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Solar Energy Driven Adsorption Cycle Cooling Machine Performance with A Collector Area of 1 M2 And A Collector Inclination of 30^o

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ABSTRACT

Solar Energy is the biggest energy on the earth, solar enegy in Indonesia can be utilized for variety of things. Based on solar radiation data collected from 18 locations in Indonesia, solar radiation for West Indonesia area has reached 4,5 kWh/m2/day with monthly variation about 10%, while East Indonesia area has reached about 5,1 kWh/m2/day with monthly variation about 9%. Therefore, the solar energy can be utilized as the main source of energy for the adsorptionrefrigeration cycle cooling machine to produce cooling effect. In this research, the main component of this machine consist of collector/adsorber, condenser, and evaporator. The surface area of this collector/adsorber is about 1m2and tilted at 30^o. The collector filled with about 18,5 kg of activated carbon, meanwhile the evaporator filled with 5 Litres of methanol. The chilled media is 4 litres of water. This experimental lasts for three days, divided by two periods that are desorption process and adsorption process. The result from this experiment was the collector can adsorb solar radiation with daily average about 7.093.769,356 Joule and could decrease the water temperature become 1,85oC at first adsorption cycle, while the ambience temperature about 26,9^{o}C.

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1. INTRODUCTION

Energy needs in Indonesia are increasing along with the rapid development of technology today (Antonov & Rahman, 2015). One of the energy that is needed today is electrical energy, however, the construction of a power plant itself is not balanced with the use of electricity (Negara, 2011). Indonesia is a tropical country, where one of the largest uses of electrical energy is in cooling or air conditioning systems (Budiman, 2019). Besides, the rapid construction of commercial buildings in big cities in Indonesia also affects the amount of electrical energy demand in terms of cooling (Kusumawanto & Astuti, 2018). Therefore, the solution that is currently being developed is the use of solar energy. Indonesia has a large enough potential for solar energy considering its geographical location in the tropics (Buana & Center, n.d.). Based on solar radiation data collected from 18 locations in Indonesia, solar radiation in Indonesia for the Western Region of Indonesia (KBI) reaches 4.5 kWh/m2/day with a monthly variation of around 10%, while for Eastern Indonesia (KTI) it is around 5.1 kWh/m2/day with a monthly variation of about 9% (Widayana, 2012). To take advantage of the potential of solar energy, thermal solar energy and photovoltaic solar energy technologies have been known (Ramadhan et al., 2016). Thermal solar energy is generally used for cooking, drying agricultural produce and heating water. Meanwhile, photovoltaic solar energy is used to meet the needs of electricity, water pumps, television, telecommunications, and refrigerators with a total capacity of about 6 MW (Pulungan et al., 2018). The development of photovoltaic solar energy in Indonesia is primarily aimed at providing electrical energy in rural areas (Bayu & Windarta, 2021). The geographical condition of Indonesia, which consists of small islands and many remote ones, makes it difficult to reach by a centralized electricity network (Rosa et al., n.d.). Thus, solar energy can be used to provide electricity in order to accelerate the village electrification ratio (Kholiq, 2015).

Because the efficiency of energy conversion is still better, this research is focused on the utilization of solar energy thermally (Ambarita, n.d.). This is very supportive for the development of a cooling machine, especially a cooling machine that is powered by solar power (Sambudi, 2016). The application of this refrigeration machine covers a very wide field, including for household purposes such as making ice, storing food and beverages, to the chemical and pharmaceutical industries, agriculture, and so on (Rofi'ath, 2019). Various kinds of cooling machines with various cycles can also be found in everyday life (Bhaskara, 2019). One type of cooling machine that is often used is a vapor compression cycle cooling machine, where this cycle requires a refrigerant called a refrigerant (D. D. H. Kusuma, 2015). However, in this research, a cooling machine is used that utilizes the adsorption process in a cycle driven by solar power, where this cycle replaces the principle of the vapor compression cycle (S. I. Kusuma, 2009). Adsorption is a process that occurs when a fluid (liquid or gas) is bound to a solid and eventually forms a film (thin layer) on the surface of the solid. In contrast to adsorption, where a fluid is absorbed by another fluid by forming a solution (Syauqiah et al., 2011). From some of the things above, it shows that the use of solar energy can be used as a background in this research (Harahap, 2019). Where one of the outlines of this research is to capture solar energy radiation in thermal form and use it to produce cooling (refrigeration) (Adha, 2021).

