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Control Strategy of Solar Thermal Cooling System under the Indonesia Climate

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***Abstract*—**Solar thermal cooling system was installed on Mechanical Research Center (MRC) Building that is located in Universitas Indonesia, Depok, Indonesia. It is the first cooling system in Indonesia that utilizes solar energy as energy input combined with natural gas; therefore, the control system must be appropriated with the climates. In order to stabilize the cooling capacity and also to maximize the use of solar energy, the system applies some controllers. Constant flow rate and on/off controller are applied for the hot water, chilled water and cooling water pumps. The hot water circulated by pump when the solar radiation is over than 400W/m^2, and the chilled water is continually circulated by pump and its temperature is kept constant 7 °C by absorption chiller. The cooling water is also continually circulated until the outlet temperature of cooling tower below than 27 ^{o}C. Furthermore, the three-way valve is used to control the hot water for generate vapor on absorption chiller. The system performance using that control system is shown in this study results.

***Keywords*—**Absorption chiller, control system, solar cooling, solar energy.

I. Introduction

NON-RENEWABLE energies are widely used to supply the high energy demand so that the number continuously diminishing. The limitation of non-renewable energy and the worst effects for the environment also become the world issue. Therefore, the use of renewable energy must be maximized in order to increase the energy supply and also protect the environment. Solar energy can be a good option to solve energy problems in the world [1]. Many researchers conducted research to maximize renewable energy through utilization of solar energy, some of researches such as the solar absorption cooling system uses a single-effect absorption chiller in the Reunion Island was built with a capacity of 30kW to supply four classrooms by using the double-glazed flat plate solar collector with area of 90m^2 [2]. In Madrid, Spain also has built a solar powered water cooled absorption refrigeration system using absorption chiller can work as a single effect (4.5 kW) or double-effect (7kW) and use the flat plate solar collector with area of 48m^2 [3]. Then, at the Engineering School of Seville (Spain), solar absorption cooling plant with a double-effect absorption chiller was built with a capacity of 174kW and using linear concentrating Fresnel solar collector area 352m^2 [4].

Based on that background, solar thermal cooling system was installed in Mechanical Research Center (MRC) Building, Universitas Indonesia. This cooling system consists of hot water flow loop system, cooling water flow loop system and chilled water flow loop system and all of them centralized on single-double-effect absorption chiller machine. The absorption chiller machine can work as single-effect mode and single-double-effect mode, the detail explanation about this type of absorption chiller machine can be seen to [5]. The single-effect mode will work when the solar energy is sufficient to cover the cooling load of MRC building and if the solar energy is not sufficient then the absorption machine will work as single-double-effect which uses dual heat sources. In general, this absorption machine works with dual heat sources namely solar energy and natural gas. Since this system is very complex hence the control strategy of this system is really important, firstly, to keep this system stable to supply the chilled water to the MRC building.

The control strategy of this system has been determined refer to the absorption chiller company standard operation. Many parameters that have to be observed from this cooling system but in this study more focus to the minimum value of solar radiation to control the hot water pump circulation and also the difference temperature between hot water from solar energy and solution enter to special generator to control open and close of the three way valve. This control strategy gives influence the performance of whole system hence the control strategy that is implemented is also expected has good performance. Furthermore, the control strategy is adapted to the Indonesia climate.

In this study to find the appropriate control strategy for controlling the circulation of hot water pump and also open/close three way valve so that the minimum value of solar radiation and the difference temperature have been decided. Then the performance and characteristics of the cooling system based on those values are explained in general at this paper.

II. System Description

Indonesia is a country located on the equator therefore it has a great potential of solar energy. The average potential of solar energy at Indonesian regions is approximately 4.8kWh/m^2/day [6]. Long duration of sunshine in round year is worth if it is seen as the availability of renewable energy but on the other hand, it also makes buildings extensive use of air conditioning system, thus the electrical energy consumption will increase. Hence, the implementation of solar thermal cooling system in Indonesia will give many beneficial. Fig. 1 shows the global horizontal solar radiation of Indonesia. This system consist of evacuated tubular collectors with the total aperture are of 181.04m^2, a hot water storage tank of 1m^3, a single-double-

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effect absorption chiller with working fluid LiBr/water has cooling capacity of 239kW, a cooling tower, a radiator, fan coil units (FCU) and other auxiliary equipment such as pumps, valves, vessels, and a data acquisition system (Fig. 2).

