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Automatic Main Cooling Water System (aMCWS)

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ABSTRACT

The parasitic load in each power generation plant is always predominated by the parasitic load from Main Cooling Water System (MCWS). In conventional power generation (e.g. coal fired, gas, and combined cycle power plants), sea-water is usually applied as the main cooling medium. Variation of sea-water temperature during the year remains relatively constant. This condition differs from conditions at geothermal power plant, where air is the main cooling medium and its conditions (wet bulb temperature and humidity) have wide variation during the year. The idea of this paper is to exploit the changes of air conditions to decrease the parasitic load in Main Cooling Water System. The principle is when the air has low temperature and low humidity, the automatic Main Cooling Water System (aMCWS) will decrease the power consumption of main cooling water pump and/or the cooling tower fan at the optimal conditions. The optimization step of the Main Cooling Water Pump and Cooling Tower Fan is performed by implementing the variable frequency drive (VFD) at the motors so that the rotation of pump and fan can be varied to the actual conditions of air measured. The conclusion of this study clarify that the application of aMCWS can reduce the power consumption of the pump and fan by up to 20% from existing power input. The economic consideration (with investment cost, operating & maintenance cost, and CDM scheme as considered parameters) in this study shows that the application of aMCWS at existing geothermal power plants is feasible.

1. INTRODUCTION

In every power plant, some of the generated power is used to operate/supply some equipment in the power plant system itself and is called the parasitic load. Pumps and fans are examples of the equipment that are powered by the parasitic load. Every step that can minimize parasitic load will increase power production directly and increase revenue.

2. BACKGROUND

Environmental conditions of conventional power plants that are generally located along beaches are different from the environmental conditions of geothermal power plants, which are generally located on the plateau. Based on data collected from monitoring environmental, it is known that there is wide variation in the temperature and humidity during the day and night and in the wet season and dry season. This condition allows us to make optimizations like reducing the amount of cooling water and cooling air in the main cooling water system without reducing the turbine power output. This paper explains the principle of controlling the amount of cooling water and the amount of cooling air by implementing a VFD (Variable Frequency Drive) on the cooling tower fan motor and Main Cooling Water Pump (MCWP) motor. Figure 1 shows a simplified flow diagram of the Main Cooling Water System in Kamojang II Geothermal power plant.

Analysis begins with construction of a thermodynamic model, which is validated in two steps. The first validation is comparing the modeling results to the design data so that the data model is appropriate under the given design considerations. The next validation is comparing modeling results with actual operating data so that the model is appropriate at actual conditions. Models constructed with this two-step validation can be used to predict the implementation of the optimization on performance in every change in environmental conditions (wet bulb temperature and humidity). Figure 2 below shows the flow chart of the modeling process.

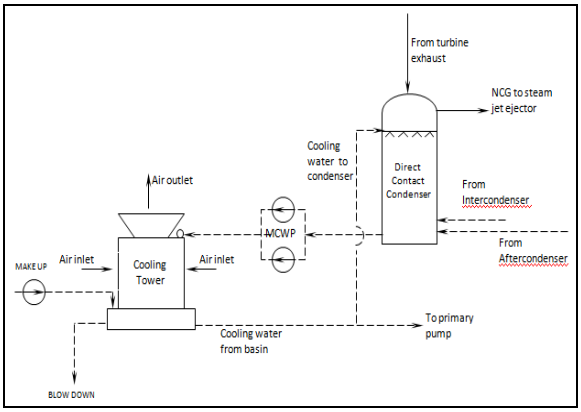

Figure 1: Main Cooling Water System (MCWS) scheme in Kamojang geothermal power plant.

