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Experimental Test Evaporator Cooling Machine Adsorption Cycle Solar with Collector Area 1 M2 Slope 30^{o} Using Activated Carbon-Methanol as Adsorbent-Adsorbate Pair

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ABSTRACT

The need for cooling systems for a variety of needs perceived life is increasing, while the existing cooling system is very wasteful in the use of electricity and also lack of environmental friendly. Therefore, in this study have a cooling system using a pair of adsorption by activated carbon and methanol material - the material is easily available and do not produce pollution, resulting in cooling systems that are environmentally friendly. One part of the refrigeration cycle is a solar adsorption with type Evaporator Finned evaporator (Finned Evaporator). The research at to look at the rate of heat transfer in the evaporator and the heat absorbed by the evaporator of the cooling medium. The result showed a minimum temperature of water at 10 ° C, total rate of transfer of heat from the water to refrigerant during the adsorption cycle of 9.

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1. INTRODUCTION

The cooling process is the process of taking heat / heat from a room or object to reduce its temperature by transferring the heat contained in the room or object (Purba et al., 2019). Thus, the cooling process is a series of heat transfer processes. The heat transfer process can occur by convection (Anwar & Sari, 2013), conduction and radiation. The development of cooling technology today is strongly influenced by two major problems in usage (Nugroho, 2019)refrigerants that have an impact on the environment, namely the depletion of the ozone layer and global warming and the use of large amounts of energy (Prayogi & Sugiono, 2022). Ozone depleting properties of refrigerants CFCs (Chloro Fluoro Carbons) and HCFCs (Hydro Chloro Fluoro Carbons) (Purnomo et al., 2015) is a type of refrigerant that must be phased out in 2030 in accordance with the 1987 Montreal Protocol and 1997 Kyoto Protocol (Fauziah, 2016). The adsorption cycle is one of the cycles used in environmentally friendly refrigeration machines (Purba et al., 2019).

The advantage of this adsorption cycle cooling machine is that it uses renewable energy, namely solar thermal energy (Sitorus, 2018). This adsorption cycle cooling machine is very suitable for use in Indonesia because Indonesia is located in the equator (Purba et al., 2021), namely at latitudes 6oLU - 11oLS and 95oBT - 141oBT, and taking into account the solar cycle in a year that is (Bashori, 2015) in the area of 23.5o North Latitude and 23.5o South Latitude, Indonesia will always be exposed to the sun for 10 -12 hours a day (Heri, 2012). In this adsorption cycle cooling machine, the refrigeration system uses activated carbon-methanol pasangan (Hintingo & Martin, n.d.), the choice of this activated carbon-methanol pair is due to its environmentally friendly nature (Permatasari & Harjunowibowo, 2013). Does not produce exhaust gases that damage the ozone layer as in other engine cooling systems (Kusuma, 2015).

The objectives of this research are: (1) To determine the volume of methanol adsorption by activated carbon (Damanik, 2016)(2) Analyzing the performance of the evaporator with activated carbon and methanol refrigeration (Harjunowibowo et al., 2014) (3) To determine the minimum temperature that can be achieved by chilled water. The benefits of this research are: (Taufiq, 2004)(1) Produce recommendations for environmentally friendly and energy efficient cooling systems (Alhamid et al., 2015) (2) As a discourse and support for further research on adsorption cycle refrigeration machines (Radjasa, 2017).

2. RESEARCH METHOD

2.1 Research Implementation Method

In carrying out this research, activities are carried out which include the following stages:

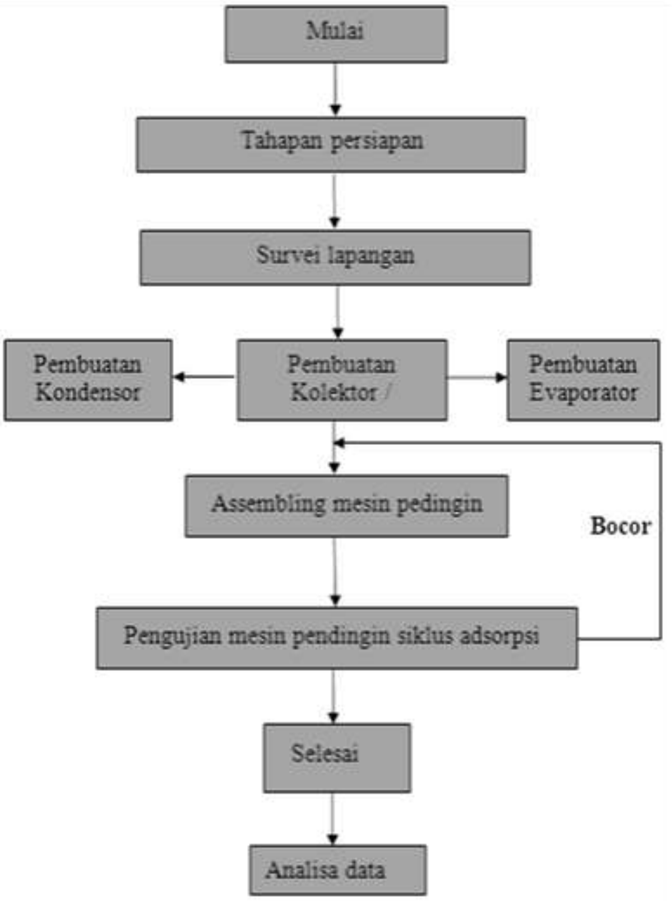

Figure 1. Stages of Research Implementation

2.2 Experimental Set-Up

The collector containing the activated carbon adsorbent (adsorber) is heated so that the temperature and pressure increase which causes desorption of steam (Hintingo & Martin, n.d.). The adsorbate in liquid form will flow into the evaporator (Arif et al., 2019). The experimental set-up can be seen as shown in Figures 3.8 and 3.9 below (Ismayana, 2021).

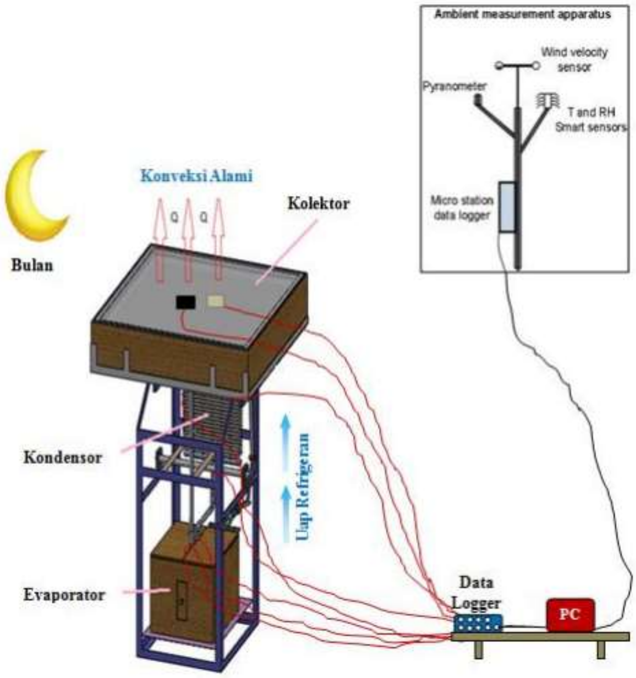

Figure 2. Experimental Set-Up on the Adsorption Process

3. RESULTS AND DISCUSSIONS

3.1. Test result

The test was carried out for three days starting on November 26, 2015 - November 29, 2015. To get accurate temperature change data, the thermocouple sensor on the evaporator was installed at 3 points, namely Channel 1 (T1), Channel 7 (T7), and Channel 8(T8). The image of the placement of the thermocouple sensor on the evaporator can be seen in Figure 4.1.