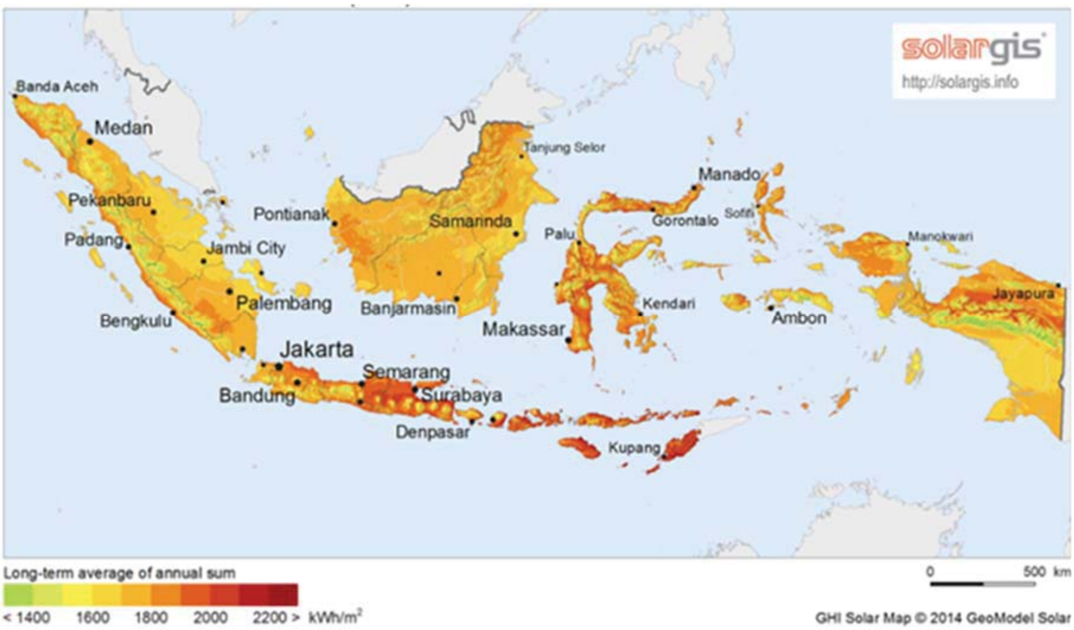

Fig. 1 Global horizontal solar radiation of Indonesia [7]

