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Investigation of Cycle Time for Adsorption Cooling System

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Abstract: *One of the crucial concerns to society nowadays is regarded in environmental issues. One of the solutions to achieve sustainable ecology is using clean energy resources such as solar energy. Solar energy can drive the operation of the adsorption cooling system since it can operate with a low thermal grade heat source. However, there are drawbacks to the adsorption cooling system, such as a low Coefficient of Performance (COP) and low Specific Cooling Power (SCP), which lead to a large size and heavy machine. This low performance is due to a massive amount of adsorbent that is needed to deliver significant cooling power. The improvement of the performance had been made through the experiments. It was succeeded in identifying the optimum variable parameters that affect the performance, such as adsorption/desorption time variation in one refrigeration cycle, pre-cooling/pre-heating time variation, which occurs in between adsorption/desorption process. The experiment was started by identifying the optimum variable of each parameter one by one and accumulate all optimum variable parameters at one final optimum result. The experiment outcome was able to determine better COP and higher cooling capacity with the same amount of adsorbent.*

Keywords: Adsorption cooling system, compact generator, waste heat, solar, performance parameter

1. Introduction

The conventional air-conditioning system that leads to environmental hazards is worrying. There is a lot of discussion on how the improvement of the air conditioning system can bring less harm to the environment. Reported by BB. Saha et al., 2003, since 1979 some researchers such as Tchernev have studies on robust vapor system using zeolite as adsorbent and water as adsorbate for solar adsorption air condition and refrigeration system. It continued in 1981 by Alefeld and team which they were using the same pair to different applications such as heat pump and heat storage. Different pair which is activated carbon-methanol, studied by Pons and Guilleminot in 1986, and Exell in 1993 for ice production by using renewable energy. Until now, the study continues by many dedicated researchers.

There are many advantages of the adsorption cooling system compared to the other conventional cooling system. For example, the adsorption cooling system is quiet, less harm to the environment, and cheaper in operational cost (D.C. Wang et al., 2005). Other than that, the cooling system uses less energy, non-impact to ozone depletion, and it can operate using heat sources with low temperatures (A. Akahira et al., 2004). Also, the system produces much less vibration, which results in making less noise, lower initial cost, and easy to operate in terms of control (Z.S. Lu, 2011).

The adsorption cooling system required a heat source to run the desorption process (G. Najeh et al., 2016). The heat source is needed to heat the adsorbent can be from solar energy (X.Q. Zhai et al., 2010) and other applications that produce waste-heat such as automobiles (M. Hamdy et al., 2015), exhaust gas from the steam turbine, geothermal, biomass and electrical power (I.M. Astina et al., 2017).

Most typical applications of adsorption cooling systems are using activated carbon-methanol, silica gel-water, and zeolite-water as adsorbent-adsorbate pair. The criteria to select the working pairs depend on the requirement of the cooling power needed to deliver by the system (K. Sen Chang et al., 2005). Silica gel as adsorbent and water as adsorbate are both easy to handle and environmentally friendly. There are several reasons why they choose the material in the solar adsorption system. According to G. Najeh et al., 2016, the water itself has a high latent heat of evaporation, which means it needs a substantial amount of heat to change the state from liquid to vapor. Other than that, regeneration of silica gel can occur by using a low heat source. According to Liu, the adsorption cooling system able to operates on 70-95 C by using silica gel-water as adsorbate-adsorbent (Y.L. Liu, et al., 2005). While for Wang and Vineyard, they wrote that 50℃ was enough to run the adsorption cooling system (W.Kai et al., 2011).

