THE VERIFICATION OF THE RSG-GAS REACTOR COOLING TOWER HEAT TRANSFER CAPACITY

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ABSTRAK

VERIFIKASI KAPASITAS PEMINDAHAN PANAS MENARA PENDINGIN REAKTOR RSG-GAS. Telah dilakukan penggantian menara pendingin Reaktor RSG-GAS. Spesifikasi teknis menara pendingin baru menyebutkan kemampuan pemindahan panas dari air pendingin sekunder ke lingkungan sebesar 5500 kW per modul. Penelitian ini menguraikan tentang verifikasi kemampuan pemindahan panas dari pendingin sekunder ke lingkungan dengan perhitungan teoritis menggunakan data hasil pengujian. Pada operasi daya 30 MW yang dilakukan pada 20 Desember 2018, dilakukan pengambilan data meliputi temperatur pendingin primer masuk dan keluar teras, temperatur pendingin sekunder masuk dan keluar menara pendingin, temperatur *wet bulb* dan temperatur *dry bulb* lingkungan, serta temperatur udara masuk dan keluar menara pendingin. Data tersebut digunakan untuk perhitungan kemampuan pemindahan panas dari air pendingin sekunder ke lingkungan. Dari perhitungan diperoleh bahwa setiap sel menara pendingin Reaktor RSG-GAS mampu memindahkan panas ke lingkungan sebesar 5528,52 kWatt. Nilai tersebut telah sesuai dengan spesifikasi teknis yang tertulis dalam Laporan Analisis Keselamatan RSG-GAS revisi 11.

Kata kunci: kapasitas, menara pendingin, panas, spesifikasi, teoritis

ABSTRACT

The RSG-GAS reactor has been replaced and the technical specifications for the new cooling tower specify that the heat transfer capacity from the secondary cooling water to the environment is 5500 kW per module. Therefore, this study aims to verify the theoretical calculations of the heat transfer capacity using performance test data collected on the 30 MW power operation on December 20, 2018, such as the temperature of the primary and secondary coolant entering and exiting the cooling tower, wet bulb and environmental dry bulb temperature, as well as the inlet and outlet air temperature. Furthermore, the data were used to calculate the heat transfer capacity from the secondary cooling water to the environment. The results showed that each cell of the RSG-GAS cooling tower reactor transfers the heat of approximately 5528.52 kW. This value is consistent with the technical specifications written in the revised RSG-GAS Safety Analysis Report 11.

Keywords: capacity, cooling tower, heat, specification, theoretical.

INTRODUCTION

The Multipurpose G. A. Siwabessy (RSG-GAS) is a reactor used for research, irradiation, education, and training. The facility has been under construction since 1983, while the operation reached its first critical condition in July 1987. Besides, the reactor was inaugurated by the President of Indonesia on 20 August 1987 and the nominal power operation of 30 MW was achieved in March 1992 [1].

The operating support system includes ventilation, process 1 and 2, liquid waste collection, electrical, radiation, as well as earthquake monitoring, control rod drive, and reactor protection systems. Meanwhile, one component of process system 2 is the cooling tower [1]. Since commissioning, the cooling tower has been used for more than 30 years. This led to a decrease in the heat transfer capacity to the environment. Furthermore, a test on the cooling tower carried out in terrace 96 on 18 May 2018 showed that at 30 MW of operation for 45 minutes, the primary coolant reached a temperature of 41,962 ^oC. The increasing trend of the primary coolant temperature tends to continue until a steady condition is reached. The reactor automatically SCRAM when used for a long time because the temperature of the primary coolant has exceeded the activation limit of the protection system which is 42 ^oC. Consequently, the RSG-GAS cooling tower after 30 years of operation no longer meets the safety criteria for reactor operation [2].

The seven cell cooling towers of the RSG-GAS reactor have been replaced, while the heat transfer capacity to the environment was tested on December 20, 2018. The results showed that at a steady state of 30 MW, the temperature of the primary coolant leaving and entering the core is 44^{o}C and 36^{o}C, while the inlet and outlet temperatures of the secondary coolant is 36.94^{o}C and 29.86^{o}C respectively. Additionally, 6 operating cooling towers were able to transfer heat to the environment. Furthermore, the temperature of the primary coolant entering the core did not exceed the activation limit of the protection system [3]. The project handover document stated that the cooling tower's heat transfer capacity is 5500 kW per module. Therefore, this study aims to verify the cooling tower heat transfer capacity per module based on theoretical calculations using performance data.