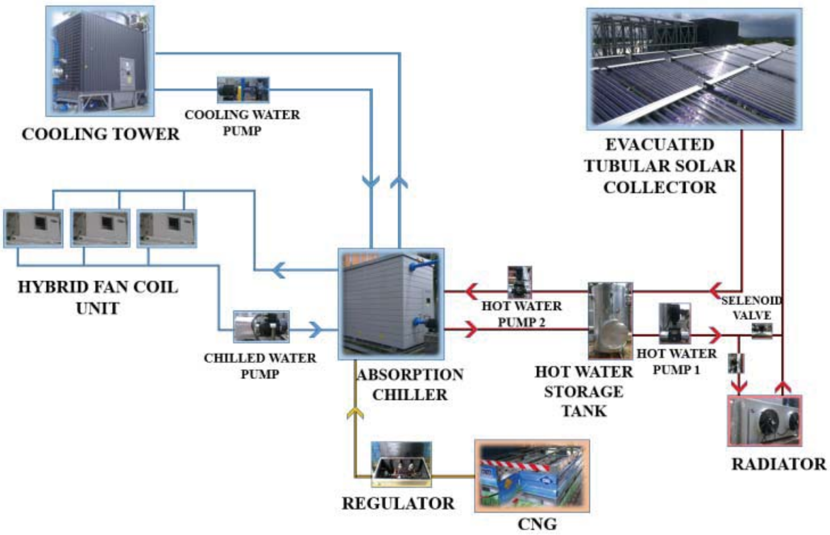

Fig. 2 Solar thermal cooling system

The absorption chiller is located around the building together with cooling tower, storage tank, radiator, and gas cylinders. The solar collectors are located separately on the top of building to maximizing the absorption of sunlight. The hot water from the collectors is not directly entering the absorption chiller but temporary mixing in the storage tank to keep stable the hot water temperature. In the morning, the natural gas is used as the energy source to reach the cooling capacity, while solar energy will be utilized when the hot water temperature that is produced by collectors is higher than the requirement temperature (solution outlet temperature of special temperature generator).

III. Control System

A. Hot Water from Solar Flow Loop

Hot water will circulate when the solar radiation is higher than 400 W/m^2. The hot water from solar collectors enters the hot water storage tank before goes to the absorption chiller. In the tank, hot water from solar collectors will joint with hot water comes out from the absorption chiller. When temperature in the storage tank is 2 °C lower than the temperature of the solution out of the special generator, the three-way valve will remain closed for the flow direction to the absorption chiller and the hot water pump 2 is also stopped. The valve will open and the pump will work when hot water temperature is 2 °C higher than the temperature of solution. For safety, this system has a radiator to release the excess heat when the hot water temperature is higher than 95 °C. Even though the absorption chiller stops but this system still works in order to prevent the excessive hot water temperature in the solar collector. The heat is directly released into environment by the radiator.

B. Cooling Water Flow Loop

In this system, the pump will circulate cooling water continuously from the absorption chiller to cooling tower until the cooling water reaches temperature of 27°C. When the temperature reaches 27°C then the pump and cooling tower will stop. Make-up water is needed to replace the lost water due to the open-type of cooling tower.

C. Chilled Water Flow Loop

The pump supplies chilled water to the fan coil unit (FCU) in the building. Chilled water is distributed in parallel for each floor, thus the chilled water is supplied to the FCU has the same temperature.

D. Absorption Chiller Machine

The first start of this absorption chiller uses double-effect mode because hot water in the storage tank is not enough to provide heat hence the high generator works. Absorption chiller uses a direct fired in the high generator. Control burner based on evaporator chilled water outlet temperature sensor. When the chilled water outlet temperature is 7.5 °C, the burner works until the chilled water outlet temperature of 6 °C. Since the hot water from solar collectors can be used, the absorption chiller works with gas and solar energy.

IV. Performance Model

The operation condition of this system can be seen in Table I. Constant flow rate of water is applied to this system is based on the standard operational of absorption machine. In the future, to optimize the performance of this system, particularly during the real time, the controller must be applied appropriate water flow rate based on the real condition. At this study, safety operational is really important because there is no previous experience. Hence, the constant water flow rate is adopted.

TABLE I
EXPERIMENT CONDITIONS

	Value	Unit
Chilled water outlet temp.	7	°C
Chilled water flow rate	25.7	m^3/h
Cooling water flow rate	68	m^3/h
Hot water flow rate 1	12	m^3/h
Hot water flow rate 2	7.8	m^3/h

The measurement only produces the temperature and flow rate data, hence for the other values such as capacity and performance should be calculated with some equations as following:

The amount of solar energy is influenced by the flow rate and temperature difference. To calculate the amount of solar energy uses (1).

$$Q_{solar} = \dot{m}_{solar} c_p \Delta T \tag{1}$$

where Q_{solar} = solar heat amount [kW], $\dot{m}_{solar}$= hot water mass flow rate [kg/s], c_p= specific heat of water [kJ/kgK], ΔT= difference temperature between inlet and outlet solar collector [°C]