The objectives of this study are: (a) To increase the effectiveness of the adsorption refrigeration machine in the previous test by modifying the components of the adsorber and evaporator. (b) Calculate the intensity of radiation that reaches the collector component. (c) Knowing the minimum water temperature that can be achieved. (d) Calculating the efficiency of the adsorption refrigeration machine. (e) Calculating the value of the Coefficient of Performance (COP) of the cooling engine. The benefits of this research include: (a) Produce cooling machines that are energy efficient and environmentally friendly (b) Meet the need for refrigeration equipment in areas not yet covered by electricity (c) As a discourse and reference in refrigeration systems that can be developed for research which is further.

2. RESEARCH METHOD

2.1 Research Implementation Method

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

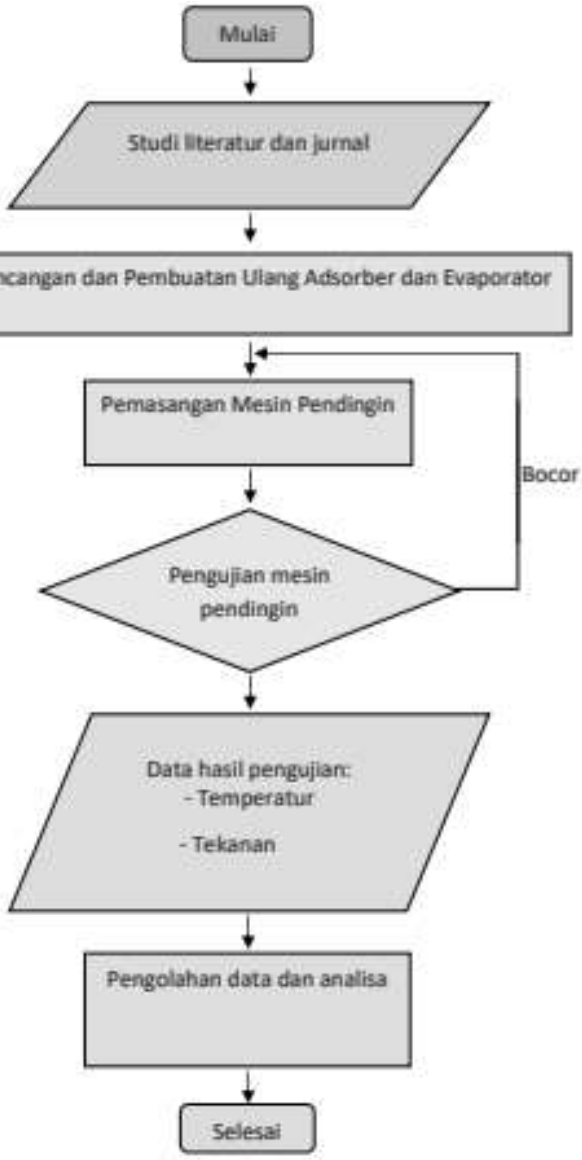

Figure 1. Research Flowchart

3. RESULTS AND DISCUSSIONS

3.1. Test Result Data

Table 1. Test Result Data

Waktu	Kolektor		Kondensor		Evaporator		T. Air (°C)	Intensitas Radiasi Surya (W/m²)
	T(°C)	P (bar)	T in(°C)	T out(°C)	T (°C)	P (bar)		
18.00	65,33	0,09	34,75	30,9	21,65	0,45	21,33	44,4
18.30	58,67	0,11	32,37	28,75	19,43	0,15	19,82	0,6
19.00	50,02	0,11	30,68	27,83	18,31	0,15	18,47	0,6
19.30	44,07	0,11	29,69	27,43	17,98	0,15	18	0,6
20.00	39,81	0,11	29,21	27,44	18,07	0,15	17,99	0,6
20.30	36,75	0,11	28,44	27,05	18,25	0,15	18,06	0,6
21.00	34,91	0,11	28,01	26,71	18,46	0,15	18,2	0,6
21.30	34,24	0,16	27,74	26,48	18,53	0,15	18,28	0,6
22.00	33,57	0,17	27,47	26,26	18,61	0,17	18,36	0,6
22.30	32,9	0,19	27,2	26,03	18,68	0,18	18,44	0,6
23.00	32,23	0,20	26,93	25,81	18,76	0,20	18,52	0,6
23.30	31,55	0,21	26,66	25,58	18,83	0,21	18,6	0,6
00.00	30,88	0,23	26,39	25,36	18,91	0,22	18,69	0,6
00.30	30,21	0,24	26,12	25,13	18,98	0,23	18,77	0,6