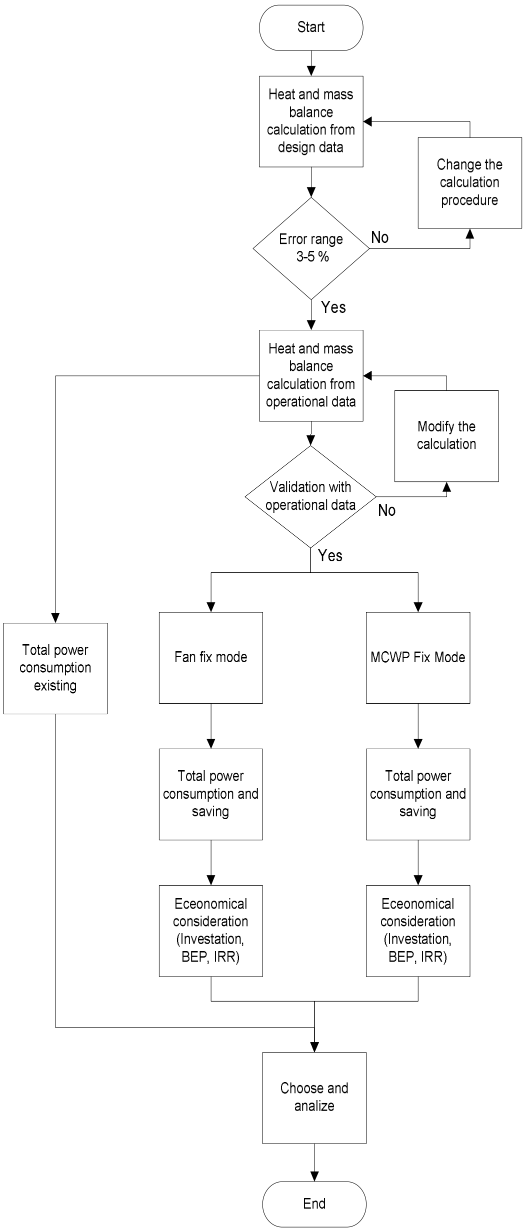

Figure 2: Modeling process flow chart.

3.THERMODYNAMIC MODELING OF KAMOJANG GEOTHERMAL POWER PLANT

Modeling is done using the software Macro Excel VBA. Figure 3 shows the thermodynamic model.

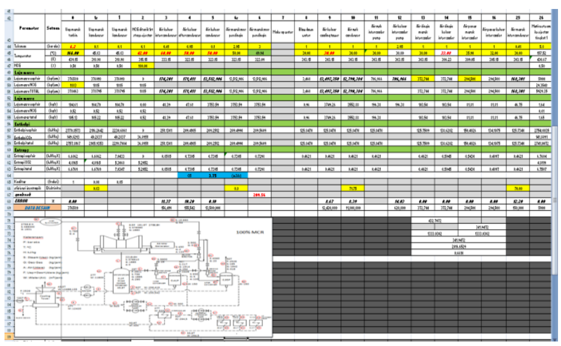

Figure 3: Thermodynamic model of Kamojang geothermal power plant using Microsoft Macro VBA.

The conditions resulting from modeling for each state at every component in Kamojang II geothermal power are shown in Appendices 1 and 2. This model is used to predict the influence of changing environmental conditions of the power plant performance after implementing the application of the VFD on the main cooling water system.

To ensure the confidence level in the model, validation is performed by comparing with the design data and actual data. This first validation is intended to determine the equipment performance at the beginning and guarantee the implementation of mass and energy balance equation to determine that all stated conditions are acceptable. Validation of the design data indicated in Table 1.

Table 1: Validation Model with Design Data.

Parameters	% Error
Mass flow rate of cooling water at intercondenser inlet	4.23
Mass flow rate of condensate water at intercondenser outlet	3.72
Mass flow rate of cooling water at aftercondenser inlet	3.66
Mass flow rate of condensate water at aftercondenser outlet	3.56
Mass flow rate of cooling water at condenser inlet	1.66
Mass flow rate of condensate water at condenser outlet	1.57
Mass flow rate of cooling water at cooling tower inlet	1.57
Mass flow rate of cooling water at cooling tower outlet	1.57

Table 1 shows an error of less than 5% between model and design data, indicating that the model that has been built is valid.

The next validation is comparing the thermodynamic model with the actual operating data. The objective is to see how big the changes of the performance of each piece of equipment which has been operated for more than 20 years. The validation results are indicated in Table 2.