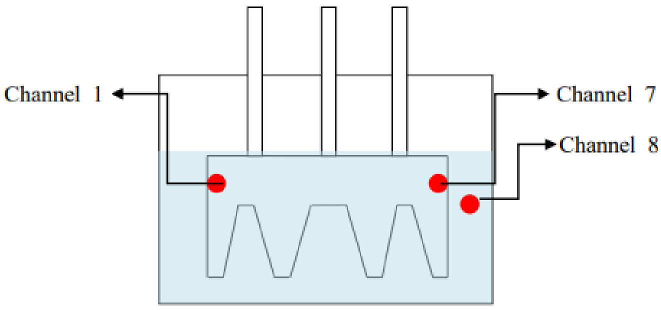

Figure 3. Location of the Thermocoupl Sensor on the Evaporator

3.1.1. First Day Test

Table 1. Desorption Process

Waktu (WIB)	Evaporator				Ta (°C)
	P (cmHg)	T_{e1*} (°C)	T_{e2} (°C)	Tw (°C)	
07.00	-	-49.6	23.6	23.6	24.70
07.30	-	-49.5	23.7	23.7	25.49
08.00	-	-49.2	24	24	27.54
08.30	-	-48.7	24.4	24.4	29.50
09.00	-	-48	24.8	24.8	30.40
09.30	-	-47.4	25.2	25.2	31.36
10.00	-	-46.9	25.4	25.4	31.99
10.30	-	-46.4	25.3	25.1	32.70
11.00	-	-46.3	25.4	25.4	32.92
11.30	-	-46.3	25.6	25.4	32.89
12.00	-	-46	25.9	25.6	33.43
12.30	-	-45.4	26	26	34.09
13.00	-	-45.7	25.6	25.7	33.80
13.30	-	-46.6	25.8	25.9	32.66
14.00	-	-46.4	25.9	26	32.20
14.30	-	-45.9	25.8	25.7	33.21
15.00	-	-45.2	25.9	26.2	31.31
15.30	-	-45.1	26.3	26.1	31.87
16.00	-	-45.4	26.2	26.2	31.79
16.30	-	-45.7	27	27.2	31.10
17.00	-66.0	-46.4	26.9	26.8	30.27

Keterangan : * sensor Te1 error

Table 2. First Day Adsorption Process (26 -27 November 2015)

Waktu (WIB)	Evaporator				Ta (°C)
	P (cmHg)	T_{e1*} (°C)	T_{e2} (°C)	Tw (°C)	
17.00	-66.0	-46.4	26.9	26.8	30.27
17.30	-66.5	-46.9	19.4	21.3	29.59
18.00	-67.0	-47.3	13.7	15.4	29.04
18.30	-68.5	-47.7	12.1	12.5	28.84
19.00	-69.0	-48.1	11	11.1	28.74
19.30	-69.0	-48.5	10.9	10.5	28.84

20.00	-69.5	-48.6	10.7	10.2	28.72
20.30	-69.5	-48.7	10.3	10.3	28.84
21.00	-70.0	-48.7	10.8	10	28.82
21.30	-70.5	-48.8	10.9	10.3	28.69
22.00	-70.5	-48.8	11.2	10.5	28.39
22.30	-71.5	-48.9	11	10.7	28.15
23.00	-71.5	-48.9	11.4	11.4	26.52
23.30	-71.5	-49	11.3	11.1	25.48
00.00	-71.5	-49	11.9	11.2	25.87
00.30	-71.0	-49.1	12.3	11.9	25.53
01.00	-71.0	-49.1	12.2	11.8	25.40
01.30	-71.0	-49.3	12.3	12.5	24.75
02.00	-70.5	-49.4	12.4	12.6	24.17
02.30	-70.5	-49.4	12.7	12.9	23.98
03.00	-70.5	-49.6	13	12.6	24.05
03.30	-70.0	-49.7	13.2	12.9	24.29
04.00	-70.0	-49.7	13.1	13	24.20
04.30	-70.0	-49.9	13.4	13.3	24.29
05.00	-69.5	-49.9	13.8	13.4	24.44
05.30	-69.5	-50	13.5	13.7	24.39
06.00	-69.0	-50.1	13.8	13.9	24.34
06.30	-68.0	-50.3	14.1	14.1	24.29
07.00	-67	-50.4	14.8	14.2	24.73

Keterangan : * sensor Te1 error

3.1.2. Heat Received by the Evaporator from the Condenser

During the desorption process, the collector and condenser are connected so that the rate of heat entering the condenser, qin, is equal to the rate of heat flow entering the collector. The heat that enters the condenser will undergo a convection process to the environment while the rest will go to the evaporator. Calculating the rate of heat entering the condenser, qin. The rate of heat entering the condenser can be calculated by the following formula:

$Qin\ kondensor = Qadsorpsi\ kolektor - QL\ kolektor$ (1)

Untuk Hari Pertama :