METHOD

Heat Transfer in Cooling Towers

The cooling tower transfers heat from the water to the ambient air [4]. This process occurs due to direct contact in two ways, namely heat transfer from cooling water to air (sensible) and through evaporation (latent) [5]. Heat transfer from cooling water to air depends on the temperature and moisture content indicated by the Wet Bulb Temperature (WBT) parameter. Ideally, the cooling water might condense to WBT, but this has never been achieved given that the cooling water rarely has direct contact entirely with the air. Meanwhile, the Cold Water Temperature (CWT) depends on the contact time with the air and cooling water, the amount of surface area of the fill, and water that becomes droplets [6]. The smaller the difference between WBT and CWT, the better the cooling tower's heat transfer performance.

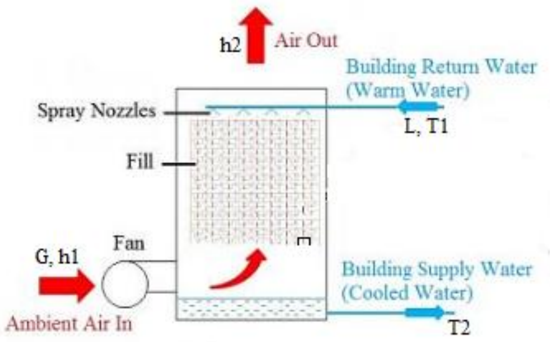

Figure 1. Cooling Tower Schematic [7]

Secondary cooling water with mass rate L and inlet temperature T1 enters and exits with outlet T2, while the environmental air with mass rate G and enthalpy h1 enters and exits with enthalpy h2. Heat transfer occurs from water to air and the cooling tower schematic is shown in Figure 1.

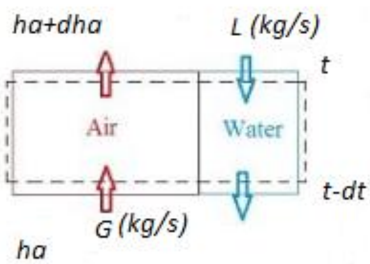

Figure 2. Control of Heat and Mass Transfer Volume in Cooling Tower [7, 8]

Figure 2 shows the volume control of the heat and mass transfer processes in a cooling tower. The analysis of heat and mass transfer is as follows. Water enters at t and leaves the section at a lower temperature, i.e. t-dt, while air enters with ha and leaves with the enthalpy ha+dha. The rate of heat transfer from water is equal to the rate of heat received by air [9]. The equation is as follows [10]:

$$dQ = G.dha = L.Cp.dt \qquad (1)$$

According to the principle of enthalpy potential, the heat transferred from the cooling water to the air over a wide interval is:

$$dQ = \frac{hc \, . \, dA}{Cpm} \, (hi - ha) \qquad (2)$$

To calculate the heat transfer rate in all parts of the cooling tower, equations 1 and 2 are integrated to obtain the following equations:

$$L.Cp \, . \int_{tout}^{tin} \frac{dT}{hi - ha} = \int_{0}^{A} \frac{hc.dA}{Cpm} \qquad (3)$$

$$L.Cp \, . \int_{tout}^{tin} \frac{dT}{hi - ha} = \frac{hc.A}{Cpm} \qquad (4)$$

$$NTU = \frac{hc.A/Cpm}{G} \qquad (5)$$

$$Q = \frac{hc.A}{Cpm} . (hi - ha) \qquad (6)$$

where:

dq	: heat transfer rate
G	: air mass flow rate
dha	: enthalpy change of air
L	: water mass rate
Cp	: the specific heat capacity of water
Dt	: change in water temperature
hc	: convection coefficient
hi	:enthalpy of saturated air at the water temperature
ha	: enthalpy of air
Cpm	: humid air type heat
tin	: inlet water temperature
tout	: outlet water temperature
A	: Heat Transfer Area
NTU	: Number of Transfer Unit

The use of equations 1-6 is based on the assumption that the flow rates of water and air are constant.

Figure 3 shows the relationship between water and air and the driving potential of a counterflow cooling tower. AB is the line of work for water and is determined by the inlet and the cooling tower outlet temperature, while CD is the line for aerial work and starts from point C which indicates the enthalpy of air WBT. Furthermore, BC is the beginning of the enthalpy driving force, while the ratio of liquid to gas, L/G, is the line of action gradient. The air exits the cooling tower at point D, while the cooling range is the projection of the CD line to the temperature scale or the difference between the cooling tower inlet and outlet water temperature. Meanwhile, the approach is the difference between the outlet temperature and the WBT of the ambient air. The cooling tower characteristic, KaV/L, is an integral value which indicates the area of ABCD and depends on the L/G ratio [11].