01.00	29,54	0,25	25,85	24,91	19,06	0,25	18,85	0,6
01.30	28,87	0,27	25,58	24,68	19,13	0,26	18,93	0,6
02.00	28,19	0,28	25,31	24,46	19,21	0,28	19,01	0,6
02.30	27,52	0,29	25,04	24,23	19,28	0,29	19,09	0,6
03.00	26,85	0,31	24,77	24,01	19,36	0,31	19,17	0,6
03.30	26,18	0,32	24,5	23,78	19,43	0,31	19,25	0,6
04.00	25,51	0,33	24,23	23,56	19,51	0,32	19,33	0,6
04.30	24,83	0,35	23,96	23,33	19,58	0,34	19,41	0,6
05.00	24,16	0,36	23,69	23,11	19,66	0,35	19,5	0,6
05.30	24,26	0,37	23,86	23,2	20,14	0,37	20,06	0,6
06.00	24,14	0,39	23,74	23,09	20,18	0,40	20,15	0,6
06.30	23,92	0,40	23,87	23,08	20,22	0,39	20,17	3,1
07.00	23,9	0,42	23,87	23,43	20,31	0,43	20,27	25,6
07.30	24,12	0,43	24,3	24,17	20,36	0,45	20,33	59,4

The following summarizes the data on the intensity of solar radiation and temperature obtained during the test (2 September – 3 September 2016).

Table 2. Recap of Component Temperature and Radiation Intensity

Hari	Intensitas Radiasi Surya (W/m²)		T. Evaporator (°C)				T. Air (°C)		T. Kondensor (°C)				T. Kolektor (°C)				T. Kaca (°C)	
	Maks	Min	Maks		Min		Maks	Min	Maks		Min		Maks		Min		Maks	Min
			Kiri	Kanan	Kiri	Kanan			in	out	in	out	Atas	bawah	atas	bawah		
I	551,9	0,6	25,21	25,25	1,9	2,18	25,31	1,85	35,25	31,14	23,26	22,78	88,05	77,08	24,07	23,75	53,68	21,2
II	788,1	0,6	17,4	17,42	6,39	6,44	17,43	15,35	87,71	36,07	22,92	24,48	123,54	109,92	22,76	22,67	70,84	21,11
III	789,4	0,6	21,63	21,66	17,55	17,57	20,93	18,44	58,95	35,57	23,69	23,11	131,61	103,15	108,15	23,9	75,74	21,48

3.2. Graphic Analysis

After all the data is collected, the next step is to process the data.

3.2.1. Effect of Radiation Intensity on Component Temperature

The following is a graph of the intensity of solar radiation for 3 days of testing.

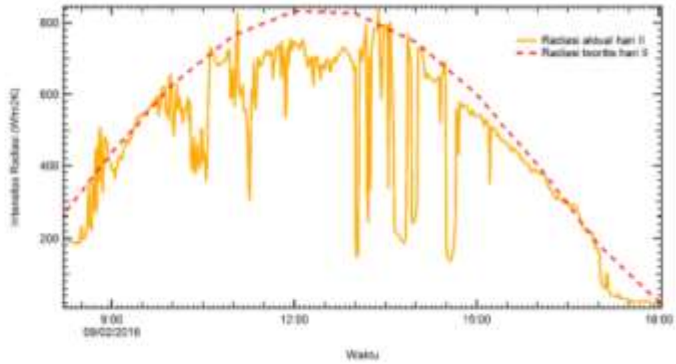

Figure 2. Graph of Comparison of Actual With Theoretical Radiation Intensity On Day Two.