Table 2: Validation model with Operation Data/Actual Condition.

Parameter	Design Performance	Actual Performance
Turbine isentropic efficiency	86	83
Fan Cooling tower efficiency	66.64	64.47
Intercondenser effectiveness	100	80
Condenser effectiveness	100	71.75

Table 2 shows that the model describes the actual condition somewhat accurately if the performance parameters are implemented to the model. The way to predict operating parameters after VFD is implemented is to use the model for two kinds of validation.

4. DETERMINING THE OPTIMUM OPERATION MODE

The way to determine the optimum operating mode in the main cooling water system is done by comparing the amount of reducing parasitic load at each alternative mode of operation that will be applied.

In principle, changes in environmental conditions can be accommodated by controlling the amount of cooling water or the amount of cooling air. Each mode can be expected to reduce the parasitic load.

The amount of cooling water will be controlled by applying VFD on the Main Cooling Water Pump (MCWP) motor, which is called VFD MCWP mode in this work. Controlling the amount of cooling air by applying VFD on cooling tower fan motor is called VFD FAN mode here.

If possible, there will be another mode that can be introduced by applying VFD not only on Main Cooling Water Pump (MCWP) but also on cooling tower fan simultaneously; nevertheless, this mode depends on the result in each mode.

4.1 VFD MCWP Operation Mode

Decreasing the ambient temperature and/or humidity allows a reduction of cooling water in the main cooling water system without changing the power output of the turbine. The reason is that the amount of cooling water required to condense the same amount of steam in the condenser could be reduced if the cooling water temperature is lower than usual.

In VFD MCWP operation mode, the way to set the amount of cooling water in the main cooling water system is performed by controlling the pump motor rotational speed. Changes in motor speed will change the Main Cooling Water Pump (MCWP) capacity.

Figure 4 below shows the relationship between power consumption in MCWS with variation of the ambient temperature at constant relative humidity.

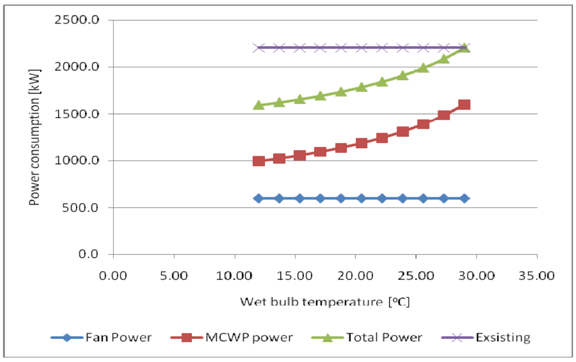

Figure 4: Relationship between power consumption with ambient wet bulb temperature variation in VFD MCWP operation mode.

4.2 VFD FAN Operation Mode

With decreasing ambient temperature and/or humidity ratio, it is possible to reduce the amount of cooling air in the cooling tower in the main cooling water system without changing the turbine power output. The reason is that the amount of cooling air can be reduced to get the same cooling water temperature at basin cooling tower when the ambient temperature lower than usual.

In the VFD FAN operation mode, we can set the amount of cooling air in the main cooling water system by controlling the cooling tower fan motor rotational speed. Changes in motor speed will provide the changes in the air delivery of cooling tower fan.

Figure 5 show the relationship between power consumption in MCWS and variation of the ambient temperature at constant relative humidity.

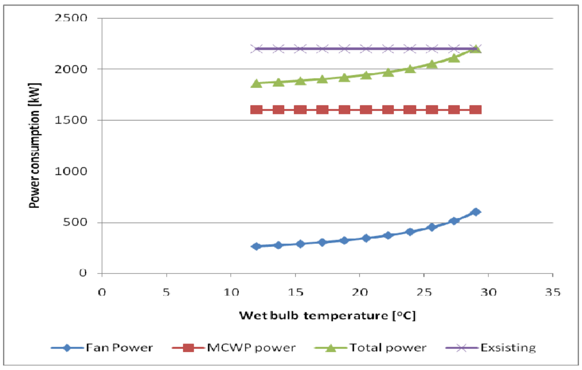

Figure 5: Relationship between power consumption with ambient wet bulb temperature variation in VFD FAN operation mode.