A basic refrigeration cycle of the adsorption cooling system consists of 4 processes on the adsorber, one operation on each evaporator and condenser. The first process on the adsorber is pre-heating. In this process, the adsorbent in the adsorber is heated to the condensation temperature in isosteric (constant volume) conditions. For the second process on the adsorber, the desorption process occurs when the adsorber reaches onto the condensing pressure. During the desorption process, the heated adsorbent will reject the adsorbate, which is the refrigerant, away from their surface, thus resulting in increased hydrostatic pressure. The desorption process occurs in an isobaric condition with an increase in temperature. In the third process, the pre-cooling phase is applied to the adsorber, which results in decreasing the refrigerant-vapor pressure. The last process cycle on the adsorber is adsorption. The adsorbent is cooled down so that the adsorbate (refrigerant) on the evaporator will adsorb to the surface adsorbent, which exists in the adsorber. It will create vaporization on the evaporator. The adsorber continuously cools down in an isobaric condition. On the condenser, the rejected adsorbate from the adsorber will condense at an isobaric state. While on the evaporator, the refrigerant will evaporate in isobaric condition but continuously decreasing in temperature during the adsorption process J.Y. Wu, et al., 2011).

Few types of research have been done on investigating the effect of the performance by applying a variation of hot water temperature, adsorption/desorption time, and pre-cooling/pre-heating time on FAM-Z02/water and activated carbon/ethanol as the adsorbent/adsorbate (F. Jerai, et al., 2015). The investigation may continue by using a different pair of adsorbent/adsorbate, such as silica gel/water. Using the same parameters variation, such as adsorption/desorption time and pre-cooling/pre-heating time, the experiment may improve the performance of the adsorption cooling system.

2.0 Methodology

2.1 Problem Identification

The purpose of problem identification is to determine the specified problem that wants to be solved by the project experiment. In this project, the main problem of the project is the lower Coefficient of Performance (COP) and Specific Cooling Power (SCP). According to Sharafianardakani, this problem will result in an extensive system and takes big spaces to operates (A. Sharafianardakani, 2015). So, this experiment will identify the optimum adsorption/desorption time and pre-cooling/pre-heating time to improve the performance in terms of COP and SCP.

2.2. Determine the Variable and Fixed Parameters

Improvement of the performance of adsorption cooling system can be made through the variations parameters such as type of adsorbents, mass of adsorbent, size of adsorber, adsorbent-adsorbate pair, configuration of adsorber, hot water supply temperature, hot water supply flow rate, the cycle time for adsorption, desorption, pre-cooling, and pre-heating. Jerai et al. have written the effect of the pre-cooling and pre-heating time on the performance of the adsorption cooling system (F. Jerai, et al., 2015). The investigation that using activated carbon-ethanol pair concludes that there is an optimum time for pre-cooling ad pre-heating time for improving the performance of the system. For this project, the experiment will only focus on two variable parameters which are: (1) the adsorption and desorption time and (2) the pre-cooling and pre-heating time.

The preliminary analysis had been done to determine the maximum time for 0.1 kg of adsorbent able to produce cooling energy during the adsorption process. The chosen parameter for adsorption/desorption time is 5 minutes, 7.5 minutes, and 10 minutes, while for the pre-cooling/pre-heating time, the variable parameter is 1 minute, 1.5 minutes, and 2 minutes. For the fixed variable parameters, the list is tabulated in the Table 1.

The hot water supply was maintained to 60 °C due to the limited capacity of the solar heater as a heat source able to be delivered to the system. While for the chilled water temperature, it is supplied at 20 °C due to the significant decrement temperature at evaporator during the adsorption process, easy to maintain the temperature, and able to deliver a cooling effect since it is below room temperature.

2.3 System Configuration

Before running the experiment, the system needs to be configured and set. The experiments were on one-bed adsorber as shown in Fig. 1. The temperature data was recorded using a data logger. The sampling time is set at 1 second. It means that the temperature was recorded every 1 second. The flow rates are measured using flow meter in the liter per minute unit, which then converts into mass flow rates by multiply with the density of water.