$qin = 07.00{-}1700 - QL\ 07.00{-}!7.00$

$qin = S07.00{-}17.00 - (qut + qub + que)07.00{-}1700$

$$q_{in} = S_{07.00-17.00} - \{U_t(T_{pm\ atas} - T_\infty) + \frac{(T_{pm\ bawah} - T_\infty)}{(\sum R_{th})_b} + \frac{(T_{pm\ sisi} - T_\infty)}{(\sum R_{th})_e}\}_{07.00-1700} \quad (2)$$

$$= \frac{(4.573.772,56\,J}{10 \times 60 \times 60\,s} - \{3,060\ {}^{W}/_{{}^\circ C}\,(333,002 - 304,364) + \frac{(319,564 - 304,364)}{2,006\ {}^{\circ C}/_{W}}$$

$$+ \frac{(327,283-304,364)}{4,422\ {}^{\circ C}/_{W}}\}$$

= 26,658 W

Calculating the rate of convection heat transfer in the condenser
For the first day:
From the test results data (attached) obtained:
Tin = 40,1 °C ; $Tout$ = 33,2$°C$ TS =

$$\frac{40,1°C+32,2°C}{2} = 36,65$$

$$T_\infty = 31,364\,°C \qquad (3)$$

Maka, $k = 0,02682\ {}^{W}/_{m.K}$; $P_r = 0,706$; $v = 1,66 \times 10^{-5}\,{}^{m^2}/_{s}$

$$\beta = \frac{1}{T_f} = \frac{1}{307,007\,K}$$

Finding the Rayleigh number
In the condenser there are vertical and horizontal pipes and horizontal fins. Then the rate of convection heat transfer in the condenser can be calculated by finding the Rayleigh number for each pipe and fin in the following way:
For vertical pipe:

$$Ra_L = \frac{g.\beta.(T_s - T_\infty).L^3}{v^2} \times P_r \qquad (4)$$

$$= \frac{9,81\ {}^{m}/_{s^2} \times \frac{1}{307,007\,K} \times (36,65\,°C - 31,364\,°C) \times (0,4)^3}{(1,66 \times 10^{-5})^2\,{}^{m^2}/_{s}} \times 0,706 = 2,77 \times 10^7$$

For horizontal horizontal pipe:

$$Ra_D = \frac{g.\beta.(T_s - T_\infty).D^3}{v^2} \times P_r \qquad (5)$$

$$= \frac{9,81\ {}^{m}/_{s^2} \times \frac{1}{307,007\,K} \times (36,65\,°C - 31,364\,°C) \times (0,0254)^3}{(1,66 \times 10^{-5})^2\,{}^{m^2}/_{s}} \times 0,706 = 7,0915 \times$$

10^3

For horizontal plate/fin condenser:

$$Ra_L = \frac{g.\beta.(T_s - T_\infty).(\frac{A_s}{p})^3}{v^2} \times P_r \qquad (6)$$

$$= \frac{9,81\ {}^{m}/_{s^2} \times \frac{1}{307,007\,K} \times (36,65\,°C - 31,364\,°C) \times (\frac{0,081}{2,004})^3}{(1,66 \times 10^{-5})^2\,{}^{m^2}/_{s}} \times 0,706 = 2,857 \times 10^4$$

After the Rayleigh value for each condenser is obtained, then look for the Nusselt number for each condenser component: for vertical pipes

$$Nu_L = \{\,0,825\ \frac{0,387\,Ra_L^{\frac{1}{6}}}{[1 + ({}^{0,492}/_{P_r})^{\frac{9}{16}})^{\frac{8}{27}}}\}^2 == \{\,0,825 + \frac{0,387\,(0,387 \times 10^7)^{\frac{1}{6}}}{[1 + ({}^{0,492}/_{0,706})^{\frac{9}{16}})^{\frac{8}{27}}}\}^2$$

$$Nu_L = 41,806$$

So :

$$h = \frac{k}{L} Nu_L = \frac{0,02682\ ^{W}/_{m.K}}{0,4\ m} \times 41,806 = 2,803\ ^{W}/_{m^2.K}$$

$A = \pi.D.L = (3,14 \times 1,905 \times 10{-}2m \times 0,4\ m = 0,024\ m2$

Then the convection heat transfer rate in the vertical pipe is: $qconv = h.\ A.\ (\Delta T)$

$$= 2,803\ ^{W}/_{m^2.K} \times 0,0024\ m^2 \times (36,65\ °C - 31,364\ °C)$$

= 0.3556W

For horizontal pipe:

$$Nu_D = \{\ 0,6\ \frac{0,387\ Ra_D^{\frac{1}{6}}}{[1 + (^{0,559}/_{P_r})^{\frac{9}{16}})^{\frac{8}{27}}}\}^2 == \{\ 0,6 + \frac{0,387\ (7,0915\ \times\ 10^3)^{\frac{1}{6}}}{[1 + (^{0,559}/_{0,706})^{\frac{9}{16}})^{\frac{8}{27}}}\}^2$$