The performance of absorption chiller can be seen from this study. The COP is calculated from cooling load divided by gas energy. It is only divided by gas because the solar energy is free from nature hence solar energy is ignored. The equations are as:

$$Q_{evap} = \dot{m}_{evap} c_p \Delta T \tag{2}$$

$$Q_{gas} = Volume\ of\ gas\ per\ hour\ \left(\frac{Nm^3}{h}\right) \times 41.8 \left(\frac{MJ}{Nm^3}\right) \times \frac{1}{3600} \times 1000\ [kW] \tag{3}$$

$$COP = \frac{Q_{evap}}{Q_{gas}} \tag{4}$$

where; Q_{evap} = cooling capacity [kW], $\dot{m}_{evap}$= chilled water mass flow rate [kg/s], c_p= specific heat of water [kJ/kgK], ΔT = difference temperature between inlet and outlet evaporator [°C], Q_{gas} = gas consumption energy [kW], COP= performance of absorption chiller only divided by gas energy [-], High heating value of CNG = 1060.292 BTU/scf or 41.8 MJ/Nm^3

V. Results and Discussion

The experiment results are based on 23rd September 2014. The results show the changes of temperature, flow rate, capacity, and COP against the time. This result represents the typical experimental data since the first time of this system was installed. The cooling capacity from the experiment was too low if it is compared to the maximum cooling capacity of the machine (239 kW); it appeared because the building was still under construction while the data was taking. The solar radiation and ambient temperature can be seen in Fig. 3. The ambient temperature sensor is located near from the solar collectors on the top floor. Ambient temperature increased from morning until the midday and then decreased back until the evening. The maximum ambient temperature can reach 37.2 °C and it happened a while during the midday. The average of ambient temperature is around 33.8 °C (07:00–17:00). The maximum of solar radiation is up to 738 W/m^2 during the midday. The number of solar energy between 07:00 and 17:00 is around 4 kW/m^2/day.

Fig. 4 shows the changes of chilled water outlet temperature because of control system on high temperature generator. The chilled water outlet is kept constant at 7 °C through the high generator. In the high generator, this absorption chiller uses direct-fired type hence to control this burner needed upper and lower limit for burner on/off. As seen in the figure, the upper limit is 7.5 °C and the lower limit is 6 °C. The chilled water outlet temperature is not exactly stable at 7 °C but during the system working it was around 6-7.5 °C. The gas flow rate moves to adjusting the chilled water outlet temperature corresponds to the target of 7 °C. In general, the working of controller in high temperature generator is not really optimal to keep constant chilled water outlet temperature and also the gas fuel consumption against the time is really fluctuation.

Hot water pump 1 works based on two criteria namely solar radiation is over than 400 W/m^2 and the hot water inside the collector is over than 90 °C. The hot water pump 1 works independently and it is not influenced by the absorption machine. It means that although the absorption machine is in idle condition, the hot water will continue to flowing.

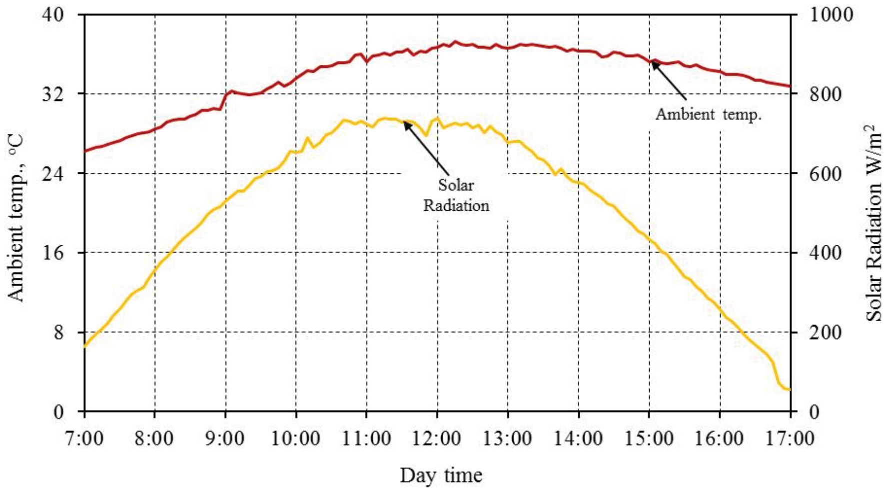

Fig. 3 Solar radiation and ambient temperature based on 23rd September 2014, Depok-Indonesia