Table 1 : Experimental Condition

Parameter	Value
Hot water tank temperature	60℃
Chilled water tank temperature	20℃
Cooled water tank temperature	Room Temperature
Mass of adsorbent	100 grams
Type of adsorbent	Silica Gel
Type of adsorbate	Water
Specific heat capacity (60℃)	4185 J/kg.K
Specific heat capacity (20℃)	4182 J/kg.K
Density (60℃)	983.13 kg/m^3
Density (20℃)	998.29 kg/m^3
Heat source flow rate	2L/min-3L/min
Condenser water flow rate	3L/min -4L/min
Chilled water flow rate	3L/min -4L/min

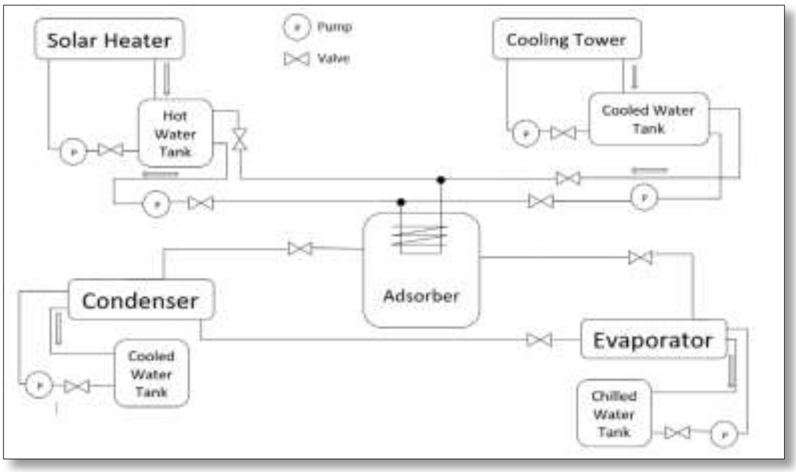

Figure 1: System configuration.

2.4 Run the Experiment

The experiments have been referring to the parameters in Table 2.

Table 2: List of experiments with variable parameters.

	Parameters			
Experiment No	Hot Water Temperature (°C)	Chilled Water Temperature (°C)	Adsorption Desorption Time (min)	Pre-cooling/ Pre-heating Time (min)
1	60	20	5	1
2	60	20	5	1.5
3	60	20	5	2
4	60	20	7.5	1
5	60	20	7.5	1.5
6	60	20	7.5	2
7	60	20	10	1
8	60	20	10	1.5
9	60	20	10	2

2.5 Data Analysis

Table 3: Governing equation

Proces	Governing equation
Mass flow rate	$\dot{m} = \rho V$ (1)
Adsorption heat	$Qads = \sum_{t=0}^{t=ads,end} \dot{m}Cp\left(T_{out,hot} - T_{in,hot}\right)\Delta t$ (2)
Evaporation heat	$Qeva = \sum_{t=0}^{t=eva,end} \dot{m}Cp(T_{in,chill} - T_{out,chill})\Delta t$ (3)
Desorption heat	$Qdes = \sum_{t=0}^{t=des,end} \dot{m}Cp\left(T_{in,hot} - T_{out,hot}\right)\Delta t$ (4)
COP	$COP = \frac{Qeva}{Qdes}$ (5)
Cooling capacity	$\dot{Q} = \frac{Qeva}{t_{ads}}$ (6)
Specific cooling capacity	$SCP = \frac{\dot{Q}}{m_{ads}}$ (7)

The energy input which denoted as $\mathrm{Q_{in}}$ can be derived from equation (1). The adsorption heat $Qads$ [J] during the adsorption process calculated by equation (2). The evaporation heat and desorption heat also calculated by using equation (3) and equation (4)respectively. The performance indices such as coefficient of performance, COP can be defined by using equation (5). The cooling capacity, $\dot{Q}$ and specific cooling power, SCP also can be defined as equation in (6) and equation (7) respectively.

3.0 Result and Discussion

To find the maximum time of adsorption that occurs on the evaporator, the experiment was held on 20 minutes of desorption and adsorption. The result, as shown in Fig. 2.