Meanwhile, in Figure 4.2. The theoretical radiation intensity condition on the second day did not look much different from the radiation intensity during the test, which reached 832.4 W/m2K theoretically and 838.1 W/m2K when doing the test.

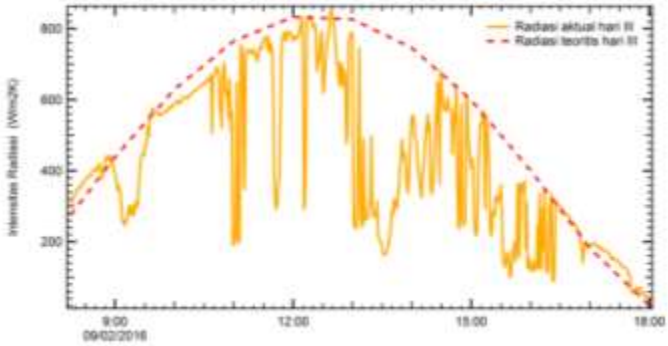

Figure 3. Graph of Comparison of Actual With Theoretical Radiation Intensity on Day Three

Meanwhile, the effect of solar radiation intensity on the temperature of each component is shown in the following graph.

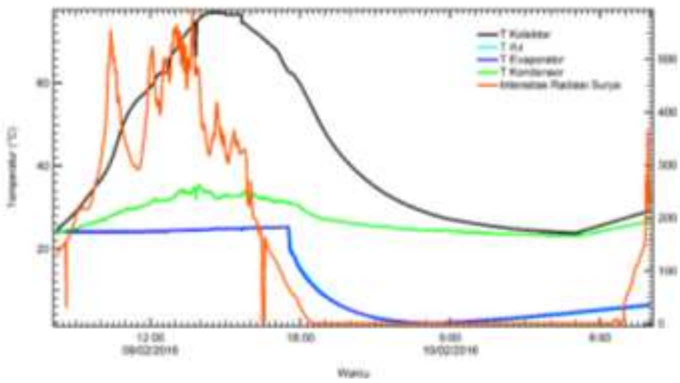

Figure 4. Graph of Solar Radiation Intensity and Temperature of Test Components on Day One

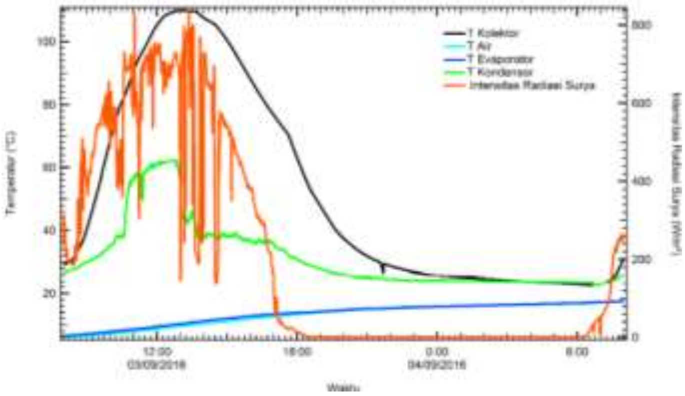

Figure 5. Graph of Solar Radiation Intensity and Temperature of Second Day Testing Components

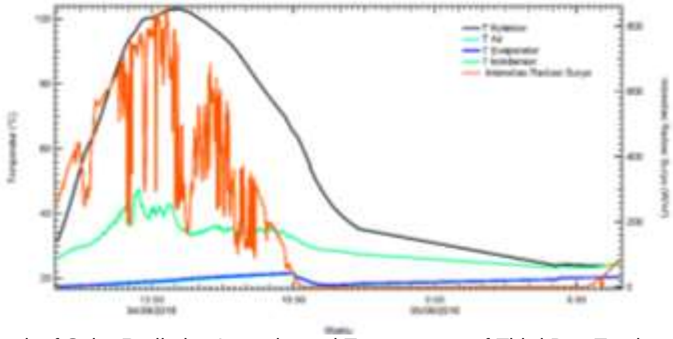

Figure 6. Graph of Solar Radiation Intensity and Temperature of Third Day Testing Components