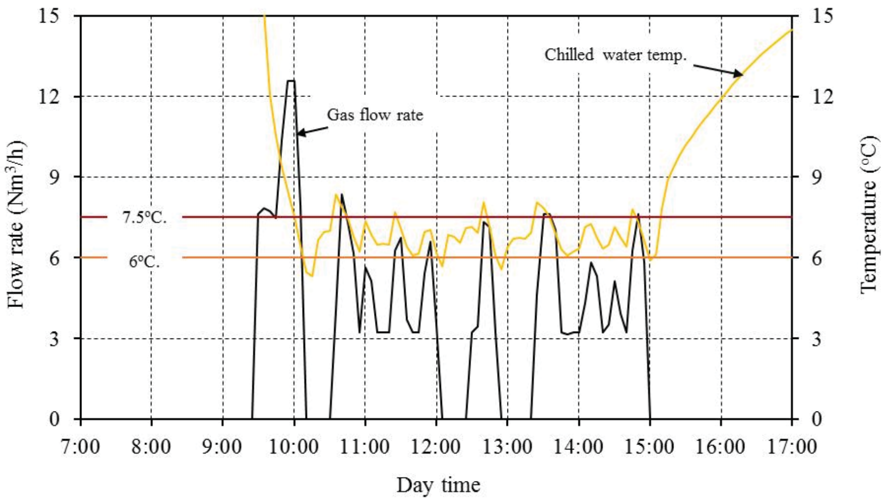

Fig. 4 Control system to keep chilled water outlet of 7°C

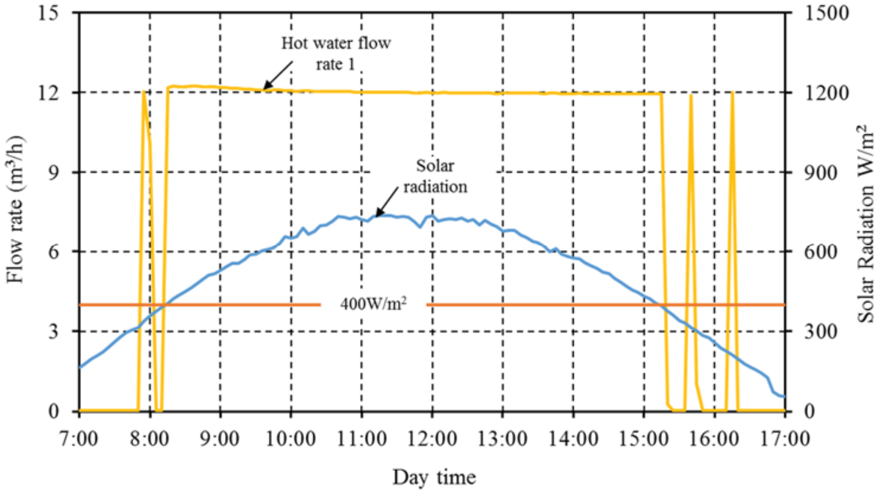

Fig. 5 Control system on hot water pump 1 based on solar radiation

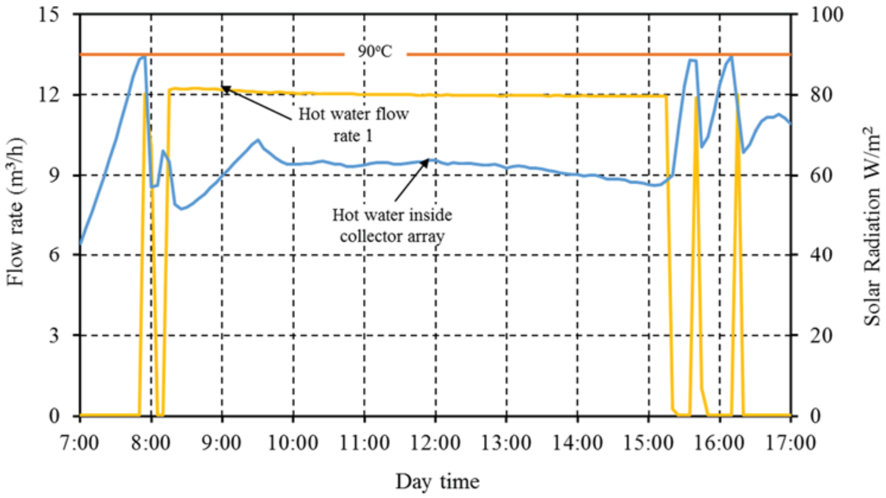

Fig. 6 Control system on hot water pump 1 based on hot water inside collectors

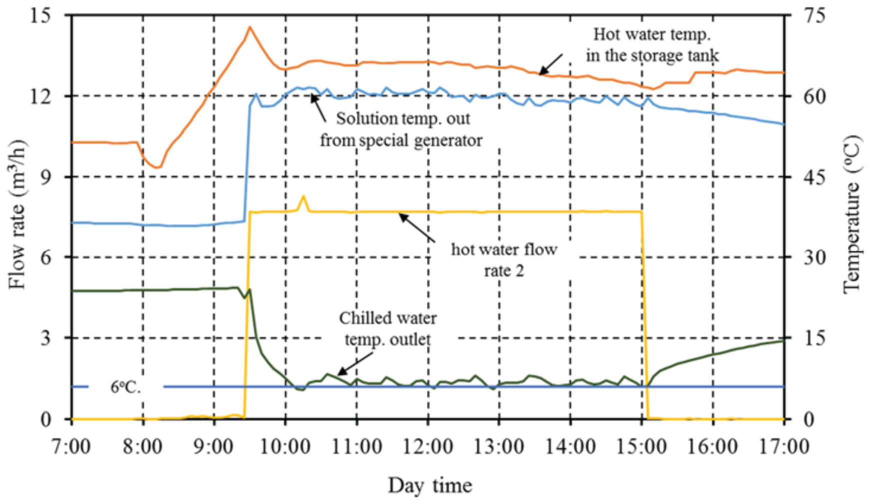

Fig. 7 Control system on hot water Pump 2 and Three Way Valve

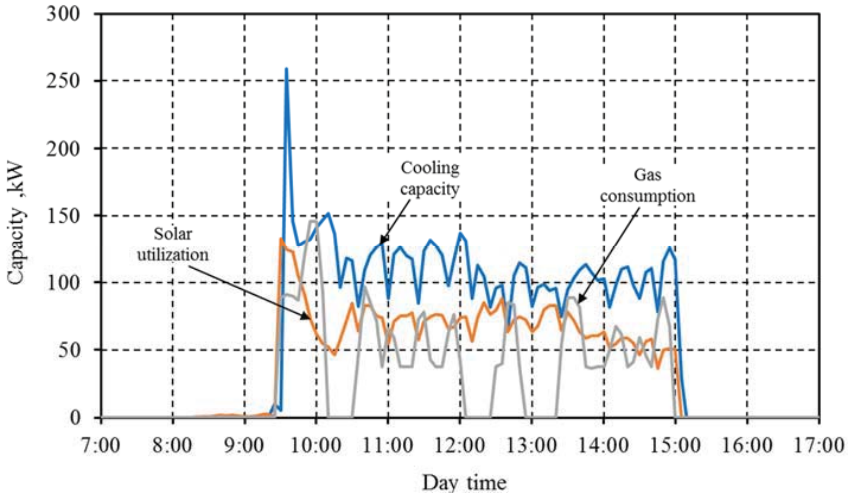

Fig. 8 Capacity of cooling, solar and gas

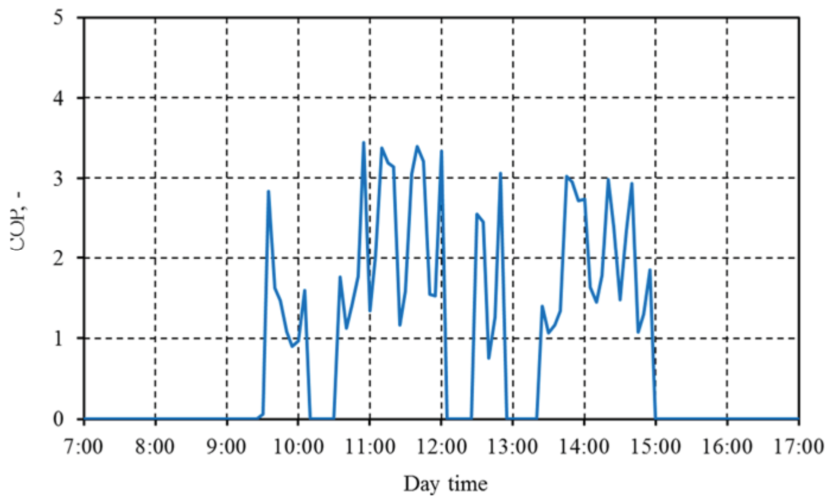

Fig. 9 Cop of single-double-effect absorption chiller

Based on Fig. 5, the hot water pump 1 works around 08:00 and 15:30 because outside that time the solar radiation values are lower than 400 W/m^2. But the hot water pump 1 can also work when the solar radiation is lower than 400 W/m^2 when the hot water temperature inside collector is over than 90 ^{o}C (Fig. 6). Actually, the hot water temperature sensor inside the collector is only one and it used to keep the temperature inside is not over than 90 ^{o}C. If the hot water temperature is over than 90 ^{o}C is worried the phase of hot water will change to be vapor and it can increase the pressure inside the collector then it will make the collector is damaged.

