jet Ejector (at normal operation using 1 x 100% steam jet or single steam jet ejector)
- 2 x 50% LRVP
- 1 x 100% Backup Steam Ejector system (Emergency option).

**Table 4. Steam jet ejector capacity, 1x100% LRVP after condenser as follows;**

| STEAM JET EJECTOR 1 X 100% | | BACKUP STEAM EJECTOR SYSTEM |
|---|---|---|
| Suction Load (Air/NCG/Water Vapor) | 358/4593/2252 kg/h | 688/4660/1022 kg/h |
| Suction / Discharge Pressure | 0.064 bara/0.154 bara | 0.0281 bara/ 0.85 bara |
| Motive Stem Pressure | 4.91 bara | 4.91 bara |
| Motive Steam Temperature | 152 deg.C | 152 deg.C |
| Motive Steam Flow | 5467 kg/h | 38420 kg/h |

**Table 5. Steam jet ejector capacity, 2x50% LRVP after condenser as follows;**

| 2 X 50% LRVP | |
|---|---|
| Pump Capacity per One Pump | 15200 $m^3/h$ (at inlet condenser) |
| NCG Inlet/Outlet Temperature | 32.0 deg.C/41.0 deg.C |
| Motor output | 460 kW |
| One LRVP inlet flow rate | 148650 kg/h |
| One Seal Water Separator outlet flow rate | NCG : 2941 kg/h , Drain 35095 kg/h |

**Table 6. NCG Concentration of Lumut Balai 2022**

**Standard max NCG concentration : 1.2%**

| MONTH | SEPARATOR 1 | SEPARATOR 6 | SEPARATOR 9 | BEFORE MIST ELIMINATOR | AFTER MIST ELIMINATOR | RELEASED BY |
|---|---|---|---|---|---|---|
| **JANUARY** | 0.07 | 0.04 | 0.04 | 0.05 | 0.05 | Laboratory of Kamojang |
| **FEBRUARY** | 0.06 | 0.04 | 0.04 | 0.04 | 0.05 | Laboratory of Kamojang |
| **MARCH** | 0.07 | 0.05 | 0.03 | 0.04 | 0.04 | Laboratory of Kamojang |
| **APRIL** | 0.07 | 0.03 | 0.03 | 0.04 | 0.04 | Laboratory of Kamojang |
| **MAY** | 0.06 | 0.04 | 0.03 | 0.05 | 0.05 | Laboratory of Kamojang |
| **JUNE** | 0.06 | 0.04 | 0.03 | 0.05 | 0.05 | Laboratory of Kamojang |
| **JULY** | 0.06 | 0.04 | 0.03 | 0.05 | 0.05 | Laboratory of Kamojang |
| **AUGUST** | 0.06 | 0.04 | 0.03 | 0.05 | 0.05 | Laboratory of Kamojang |
| **SEPTEMBER** | 0.06 | 0.04 | 0.03 | 0.05 | 0.05 | Laboratory of Kamojang |
| **OCTOBER** | 0.06 | 0.04 | 0.03 | 0.05 | 0.05 | Laboratory of Kamojang |
| **NOVEMBER** | 0.06 | 0.04 | 0.03 | 0.05 | 0.05 | Laboratory of Kamojang |
| **DECEMBER** | 0.06 | 0.04 | 0.03 | 0.05 | 0.05 | Laboratory of Kamojang |

As the design and unit capacity rated test using 1 x 100% steam jet ejector and 2 x 50% LRVP, it is obtained that the rated generation condition is 55,417 MWe Nett which is sent to the network with the parameters of the vacuum condition in the condenser 60 mba at a temperature of 36 deg.C. This condition is not much different from the reference value of the heat mass balance design of PLTP Unit 1 Lumut Balai.

Based on the measurement results of the mixed NCG content in the Lumut Balai geothermal fluid, the NCG value is less than 0.1% of the average weight of the total steam consumed to generate 55 MWe (KMJ Lab Analysis) or equivalent to 0.04% of the capacity of one LRVP. With this data, it can be used as a reference for conducting studies and assessing the feasibility of optimizing the use of 1 x 50% LRVP work. The study and assessment emphasized on the feasibility aspect of optimizing the use of 1 x 50% LRVP with generating conditions at 55 MWe (full load) by paying attention to the condition of the pressure vacuum condenser not exceeding the required value for the Heat Mass Balance and working parameters of the LRVP. So that the achievement of optimizing these conditions can be converted into a daily own use savings program and the addition of the generation value sent to the network.

## 6. ECONOMICAL EVALUATION

The main purposes of this innovation is to optimize and increase revenue to the company from efficiency of equipment energy used without neglecting the reliability and optimum production. Then, as the consideration of cost saving or revenue growth of the innovation, some calculation has been generated to quantify the benefits. There some parameter should be input such as operating day and hour until price agreement of electricity produced from PLN. The formula of revenue growth based on this

$$\boldsymbol{Cost\ Optimization\ = TOD\ per\ annum * LRVP\ power\ efficiency\ (kWh) * total\ hour * base\ price\ (USD)}$$

Notes:

TOD : Total Operating Day per annum (day) Power Efficiency : LRVP power consumption saving (kWh)
Total hour : Running hour of Pump Operation per day (hr)
Base price : Electricity price of Lumut Balai Plant (7.53 cent = 7.53/1000= 0.00753 USD)

Table 7. Cost Optimization and Growth Revenue of Single LRVP Operating

| Cost Realization 2022 | | |
|---|---|---|
| Month | Realization (USD) | Description of Changes in Work Practices to Achieve Target |
| January | 4,206.17 | In 2022, PGE in the Lumut Balai area will operate 1 x 100% Ejector and 1 x 50% LRVP which was previously 1 x 100% Ejector and 2 x 50% LRVP by taking into account the value of the NCG to Weight Ratio, with this saving 1 x power consumption. 50% of the LRVP, which will then be channeled to the network to increase the selling value of the export of electricity and reduce the cost of importing electricity from the PLTP Unit 1 Lumut Balai. |
| February | 3,464.62 | |
| March | 11,832.28 | |
| April | 17,022.80 | |
| May | 16,091.70 | |
| June | 14,772.78 | |
| July | 25,495.52 | |
| August | 20,806.03 | |
| September | 18,662.98 | |
| October | 10,294.74 | |
| November | 13,276.15 | |
| December | 2,063.85 | |
| Total Cost Realization | **157,989.60** | |

## 7. CONCLUSION

Based on the whole procedure which has been conducted and the benefits form cost optimization through this research, there are several key points to be concluded as follows:

- Single run of LRVP is sufficient enough to be implemented in Lumut Balai Power Plant Unit 1 (55 MWe) with the low concentration of NCG about 0.04-0.05%. Then, this would be the best practice for the future operation without neglecting the maximum electricity generation, equipment reliability, and safety concern.
- As the projection/estimation to the year 2022, with the basis of existing data, Lumut Balai Power Plant Unit 1 (55 MWe) will save the cost around USD 2505 from only run 1 LRVP, then increase the revenue around USD 157,989.60 from energy exports to PLN.

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