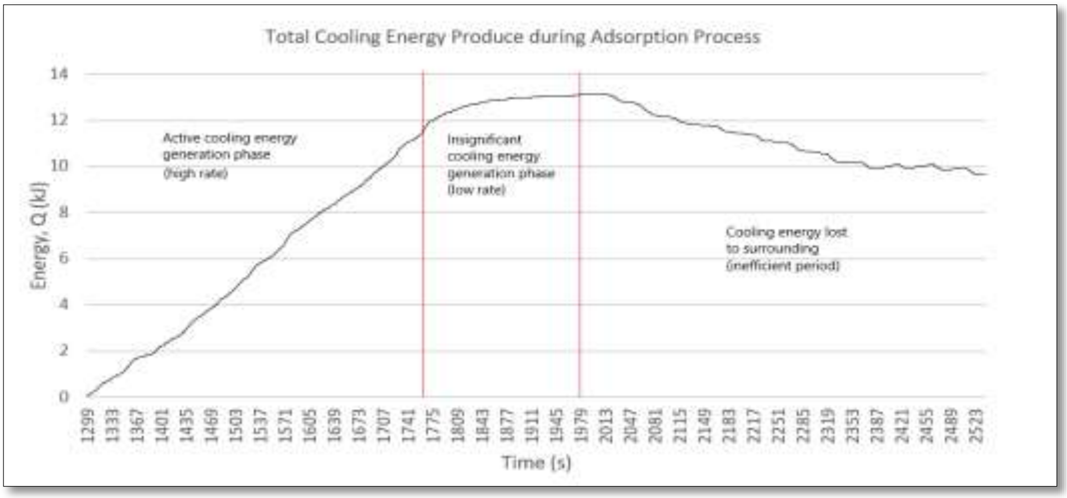

Figure 2: Total cooling energy produce during 20 minutes of adsorption process.

Fig. 2 depicts that the cooling energy is actively generated in the approximately first 10 minutes of the adsorption since there is positive increment on the graph. While for another 10 minutes, the curve seems constant and continues decreasing along the time. The reason behind this is because of the capacity of the 0.1kg of silica gel, which acts as adsorbent able to adsorb and desorb at a certain amount of water moisture. Whenever the silica gel reaches its limit to adsorb the water moisture, the adsorption process will stop. Therefore, the experiment will limit the parameter of all experiments to a maximum of 10 minutes of adsorption and desorption time.

The experiments were continued to find the optimum time for adsorption/desorption time along with the pre-cooling/pre-heating time. The chosen parameter for adsorption/desorption time is 5 minutes, 7.5 minutes, and 10 minutes, while for the pre-cooling/pre-heating time, the variable parameter is 1 minute, 1.5 minutes, and 2 minutes. Table 3 shows the summary of the performance results in terms of average COP, SCP, and total cooling power per cycle for all experiments according to the different variable parameters.

Table 3: List of Experiment with the Performance Result.

	Parameters				Performance Result		
Experiment No	Hot Water Temperature	Chilled Water Temperature	Adsorption/ Desorption Time (min)	Pre-Cooling/ Pre-Heating Time (min)	SCP (kJ/kg)	COP	Cooling Power (kJ)
1	60	20	5	1	50.39	0.28	5.04
2	60	20	5	1.5	58.67	0.36	5.87
3	60	20	5	2	81.62	0.37	8.16
4	60	20	7.5	1	92.26	0.2	9.23
5	60	20	7.5	1.5	93.21	0.23	9.32
6	60	20	7.5	2	95.1	0.31	9.51
7	60	20	10	1	96.4	0.26	9.64
8	60	20	10	1.5	105.04	0.29	10.5
9	60	20	10	2	107.28	0.38	10.73

The analysis was made to determine the optimum adsorption/ desorption time from the result of the experiment. From the result, and it was observed some trend and behaviour of pre-cooling/pre-heating time and adsorption/desorption time affect the performance of the system.

Fig.3 shows the performance of the system in terms of COP on the variable of adsorption/desorption time. By varies the adsorption/desorption time, the result of performance can be seen through this figure. From the result, it was shown that the parameter of 2 minutes of pre-cooling/pre-heating time was resulted in optimum performance compared to the parameter of 1 minute and 1.5 minutes of pre-cooling/pre-heating time. This is due to the efficient heat transfer as residual heat during desorption is being transferred to a cool water tank before adsorption process occur. For the condition of 1 minute and 1.5 minutes of pre-cooling/pre-heating time, the preferable parameters for adsorption/desorption time to use were 5 minutes. The experiments also observed that using variable parameters of 7.5 minutes of adsorption/ desorption time has the least optimum for the system. This is due to the mismatched pair of pre-cooling/pre-heating parameters that have been used in the experiments.