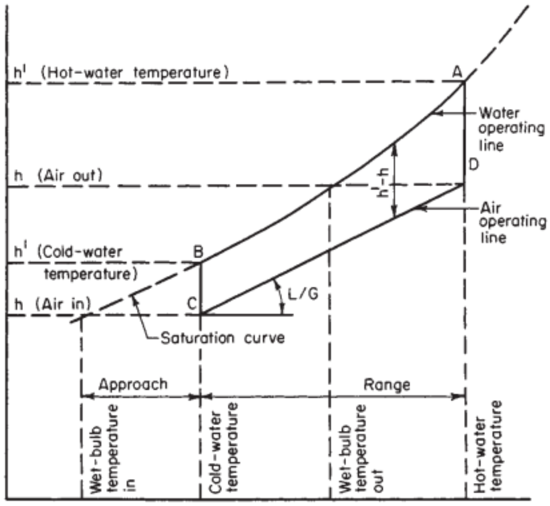

Figure 3. Water and Air Process Diagram [6]

Verification Method

The data used for the calculations are records of reactor operations and the results of cooling tower tests conducted by HAMON Company on December 20, 2018 [12, 13]. These include:

1. Coolant flow rate entering the cooling tower
2. Air flow rate in cooling tower
3. Temperature of secondary coolant entering the cooling tower
4. Secondary cooling temperature out of the cooling tower
5. Dry bulb temperature
6. Wet bulb temperature
7. Cooling tower intake air temperature
8. Cooling tower exit air temperature

The verification steps include:

1. Calculating the mass velocity of air and water
2. Dividing the heat transfer area into 5 parts
3. Calculating the energy balance at the bottom of the cooling tower (where the air enters)
4. Calculating the average enthalpy of air
5. Calculating the enthalpy of saturated air
6. Calculating the value of hc.A/Cpm (cooling tower characteristics)
7. Calculating the heat transfer capacity of cooling towers

RESULT AND DISCUSSION

A thermal performance test was carried out on the cooling tower of the RSG-GAS Reactor on December 20, 2018, and the results are shown in Table 1.

Table 1. Summary of Cooling Tower Thermal Performance Test Results [12]

Parameter	Unit	Design	Test
Inlet water	ºC	39,2	36,90
Outlet water	ºC	32,00	29,92
Range	K	7,20	6,98
Dry bulb	ºC	30,96	32,00
Wet bulb	ºC	28,00	25,10
Atmospheric pressure	mbar	1013	1013,00
Outlet air density	Kg/m^3	1,115	1,124
Air speed	m/s	4,5	2,9
Water flow rate	m^3/hour	3909	4148,00
Tower Capacity	%		107,1

The test carried out during operation with a power of 30 MW shows that the cooling tower transfers heat to the environment hence, the temperature of the primary coolant entering the core is at a steady-state of 36ºC. This value is still far from the limit for the activation of the reactor protection system, which is 42ºC. This situation shows that the replacement of the cooling tower has been able to meet the safety aspects of reactor operation.

The data used for the calculations are shown in Appendix 1 of Table 2. The first calculation performed was the mass rate of water and air entering the cooling tower and the results showed that the values were 179.98 kg/s and 115.28 kg/s respectively. Hence, the ratio of cooling water and air rate, L/G was 1.56. This value is the slope of the working air line passing through the cooling tower. The calculations for water and air mass rates are shown in Appendix 1 Table 3.

The heat transferred to the environment was determined by calculating the characteristics of the cooling tower using equation (4). This was carried out by dividing the cooling tower temperature area into 5 parts hence, the dT/n value is 1.396ºC. The energy balance at the bottom of the cooling tower was then calculated and obtained a value of 9.13 kJ/kg. The next step was to calculate the value of hc.A/Cpm as shown in Appendix 1 of Tables 4 to 6. The calculations obtained a value of 219.3098 kg/s which was then used to determine the characteristics of the cooling tower including the performance on inlet water temperature and WBT.

The NTU value was calculated using equation (5) and the results obtained a value of 1.9 which indicates the characteristics of the cooling tower, or in Merkel Theory referred to as the Merkel Number [6]. A large NTU value indicates that the outlet temperature is closer to the WBT of the inlet air and also a smaller approach. Meanwhile, the closer the approach value to WBT, the better the condition of the cooling tower. This value depends on the contact time between water and air, the surface area of the fill, and the amount of water that becomes a droplet.