NuL = 17,954

So :

$$h = \frac{k}{L} Nu_D = \frac{0,026946\ ^{W}/_{m.K}}{0,0254\ m} \times 17,954\ = 19,0468\ ^{W}/_{m^2.K}$$

$A = \pi.D.L = (3,14 \times 0,0254\ m \times 0,4\ m = 0,032\ m2$

Then the convection heat transfer rate in the vertical pipe is:

$qconv = h.\ A.\ (\Delta T)$

$$= 19,0468\ ^{W}/_{m^2.K} \times 0,0032\ m^2 \times (36,65\ °C - 31,364\ °C)$$

$$= 3,2218\ W$$

For horizontal plate/fin condenser:

$$Nu_L = 0,54\ Ra_L^{\ 1/6} =\ 0,54\ \times (2,85758\ \times 10^4)^{1/6}$$

NuL = 2.9858

So :

$$h = \frac{k}{^{A}/_{P}} \times Nu_L = \frac{0,026946\ ^{W}/_{m.K}}{0,081\ m^2/_{2,004\ m}} \times 2,9858\ = 1,9905\ ^{W}/_{m^2.K}$$

Where:

$A = 2\ [(p \times l) + (p \times t) + (l \times t)]$

$A = 2\ [(p \times l) + (p \times t) + (l \times t)]$

$= 0,081\ m2$

$P = 4p + 4t + 4t = (4 \times 0,4) + (4 \times 0,1) + (4 \times 0,001) = 2,004$

Then the convection heat transfer rate in the vertical pipe is:

$$q_{conv} = h.A.(\Delta T) = 1,9905\ ^{W}/_{m^2.K} \times 0,081 \times (36,65\ °C - 31,364\ °C)$$

$$= 0,8522\ W$$

In the condenser there are 5 vertical pipes and 2 horizontal pipes and 17 condenser fins, then the total heat transfer rate in the condenser is obtained as follows:

$$q_{conv\ total} =\ [5(q_{pipa\ vertikal)} +\ 2(q_{pipa\ horizontal}) +\ 17\ (\ q_{fin}] \quad (7)$$

$$= [5\ (\ 0,3556\ W) +\ 2(3,2218\ W) +\ 17\ (\ 0,8522\ W)]$$

= 22.709w

From the above calculation, it can be seen the amount of heat received by the evaporator from the condenser by using the following formula:

$$q_{in\ kondensor} = q_{out\ kondensor} + q_{conv\ total} \quad (8)$$

$$26{,}658\ W = q_{out\ kondensor} + 22{,}709\ W$$

$$q_{out\ kondensor} = 26{,}658\ W - 22{,}709\ W = 3{,}949\ W$$

So, the amount of heat received by the eveparator on the first day of testing is 3.949 W.

3.1.3. Compressor Work on Vapor Compression Cycle

For the same cooling load produced by this Adsorption Cycle, when compared to the vapor compression cycle with the same refrigerant in the adsorption cycle, the compressor work can be found as follows: the pH diagram for the vapor compression cycle can be seen in the diagram below:

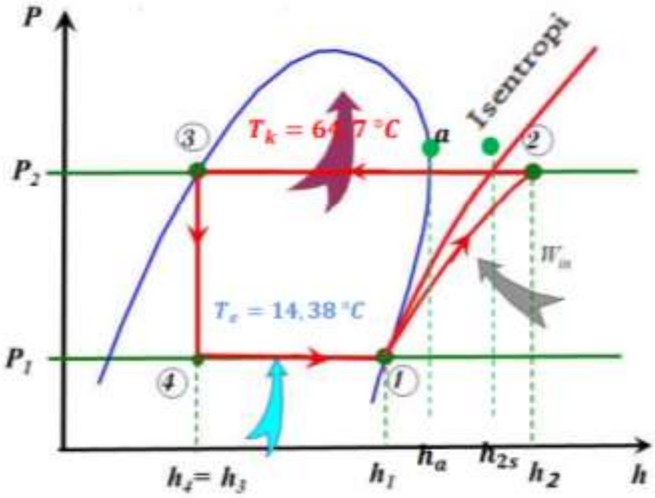

Figure 5. Vapor Compression Cycle ph diagram

By using the methanol saturation table, the following data were obtained:

$$h_1 = 523{,}508\frac{btu}{lb} = 1217{,}68\ kJ/kg\ , s_1 = 1{,}012\ btu/lb.K$$

$$h_a = 544{,}494\frac{btu}{lb} = 1266{,}493\ kJ/kg;\ \ s_a = 0{,}908\ btu/lb.K$$

$$h_3 = 71{,}376\frac{btu}{lb} = 166{,}0206\ kJ/kg;\ \ s_3 = 0{,}129\ btu/lb.K$$

$$h_4 = 71{,}376\frac{btu}{lb} = 1660{,}206\ kJ,kg$$

Enthalpy at point□2□can be found using the following equation:

$$\frac{h_{2s}-h_a}{h_a-h_3} = \frac{s_{2s}-s_a}{s_a-s_3} \quad (9)$$

Because□2□=□1, then the equation becomes:

$$h_{2s} = h_a + (h_a - h_3) \times \frac{s_1-s_a}{s_a-s_3}$$

$$h_{2s} = 544{,}494\frac{btu}{lb} + (544{,}494\frac{btu}{lb} - 71{,}376\frac{btu}{lb}) \times \frac{1{,}012\ btu/lb.K - 0{,}908\ btu/lb.K}{0{,}908\ btu/lb.K - 0{,}129\ btu/lb.K}$$

$$h_{2s} = 608{,}926\frac{btu}{lb} = 1416{,}362\ kJ/kg$$

Enthalpy at point 2 can be found using the following equation:

$$h_2 = h_1 + \frac{1}{\eta}(h_{2s} - h_1) \quad (10)$$

$$h_2 = 523{,}508\frac{btu}{lb} + \frac{1}{0{,}85}\left(608{,}926 - 523{,}508\frac{btu}{lb}\right)$$

$$h_2 = 623{,}999\frac{btu}{lb} = 1451{,}422\ kJ/kg$$

So :

Refrigeration Effect // $ER = h1 - h4$

$$= 523{,}508\left(\frac{btu}{lb} - 71{,}376\frac{btu}{lb}\right) = 457{,}132\frac{btu}{lb} = 1063{,}289\ kJ.kg$$

$$\dot{m} = \frac{Q_e}{(h_1 - h_4)} = \frac{14{,}38\ W}{1063{,}289\ kj/kg} = 1{,}353 \times 10^{-5} kg/s$$

Then the compressor work:

$Wc = m\ (h2s - h1)$ (10)

= 1,353 × 10−5kg/s (1416,362 kj/kg − 1217,68 kj/kg)

= 2,686 Wat

4. CONCLUSION

From the results of the tests that have been carried out, several conclusions can be drawn, including: (1) Methanol adsorbed by activated carbon is 0.8095 liters or 16.2% of the initial volume of methanol. (2) The cooling temperature of the drinking water is obtained on the first day of 9.9 OC or a decrease in water temperature of 17.1 OC from the initial temperature of 27 OC. (3) The total rate of heat transfer from water to refrigerant during the adsorption cycle on the first day of testing is 9.258 Watt and the rate of heat transfer from the environment to the evaporator insulation box is 1.173 Watt and the heat transfer rate received by the evaporator from the condenser is 3.949 Watt. (4) Total methanol adsorbed by activated carbon (absorbent) is 746936 on the first day of the adsorption cycle, while on the second and third day the adsorption cycle did not occur again. (5) With the same cooling load produced by the Adsorption Cycle, when compared to the vapor compression cycle with the same refrigerant in the adsorption cycle, the compressor work is 2,686 Watts.

For the success of further research, the authors suggest: (1) It is recommended to use a vacuum pump with a power greater than hp in order to obtain a higher system vacuum pressure. (2) To reduce leaks in the system, it is better to reduce or minimize connections to the system and use strong glue/adhesive. (3) It is recommended to take good care of all measuring instruments, especially Data Loggers and check all Data Logger temperature sensors whether they are functioning properly or not. (4) The thickness of activated carbon in the collector is recommended not to be too thick, so that the process of absorption and release of methanol by activated carbon can be maximized.

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