Fig.4 shows the performance of the system in terms of COP on the variable pre-cooling/pre-heating time. Form this figure, we can see that the different pre-cooling/pre-heating time will affect the performance of the system. There are variations in performance results in various parameters of adsorption/desorption time. By using the variable parameter of 5 minutes adsorption/desorption time, the COP had not changed much on 1.5 minutes and 2 minutes of pre-heating/pre-cooling time. While for the variable parameter of 7.5 minutes and 10 minutes of adsorption/ desorption time, it was observed that the COP increased significantly by varied the pre-cooling/pre-heating time. This is due to the higher of adsorption/desorption time required higher pre-cooling/pre-heating time to transfer the residual heat from adsorber to cool tank.

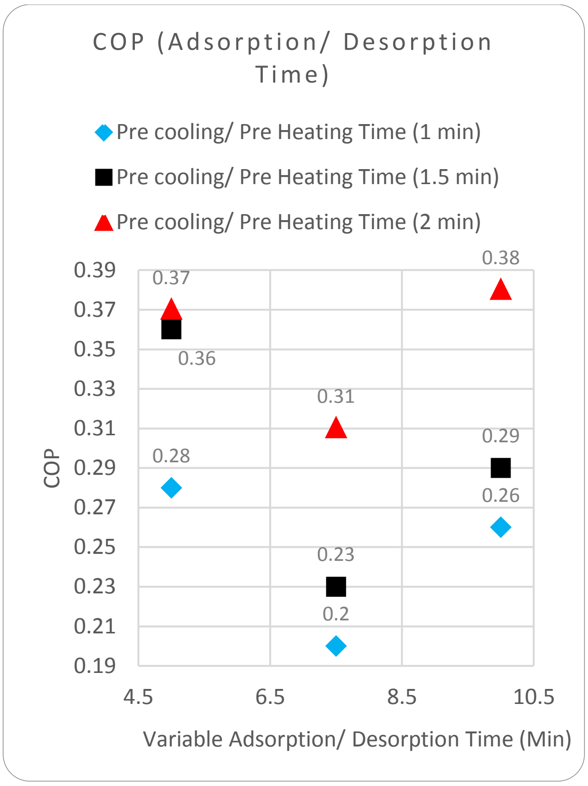

Figure 3: COP vs variable adsorption/ desorption variable time.

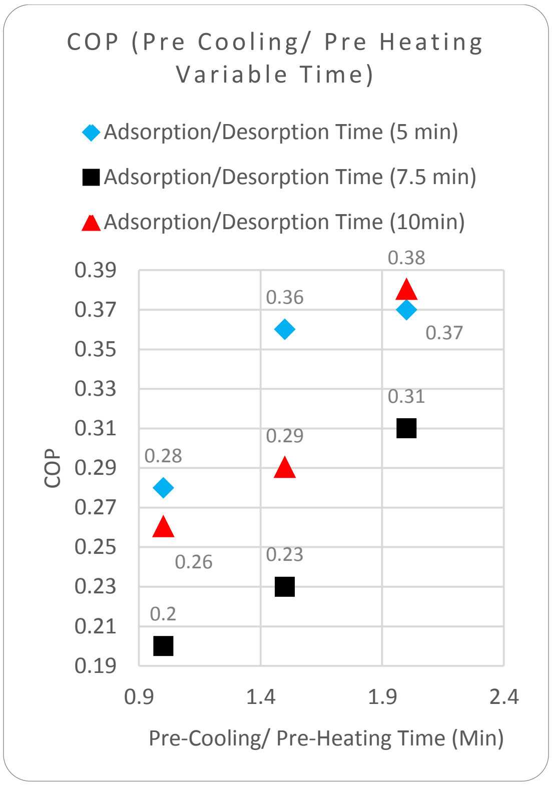

Figure 4: COP vs variable of pre-cooling/ pre-heating variable time.