Fig. 7 shows the relationship between hot water pump 2, three way valve and difference temperature of hot water temperature in the storage tank and solution temperature out from special generator. The hot water pump 2 will work when the difference temperature is over than 2 ^{o}C. As seen from Fig. 7, hot water pump 2 works from the first time the absorption chiller works until the end because the difference temperature is over than 2 ^{o}C. The hot water temperature in the storage increase dramatically from 08:00 until 9:30 then it decreases because the absorption chiller starts to use it.

Fig. 8 shows the capacity of cooling, solar and gas. The cooling capacity was really high in the beginning because the difference temperature between inlet and outlet was big. The average of cooling capacity is around 110 kW. The unstable of cooling capacity is influenced by the unstable control in the high generator.

VI. Conclusion

Solar thermal cooling system that employing single-double-effect absorption chiller is still a new system in Indonesia hence needs research and development for the future. Based on the experimental results, the control strategy that has been implemented in this system has the average COP around 2. But, from perspective of control system, the system needs improvement to make the gas fuel consumption more stable, and it is good for gas saving. To control three-way valve using 2 ^{o}C of temperature difference worked well but maybe it can still be minimized to get the optimum value of solar energy. Using 400 W/m^2 solar radiation as the minimum value for controlling hot water pump makes the system can utilize solar energy for 8 hours.

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NOMENCLATURE

COP performance of absorption chiller only divided by gas energy [-]
c_p specific heat of water [kJ/kgK]
CNG Compressed Natural Gas
High heating value of CNG = 1060.292 BTU/scf or 41.8 MJ/Nm^3
FCU Fan Coil Unit
Li/Br Lithium bromide
$\dot{m}_{solar}$ hot water mass flow rate [kg/s]
$\dot{m}_{evap}$ chilled water mass flow rate [kg/s]
Q_{solar} solar heat amount [kW]
Q_{evap} cooling capacity [kW]
Q_{gas} gas consumption energy [kW]
ΔT difference temperature [°C]

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