4.3 Comparison between VFD MCWP and VFD FAN Operation Mode

The optimum operation mode will be determined by selecting which has the highest parasitic load reduction. Figure 6 below shows the comparison between VFD MCWP and VFD FAN power consumption with varying ambient wet bulb temperatures at constant relative humidity.

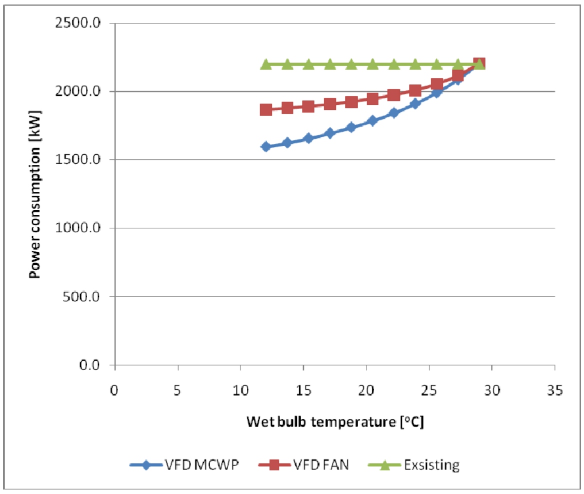

Figure 6: Comparison between power consumptions in VFD MCWP and VFD FAN modes at ambient wet bulb temperature variations.

Figure 6 shows that implementing VFD to MCWP gives higher parasitic load reduction than implementing VFD to cooling tower fan. Therefore, there will be no additional operation modes like a combination of VFD MCWP and VFD FAN.

5. ECONOMIC ANALYSIS

In the economic analysis, the calculation process considers the monitoring environmental conditions data (temperature and humidity) for about one year (e.g. year 2008). Figure 7 shows the normal distribution of ambient wet bulb temperature variation throughout the year of 2008.

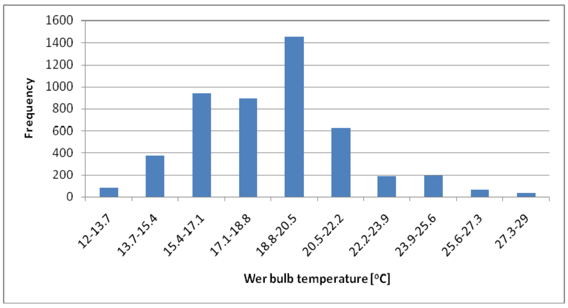

Figure 7: Normal distribution of ambient wet bulb temperature in year 2008.

By assuming the electricity price is Rp 500/kWh, the opportunity of increasing revenue can be determined for each mode operation that will be implemented.

Table 3: Economic savings associated with each modification.

	Implement VFD on MCWP [VFD MCWP]	Implement VFD on cooling tower fan [VFD FAN]
Saving [kWh]	3,951,978.5	2,358,615.14
Saving[%]	20.5	12.21
Saving [Rp]	1,975,989,272.99	1,179,307,571.65

Table 3 above shows the comparison of financial benefits from each possible operation mode that may be implemented. Determining the optimum operating mode should consider the investment cost, operating cost and maintenance cost of the additional installation required.

The feasibility of an investment is best determined by the NPV, IRR, and PBP (Pay Back Period) parameters.

The investment price of VFD for Main Cooling Water Pump (MCWP) that has a specification 6.3 kV and 800 kW is Rp 5,000,000,000 (each) and VFD for cooling tower fan that has specification 380 V and 600 W is Rp 86,000,000 (each). The result from economic analysis for each operating mode is shown in Table 4 below.

Table 4. Economic Analysis for each Operating Mode.