Fig. 5 shows the performance of the system in terms of SCP on the variable of adsorption/desorption time. The Specific Cooling Power (SCP) is a total energy that the 1 kg of adsorbent able to produce during the adsorption time. From the figure, it shows increasing trend of the SCP as on the increased adsorption/desorption time. This is due to the accumulation of all energy produce during the adsorption time. The longer the adsorption time, the more energy able to be produced by the system.

Fig. 6 shows the performance of the system in terms of SCP on the variable of pre-heating/pre-cooling time. As we observed in the chart, the performance in term of SCP is improve and the parameters of pre-cooling/pre-heating also affecting the SCP. This is due to the better efficiency of the system in term of COP that will result in produce higher energy, Q_{eva}.

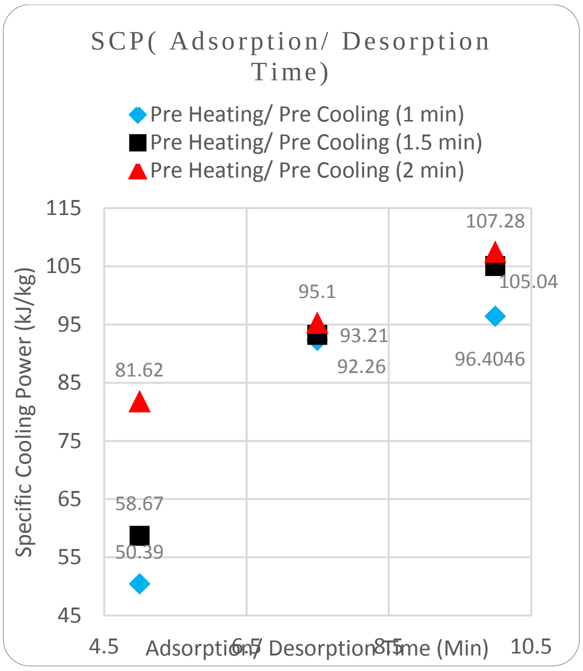

Figure 5: Specific cooling power vs adsorption/ desorption variable time.

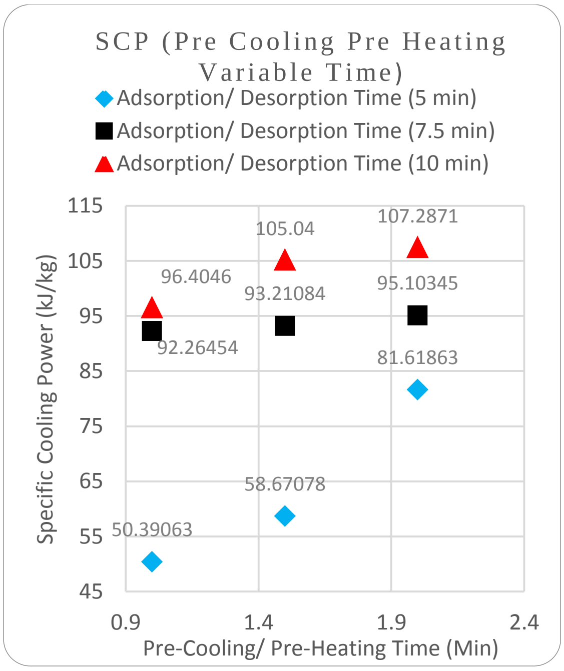

Figure 6: Specific Cooling Power vs Pre-Cooling/ Pre-Heating Variable Time.

From the analysis, we observed that the optimum time for adsorption/desorption was 10 minutes, with the pre-cooling/pre-heating of 2 minutes. These two optimum parameters, which have been done in experiment 9, have the best result in both two indicators of performance which are COP and SCP.