The highest radiation intensity on the first day of testing was 588.1 W/m^2 at 13:41 WIB, the second day was 838.1 W/m^2 at 13:23 WIB, and the third day was 854.4 W/m^2 at 12:38 WIB. From Figures 4.4, 4.5, and 4.6 it can be seen that the radiation intensity has the most effect on the collector temperature, the condenser is quite affected by the radiation intensity but not so significantly, as well as the evaporator does not appear to be affected at all by the radiation intensity at all. From Figure 4.3, on the third day the theoretical radiation intensity conditions and during the test were also not much different, where the theoretical radiation intensity reached 833.23 W/m^{2}K and the radiation intensity during the test reached 854.4 W/m^{2}K.

3.3. Data Processing

Research on solar adsorption cycle cooling machines has already been carried out in various countries and several people from the USU Department of Mechanical Engineering have also done it. Therefore, this study is also based on these studies and from the results of these studies several conclusions can be drawn such as: (1) The most commonly used collectors are flat plate and parabolic evacuated tubes, but among the two collectors the most frequently used is the flat plate type because it is more economical, easy to maintain and quite efficient. (2) The condenser used is an air cooled condenser so that the condensation process takes place due to natural convection. (3) The evaporator used is in direct contact with the cooled water (direct cooling). (4) The main component materials (collector/absorber, condenser and evaporator) commonly used are copper or stainless steel. (5) The activated carbon-methanol pair has been widely used in previous studies. Because the final temperature obtained is able to reach temperatures below 0oC. The resulting Coefficient of Performance (COP) is also high. (6) The optimum mass of activated carbon to be filled into the collector is 20 – 26 kg/m2. (7) The ratio of effective absorption to methanol is only 0.26 kg/kg activated carbon. In other words, for 1 kg of activated carbon it is only able to absorb a maximum of 26% of the mass of activated carbon used. (8) The collector slope angle reference for the equator (Indonesia) is ± 30o. condenser and evaporator) which is commonly used is copper or it can also use stainless steel. (5) The activated carbon-methanol pair has been widely used in previous studies. Because the final temperature obtained is able to reach temperatures below 0oC. The resulting Coefficient of Performance (COP) is also high. (6) The optimum mass of activated carbon to be filled into the collector is 20 – 26 kg/m2. (7) The ratio of effective absorption to methanol is only 0.26 kg/kg activated carbon. In other words, for 1 kg of activated carbon it is only able to absorb a maximum of 26% of the mass of activated carbon used. (8) The collector slope angle reference for the equator (Indonesia) is ± 30o. condenser and evaporator) which is commonly used is copper or it can also use stainless steel. (5) The activated carbon-methanol pair has been widely used in previous studies. Because the final temperature obtained is able to reach temperatures below 0oC. The resulting Coefficient of Performance (COP) is also high. (6) The optimum mass of activated carbon to be filled into the collector is 20 – 26 kg/m2. (7) The ratio of effective absorption to methanol is only 0.26 kg/kg activated carbon. In other words, for 1 kg of activated carbon it is only able to absorb a maximum of 26% of the mass of activated carbon used. (8) The collector slope angle reference for the equator (Indonesia) is ± 30o. Because the final temperature obtained is able to reach temperatures below 0oC. The resulting Coefficient of Performance (COP) is also high. (6) The optimum mass of activated carbon to be filled into the collector is 20 – 26 kg/m2. (7) The ratio of effective absorption to methanol is only 0.26 kg/kg activated carbon. In other words, for 1 kg of activated carbon it is only able to absorb a maximum of 26% of the mass of activated carbon used. (8) The collector slope angle reference for the equator (Indonesia) is ± 30o. Because the final temperature obtained is able to reach temperatures below 0oC. The resulting Coefficient of Performance (COP) is also high. (6) The optimum mass of activated carbon to be filled into the collector is 20 – 26 kg/m2. (7) The ratio of effective absorption to methanol is only 0.26 kg/kg activated carbon. In other words, for 1 kg of activated carbon it is only able to absorb a maximum of 26% of the mass of activated carbon used. (8) The collector slope angle reference for the equator (Indonesia) is ± 30o. for 1 kg of activated carbon is only able to absorb a maximum of 26% of the mass of activated carbon used. (8) The collector slope angle reference for the equator (Indonesia) is ± 30o. for 1 kg of activated carbon is only able to absorb a maximum of 26% of the mass of activated carbon used. (8) The collector slope angle reference for the equator (Indonesia) is ± 30^o.