Parameter	Implement VFD on MCWP [VFD MCWP]	Implement VFD on cooling tower fan [VFD FAN]
NPV [Rp]	3,458,195,170.98	Rp7,602,104,061.88
IRR [%]	18	274
PBP	5 years	0.4 years ≈ 4 months

6. CONCLUSION

The results of the modeling led to several conclusions:

- The model that has been built is valid because it already represents the design and operating conditions.
- Although implementing VFD on Main Cooling Water Pump (MCWP) gives the highest parasitic load reduction and gives the highest savings from the economic side, when the investment and OM (Operation and Maintenance) costs are considered, implementing VFD on the cooling tower fan gives a better result.
- From technical point of view, the operation mode through with application of the VFD can be achieved.

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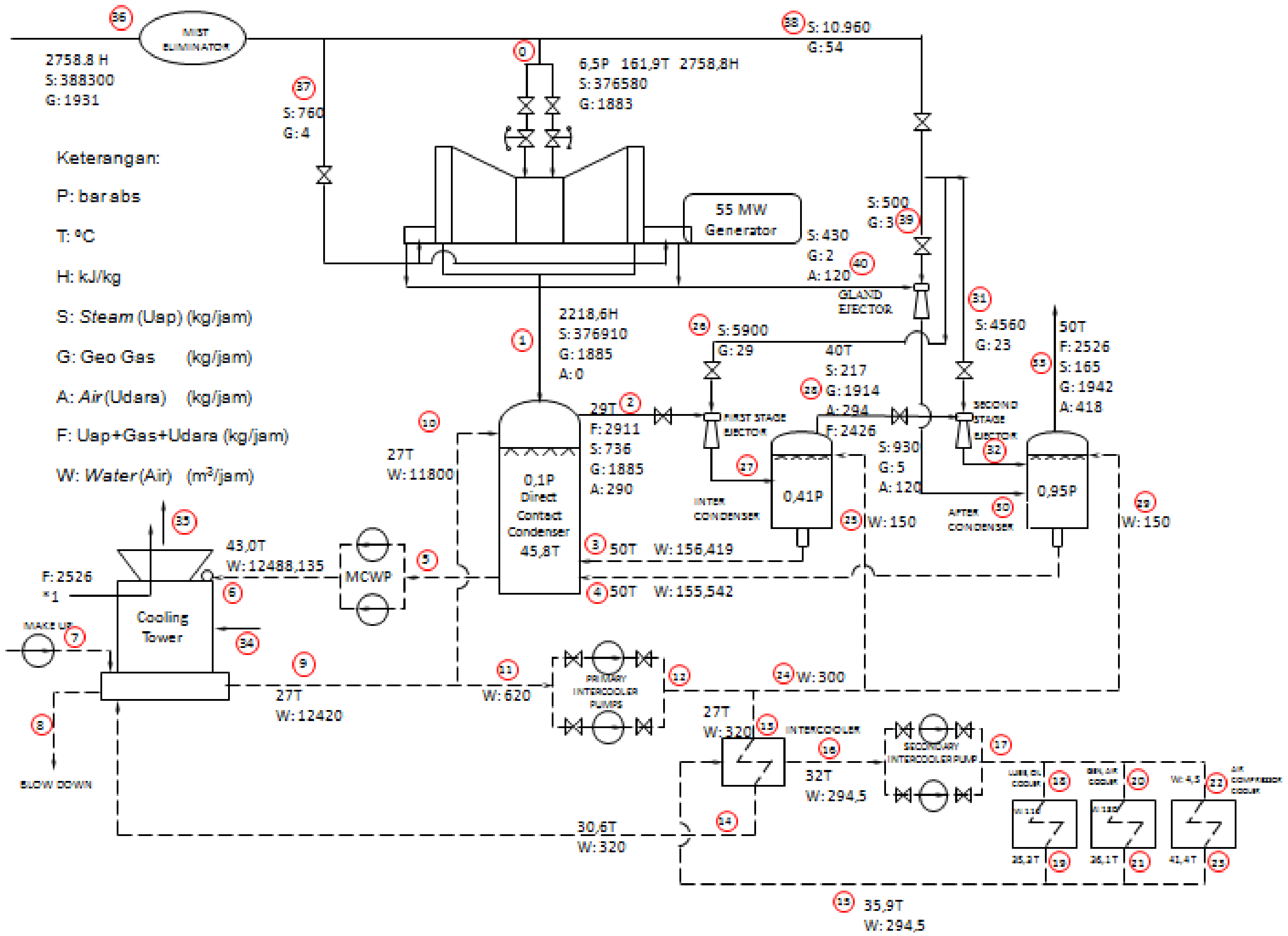
Appendix 1 Kamojang II geothermal power plant scheme.