After obtaining the hc.A/Cpm value, the heat transfer capacity to the environment was then calculated using Equation (6). The Q value which represents heat transferability is indicated by the inlet air or the water falling into the cooling tower pool, namely Q1. The calculation of the heat transfer capacity is shown in Appendix 1 of Table 7. A Q value of 5528.52 kW was obtained based on the theoretical calculations from the cooling tower test results at a nominal power of 30 MW.

CONCLUSION

The heat transfer capacity of the cooling tower to the environment is 5528.52 kW per module. This value is consistent with the specifications and contract requirements for the RSG-GAS cooling tower revitalization and cooling tower design data in the Revised 11 LAK.

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Appendix 1.

Table 2. The Calculation Data

Data	Value	Unit	Description
Water flow rate	651,44	m3/h	Design
Air flow rate	104,8	m3/s	Design
Inlet water to the cooling tower	36,90	ᵒC	Measurement
Outlet water of cooling tower	29,92	ᵒC	Measurement
Dry Bulb Temperature	32,00	ᵒC	Measurement
Wet Bulb Temperature	25,10	ᵒC	Measurement
Tb1 (inlet air)	32,00	ᵒC	Measurement
Tb2 (outlet air)	38,00	ᵒC	Measurement

Table 3. The Calculation of Water Mass Rate and Air Mass Rate

Data	Value	Unit
Range	6,98	ᵒC
Approach	4,82	ᵒC
T water average	33,42	ᵒC
P water at T mean	994,62	kg/m3
L (water flow rate x ρ water)	647933,10	kg/h
L	179,98	kg/s
T air average	35,00	ᵒC
ρ air at T mean	1,11	kg/m3
G (flow rate x ρ air)	6916,8	kg/m
G	115,28	kg/s
L/G	1,56	
Cooling Tower divided by 5, dT/n	1,396	ᵒC
The bottom of the energy balance, d(ha,n -ha,n-1)=ha,1-ha,0		
ha,1-ha,0 = L/G x 4,19 x dT/n	9,13	kJ/kg

Table 4. The Calculation of Mean Value of Air Enthalpy

ha,n=ha,n-1+L/G x 4,19 x dT/n	Value	Unit	ha, mean
ha,0= ha(TWB, TDB)=h inlet air	76,29	kJ/kg	
ha,1=ha,0+L/G x 4,19 x dT/n	85,42	kJ/kg	80,86
ha,2=ha,1+L/G x 4,19 x dT/n	94,55	kJ/kg	89,99
ha,3=ha,2+L/G x 4,19 x dT/n	103,69	kJ/kg	99,12
ha,4=ha,3+L/G x 4,19 x dT/n	112,82	kJ/kg	108,25
ha,5=ha,4+L/G x 4,19 x dT/n	121,95	kJ/kg	117,38

Table 5. The Calculation of Enthalpy of Saturated Air

T water (ᵒC)		T mean (ᵒC)	ln Pws	Pws	Ws	hi, mean
T0	29,92					
T1	31,32	30,62	8,43	4577,53	0,02943	106,06
T2	32,71	32,01	8,51	4953,52	0,03197	114,05
T3	34,11	33,41	8,59	5356,04	0,03471	122,57
T4	35,50	34,81	8,66	5786,60	0,03767	131,65
T5	36,90	36,20	8,74	6246,84	0,04087	141,36

Table 6. The Calculation of hc.A/Cpm

hi-ha	(kJ/kg)	1/(hi-ha)
h1-ha,1	25,21	0,0397
h2-ha,2	24,06	0,0416
h3-ha,3	23,45	0,0426
h4-ha,4	23,40	0,0427
h5-ha,5	23,97	0,0417
Total		0,2083
hc.A/Cpm = L x 4,19 x dT x Σ 1/(hi-ha)		
hc.A/Cpm (kg.d.a/kJ)		219,3098

Table 7. The Calculation of Heat Transfer Capacity

Q=hc.A/Cpm.(hi,n-ha,n)	Value	Unit
Q1= hc.A/Cpm.(hi,1-ha,1)	5528,524	kW
Q2= hc.A/Cpm.(hi,2-ha,2)	5277,460	kW
Q3= hc.A/Cpm.(hi,3-ha,3)	5142,384	kW
Q4= hc.A/Cpm.(hi,4-ha,4)	5132,333	kW
Q5= hc.A/Cpm.(hi,5-ha,5)	5257,116	kW