Based on the conclusions above, it is used as the basis for this research which can be described as follows: (1) The collector used is a flat plate type.

(2) The condenser used is an air-cooled condenser with the addition of fins in the form of a horizontal flat plate with the aim of accelerating the process of heat transfer from the condenser to the ambient air. (3) The evaporator used is in direct contact with the cooled water. Therefore, at the bottom of the evaporator there is the addition of fins (trapezoidal grooves) with the aim of increasing the surface area of contact of the evaporator wall with the cooled water so as to accelerate the process of absorption of heat/heat from the water. The mass of the evaporator used = 2.3 kg. (4) The main material of the component (collector/absorber, condenser and evaporator) used is stainless steel with consideration of lighter and cheaper although its conductivity is lower than copper but still optimally used in adsorption cycle refrigeration machines. (5) The adsorbent used is ordinary/technical activated carbon with consideration of a more affordable price, widely available and easy to obtain. While the adsorbate/refrigerant is pro-analyst methanol (purity 99.9%). The use of pro-analyst methanol due to its high purity is expected to be optimally adsorbed by activated carbon. (6) For a collector with an absorber surface area of 1m2, then: The optimum mass of activated carbon used is 20kg – 26kg. In the previous test, the mass of activated carbon used was 25kg. However, to increase absorption effectiveness, In this study, the collector thickness was reduced by half from the previous collector thickness by remaking the collector, so that the mass of activated carbon that can be filled in the collector is 18.5 kg. (7) For 18.5 kg of activated carbon, then: Maximum mass of methanol = 26% x 18.5 kg of activated carbon = 4.81 kg = 6.08 liters (ρ = 0,790 kg/lite) 8. The angle of inclination of the collector is 30oC.

3.3.1. Actual Cooling Capacity (Quc) and Coefficient of Performance (COP)

The actual cooling capacity Qc can be evaluated using the following Equation

$$Quc = mwCpw\Delta Tw + mihsf + miCpi\Delta Ti \quad (1)$$

3.3.1.1. First Day Test

From the test, the following data were obtained: (1) Vw = 4 L, (2) w = 1000 kg/m3, (3) mw = 4 kg, (4) Cpw = 4179 J/kg.K (5) Tw = 23.46oC. Since no ice mass was produced in the test, (mi hsf) and (miCpiΔTi) can be considered zero. So the actual cooling capacity of the first day of testing is obtained: Quc = 4 x 4179 x 23,46, = 392.157,36 J, Quc = 392,157 kJ. Meanwhile, the actual coefficient of performance (COP) of the first day of the test cycle can be calculated as follows.

$$COP = \frac{Q_{uc}}{Q_{ic}} \quad (2)$$

So that,

$$COP = \frac{392.157,36\ J}{889.296,9\ J}$$

COP = 0.44

3.3.2. Second Day Test

The calculation of the actual cooling capacity, Quc, on the second day cannot be calculated, because on the second day no refrigerant is adsorbed. This was caused by the failure of the adsorber to desorption on the second day which resulted in the closing of the activated carbon pores and the adsorption process failed. Failure to carry out the adsorption process on the second day caused no decrease in the temperature of the water to be cooled. So that Tw = 0 and the cooling capacity Qc, cannot be concluded. This also causes the actual COP value of the cycle to be inferred, because Quc is used in calculating the actual COP value of the solar refrigeration cycle.