Appendix 2 State condition at every components state of Kamojang II geothermal power plant.

Parameter	Satuan	0	1s	1	2	3	4	5	8	9	10	11	13
		Uap masuk turbin	Uap masuk kondenser	Uap masuk kondenser	NCG ditarik 1st stage ejector	Air keluar intercondenser	Air keluar aftercondenser	Air keluar condenser	Blow down water	Air keluar cooling tower	Air msk condenser	Air msk intercooler pump	Air dingin masuk intercooler
Tekanan	(bar abs)	6.5	0.1	0.1	0.1	0.41	0.95	0.1	1	1	1	1	2.95
Temperatur	(oC)	161.9914741	45.83381033	45.83381033	29	50	50	43	27	27	27	27	27
	(K)	435.1414741	318.9838103	318.9838103	302.15	323.15	323.15	316.15	300.15	300.15	300.15	300.15	300.15
NCG	(%)	0.497538729	0.497538729	0.497538729	100								
Laju massa													
Laju massa uap/air	(kg/jam)	376580	376910	376910	0	162569.9231	150667.3222	12351459.32	141773.9312	12283159.32	11661312.08	621847.2453	320000
Laju massa NCG	(kg/jam)	1883	1884.641878	1884.641878	1884.641878								
Laju massa TOTAL	(kg/jam)	378463	378794.6419	378794.6419	1884.641878	162569.9231	150667.3222	12351459.32	141773.9312	12283159.32	11661312.08	621847.2453	320000
Laju massa													
Laju massa uap/air	(kg/s)	104.6055556	104.6972222	104.6972222	0	45.15831197	41.85203394	3430.960923	39.38164755	3411.988701	3239.253355	172.7353459	88.88888889
Laju massa NCG	(kg/s)	0.523055556	0.523511633	0.523511633	0.523511633								
Laju masas total	(kg/s)	105.1286111	105.2207339	105.2207339	0.523511633	45.15831197	41.85203394	3430.960923	39.38164755	3411.988701	3239.253355	172.7353459	88.88888889
Enthalpi													
Enthalpi uap/air	(kJ/kg)	2758.870002	2127.408872	2218.6	0	209.3093126	209.4104541	179.993411	113.3116154	113.3116154	113.3116154	113.3116154	113.394174
Enthalpi CO2	(kJ/kg)	146.0723393	40.28370403	40.28370403	25.45456804								
Enthalpi total	(kJ/kg)	2745.870322	2117.024616	2207.762033	25.45456804	209.3093126	209.4104541	179.993411	113.3116154	113.3116154	113.3116154	113.3116154	113.394174
Entropy													
Entropi uap/air	(kJ/kg.K)	6.721020977	6.721020977	7.005822601	0	0.730512753	0.730512753	0.638475562	0.420438152	0.420438152	0.420438152	0.420438152	0.420438152
Entropi CO2	(kJ/kg.K)	4.799441804	4.799441804	5.306830595	5.255655812								
Entropi total	(kJ/kg.K)	6.711460377	6.711460377	6.997369458	5.255655812	0.730512753	0.730512753	0.638475562	0.420438152	0.420438152	0.420438152	0.420438152	0.420438152