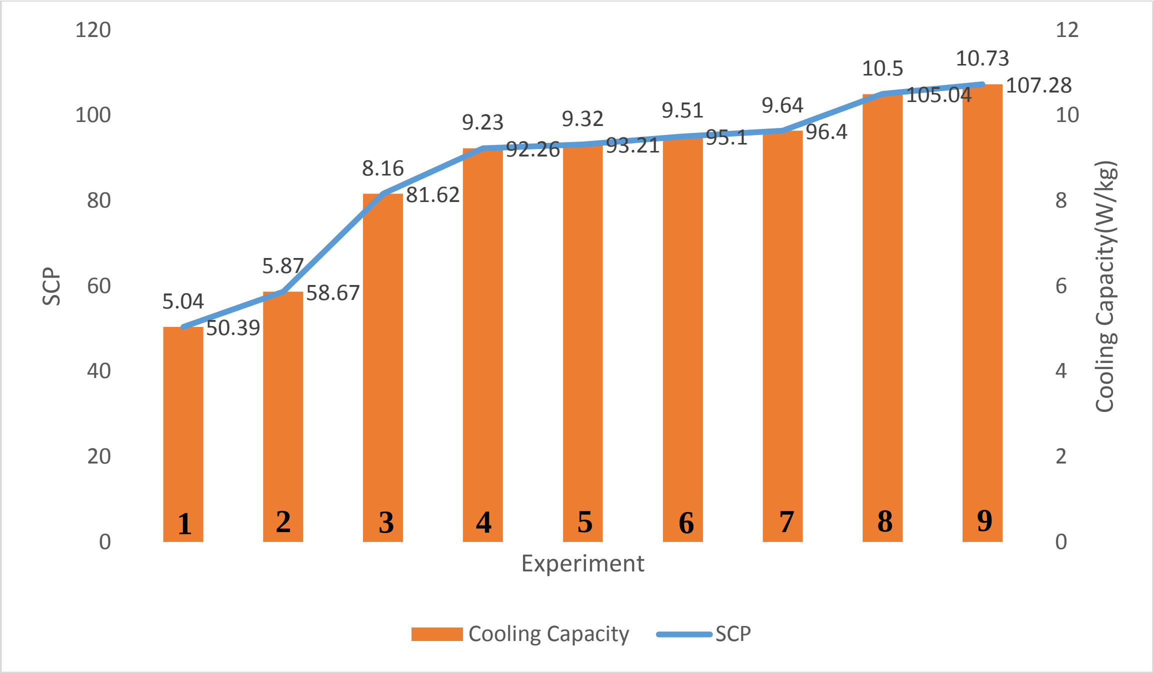

Figure 7: Specific cooling power and cooling capacity

Higher SCP and cooling power of the system resulting in smaller amount of silica gel need to be used and at the same time improve the mass and heat transfer performance of the adsorber. This also help to increase the COP of the system as it consumes less heat during regeneration modes. There are many factor that could contribute to the increase of SCP. One of the factor is duration of cycle time.

From Fig. 7, it is shows that as the cycle time increase, the amount of cooling power and SCP is also increase. It is because the increase in the cycle time will help to enhance the latent heat of vaporization of water at the same time increase the cooling capacity. The highest SCP and cooling capacity is at experiment 9 (10 min adsorption/desorption time) which are 107.28 and 10.73 W/kg respectively.

4.0 Conclusion

In conclusion, the objective to determine the optimum time of adsorption and desorption, and the optimum time of the pre-cooling and pre-heating process on the adsorber performance (COP and SCP) had successfully achieved. The optimum adsorption/desorption time for the system is at 10 minutes with the condition that it is must be paired with the 2 minutes of pre-heating/ pre-cooling time. If the system needs to use less than 2 minutes of the pre-heating/ pre-cooling time (such as 1 minute or 1.5 minutes), the system will have the best performance at 5 minutes of adsorption/desorption time. For another performance indicator, which is the SCP, the best and optimum performance comes out by using 10 minutes of adsorption/desorption time paired with 2 minutes of pre-heating/ pre-cooling time. To conclude, the optimum performance for both COP and SCP is coming from experiment 9, which uses the parameters of 10 minutes of adsorption/desorption time paired with 2 minutes of pre-heating/ pre-cooling time. The highest SCP and cooling capacity recorded are also at experiment 9 which at 10 minutes of adsorption and desorption time which is 107.28 and 10.73 W/kg.

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