3.3.3. Third Day Test

From the test, the following data were obtained: (1) Vw = 4 L, (2) w = 1000 kg/m3, (3) mw = 4 kg, (4) Cpw = 4179 J/kg.K, (5) Tw = 3.38oC. Since there is no ice mass in the test, (mihsf) and (miCpiΔTi) can be considered zero. So the actual cooling capacity of the first day of testing is obtained:$= 4\ 4179\ 3.38, = 56{,}500.08\ , = 56{,}500$

Meanwhile, the actual coefficient of performance (COP) of the first day of the test cycle can be calculated as follows.

$$COP = \frac{Q_{uc}}{Q_{ic}} \quad (3)$$

So that

$$COP = \frac{56.500,08\ J}{2.933.202,2\ J}$$

$$COP = 0,019$$

4. CONCLUSION

Based on the research and analysis that has been done, it can be concluded that: 1) The components of the solar powered adsorption refrigeration machine, namely the collector and evaporator, have been modified, so that the performance of the adsorption refrigeration machine has been successfully improved and achieved a lower water cooling temperature than previous studies. namely by brother Piter Harefa with 9.9oC . (2) The total solar radiation intensity that reaches the collector during the test is 7.4915 MJ in the first test, 11.3025 MJ in the second test, and 10.3364 MJ in the third test. Where from the results of the calculation of the intensity of total solar radiation that reaches the largest collector is in the second test, namely from 08.00 WIB on September 3, 2016 until 08. 00 WIB on September 4, 2016. (3) The minimum water temperature achieved during this research was 1.85oC at 23.05 WIB on September 2. The decrease in water temperature is 23.46 oC from the initial water temperature of 25.31oC. (4) The efficiency of the collector in the first test is 39.36%, while in the second test it is 31.74% and in the third test it is 32.3%. The total convection Q of the condenser obtained on the first day is 5.4377 Watt, the second day is 38.7387 Watt, and the third day is 19.714 Watt. While the efficiency of the evaporator is obtained at 49.91% on the first day, on the second and third days there is no cooling process. (5) The cycle performance coefficient (COP) on the first day was 0.44.

For the continuation and development of research on the next solar energy-driven adsorption cycle cooling machine, the authors suggest the following: (1) The selection of testing time is recommended in the dry season to get a maximum intensity of solar radiation, which is above 16 MJ/m2, so that the process desorption can be maximized as well. (2) We recommend using a vacuum pump with a power greater than hp in order to obtain a higher vacuum pressure and reduce the decrease in COP on the second and third day of testing. (3) To maintain system vacuum, it is better to reduce the use of joints in the system and also the use of different materials in the system so that the glue used can glue stronger. (4) Testing tools such as the HOBO Microstation should be checked intensively to ensure that the equipment continues to record environmental weather conditions, if an error occurs, repairs to the sensor or connecting cable are not properly connected. Likewise, the location of the thermocouple points or the data acquisition channel should be calibrated and checked beforehand so that there are no measurement errors during the test, if an error occurs, re-attachment is carried out at the error point. (5) The measurement of the volume of methanol should be carried out using a measuring instrument that is more accurate and tested, so that it can measure the volume reduction more optimally. if an error occurs, repairs are made to the sensor and connecting cables that are not connected properly. Likewise, the location of the thermocouple points or the data acquisition channel should be calibrated and checked beforehand so that there are no measurement errors during the test, if an error occurs, re-attachment is carried out at the error point. (5) The measurement of the volume of methanol should be carried out using a measuring instrument that is more accurate and tested, so that it can measure the volume reduction more optimally. if an error occurs, repairs are made to the sensor and connecting cables that are not connected properly. Likewise, the location of the thermocouple points or the data acquisition channel should be calibrated and checked beforehand so that there are no measurement errors during the test, if an error occurs, re-attachment is carried out at the error point. (5) The measurement of the volume of methanol should be carried out using a measuring instrument that is more accurate and tested, so that it can measure the volume reduction more optimally. If an error occurs, then re-gluing is carried out at the point of the error. (5) The measurement of the volume of methanol should be carried out using a measuring instrument that is more accurate and tested, so that it can measure the volume reduction more optimally. If an error occurs, then re-gluing is carried out at the point of the error. (5) The measurement of the volume of methanol should be carried out using a measuring instrument that is more accurate and tested, so that it can measure the volume reduction more optimally.

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