Parameter	Satuan	14	15	16	25	26	27	28	29	31	32	33	40	39	30
		Air dingin keluar intercooler	Air panas masuk intercooler	Air panas keluar intercooler	Air masuk intercondenser	Motive steam ke ejector tingkat 1	NCG masuk intercondenser	NCG ditarik 2nd stage ejector	Air masuk aftercondenser	Motive Steam ke ejector tk. 2	NCG masuk aftercondenser	NCG keluar aftercondenser	NCG ditarik Gland Ejector	Motive Steam ke Gland Ejector	NCG masuk aftercondenser dr Gland
Tekanan	(bar abs)	2.95	2.95	2.95	2.95	6.5	0.41	0.41	2.95	6.5	0.95	0.95	0.7	6.5	0.95
Temperatur	(oC)	30.57869719	35.9	32	27	161.9914741	124.6304218	40	27	161.9914741	124.9278766	50	89.95911856	161.9914741	118.0870668
	(K)	303.7286972	309.05	305.15	300.15	435.1414741	397.7804218	313.15	300.15	435.1414741	398.0778766	323.15	363.1091186	435.1414741	391.2370668
NCG	(%)					0.497538729	24.49446481	100		0.497538729	29.81035096	100	0.497538729	0.497538729	0.495075536
Laju massa															
Laju massa uap/air	(kg/jam)	320000	294500	294500	156669.9231	5900	5900	0	145177.3222	4560	4560	0	430	500	930
Laju massa NCG	(kg/jam)					29.35478501	1913.996663	1913.996663		22.68776604	1936.684429	1941.311539	2.139416535	2.487693645	4.62711018
Laju massa TOTAL	(kg/jam)	320000	294500	294500	156669.9231	5929.354785	7813.996663	1913.996663	145177.3222	4582.687766	6496.684429	1941.311539	432.1394165	502.4876936	934.6271102
Laju massa															
Laju massa uap/air	(kg/s)	88.88888889	81.80555556	81.80555556	43.51942308	1.638888889	1.638888889	0	40.32703394	1.266666667	1.266666667	0	0.119444444	0.138888889	0.258333333
Laju massa NCG	(kg/s)					0.008154107	0.53166574	0.53166574		0.006302157	0.537967897	0.539253205	0.000594282	0.000691026	0.001285308
Laju masas total	(kg/s)	88.88888889	81.80555556	81.80555556	43.51942308	1.647042996	2.170554629	0.53166574	40.32703394	1.272968824	1.804634564	0.539253205	0.120038727	0.139579915	0.259618642
Enthalpi															
Enthalpi uap/air	(kJ/kg)	128.3462594	150.5772508	134.2841534	113.394174	2758.870002	2731.521	0	113.394174	2758.870002	2726.844862	0	2660.071023	2758.870002	2713.173835
Enthalpi CO2	(kJ/kg)					146.0723393	111.393708	35.13002544		146.0723393	111.6673851	43.97363274	79.76250898	146.0723393	105.3832939
Enthalpi total	(kJ/kg)	128.3462594	150.5772508	134.2841534	113.394174	2745.870322	2089.738809	35.13002544	113.394174	2745.870322	1947.255592	43.97363274	2647.232989	2745.870322	2700.263813
Entropy															
Entropi uap/air	(kJ/kg.K)	0.470131129	0.543039138	0.489720022	0.420438152	6.721020977	7.074355578	0	0.420438152	6.721020977	7.071284955	0	7.473321046	6.721020977	7.143211838
Entropi CO2	(kJ/kg.K)					4.799441804	5.236202937	5.022483491		4.799441804	5.078161257	4.892340123	5.04914197	4.799441804	5.061196048
Entropi total	(kJ/kg.K)	0.470131129	0.543039138	0.489720022	0.420438152	6.711460377	6.624109926	5.022483491	0.420438152	6.711460377	6.477127786	4.892340123	7.461259816	6.711460377	7.132904287

Parameter	Satuan	34	35
		Udara kering masuk menara pendingin	Udara kering keluar menara pendingin
Tdb	oC	20.86034968	33.5
Tdb	K	294.0103497	306.65
Twb	oC	18.5	33.5
Twb	K	291.65	306.65
RH	%	79.99992745	100
Entalpi udr kering	kJ/kg	52.17413478	118.7684915
kg per kg	kg/kg	0.012283993	0.03319233
m ud kering (5)	kg/s	3275.22288	3275.22288
evaporation loss	kg/s		68.47946357
evaporation loss	%		1.995926654
Daya kipas (5)	kW	544.9962458	