



Experimental Study of Condenser Performance for Solar Energy Driven Adsorption Cycle Refrigeration

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ARTICLE INFO

Article history:

Received September 11, 2020

Revised October 02, 2020

Accepted November 28, 2020

Keywords:

Activated Carbon
Adsorption
Condenser
Methanol
Solar energy

ABSTRACT

The condenser is one component of the refrigeration machine that can change the fluid phase and can exchange heat. The condenser, collector and evaporator are part of the cooling machine that is designed to be a prototype machine. In this design specifically the author is in charge of designing and manufacturing and testing the condenser. The cooling machine consisting of a collector/generator that uses activated carbon functions to absorb and store solar energy. The evaporator which uses methanol functions to absorb the surrounding heat. This cooling machine is driven by solar energy using an adsorption cycle process. The collector/generator that has been heated to solar energy will absorb the methanol contained in the evaporator and the methanol also absorbs all the surrounding heat so that the water temperature gets lower. The condenser in this design functions to change the vapor phase methanol in the collector which will be condensed into a liquid phase which is then flowed to the evaporator. From this design produces an adsorption cycle cooling machine that is driven by solar energy.

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1. INTRODUCTION

In engineering, the term refrigeration must be thought of as more than just cooling or keeping something cool (Bonardo et al., 2018), but rather a system that results in heat transfer from a cooler source to a hotter sink where it requires additional work or energy input (Abdi et al., 2018). The heat transfer process can occur by convection, conduction or radiation (Irawati et al., 2019). Convection is the transfer of heat that occurs due to an external force called forced convection (Supu et al., 2017), whereas if the fluid movement occurs due to differences in density due to differences in temperature, it is called free convection (Walujodjati, 2006). The cooling process is an attempt to lower the temperature in the room or on a material (Prianto, 2007), in other words get the desired condition by the product or material (Son & Rinaldi, 2013), in this case a low temperature so that the product or material can be stored for a relatively long time (Mareta & Awami, 2011), whether for consumption, production, or trade (Aldillah, 2015). Food storage and transportation, food and beverage processing (Wardana et al., 2017), making ice (ice making) are some examples of activities that require cooling and freezing processes (Siegers et al., 2022). So the cooling process is a series of heat transfer processes (Anwar & Sari, 2013). When viewed from the current level of energy consumption worldwide, energy use is predicted to increase by 70 percent between 2000 and 2030 (Nasional, 2019). The condition of limited energy sources in the

midst of increasing world energy needs from year to year (energy consumption growth in 2004 alone was 4.3 percent) (Jatmiko et al., 2011), as well as demands to protect the earth from global warming and environmental pollution make demands to immediately realize new technologies for renewable energy sources (Sari, 2019).

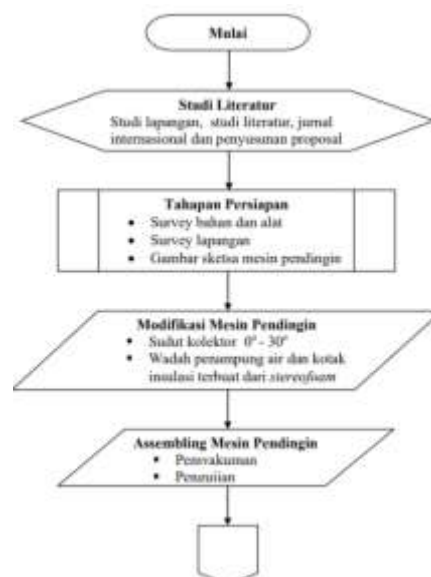
The energy released by the sun is very large (Priatam et al., 2021). One of the potential options for utilizing solar thermal energy is to drive the adsorption cycle for areas that do not have electricity (Maarif et al., 2020). Meanwhile, many villages in Indonesia are in dire need of cooling machines (refrigeration) to support economic activities. For example, for preservation and manufacture of food, or for storage of vaccines and others. Therefore, cooling machines that can be driven by solar energy and do not require electricity are urgently needed, especially for rural areas in Indonesia. This thesis is entitled Experimental Study of Condenser Performance for an Adsorption Cycle Cooling Machine Driven by Solar Energy. This thesis is an advanced stage of previous research by team II consisting of (A'yunina, 2014). Masrin Damanik, Marlundu Naibaho and Donny O Samosir conducted in 2011. However, what is different is the material and size of the design (Musthofa et al., 2016). The material used is stainless steel and the size of the design is smaller than previous studies (Setiabudi, 2016).

The benefits to be achieved from this research are: 1. Creating an alternative technology for cooling machines that are friendly to the environment (Lubis et al., 2021), 2. Can help fulfill the cooling machine for residents who have not been reached by electricity. This cooling machine can later be used for meat preservation and vegetable preservation, (Kusnadi, 2018) 3. This process does not damage the ozone layer, 4. Adding a reference in the Refrigeration Laboratory of the Department of Mechanical Engineering, Faculty of Engineering, University of North Sumatra (Amin, 2019). (1) General purpose. The general objective of this research is to design a cooling machine that works based on the adsorption cycle and utilizes solar energy as its power source. The main components of this adsorption cycle consist of an evaporator, a condenser, and a solar collector which is also a generator (Rezeki, 2018). All of these components will be designed, manufactured and assembled into a prototype cooling machine unit and then tested (Fathun, 2020). (2) Specific purposes. The specific purpose of this research is to design, fabricate and test the performance of the condenser on a cooling engine using activated carbon and methanol.

2. RESEARCH METHOD

2.1 Research Implementation Method

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



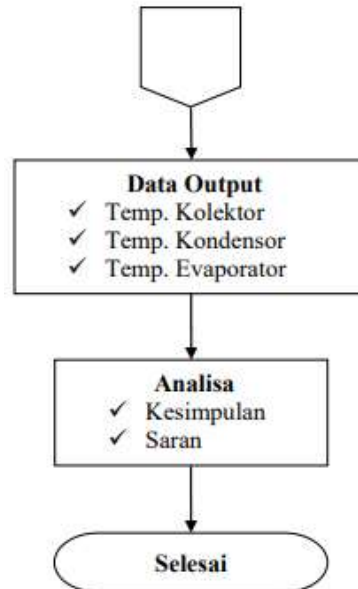


Figure 1. Research Method Flowchart

3. RESULTS AND DISCUSSIONS

3.1. Test result

The research was conducted at the Refrigeration Laboratory of the Department of Mechanical Engineering, Faculty of Engineering, University of North Sumatra. This research process is also related to the HOBO data contained in the appendix. Where during the research process, the source of energy used is the sun. The HOBO meter measures ambient temperature, solar radiation and humidity. The following is the data from the HOBO test results on days I, II and III. HOBO data on day I (02-04-2012)

(1) the average temperature is 31,58065oC (2) the average solar radiation is 438,0991 W/m², the environmental humidity is 82,380 %. HOBO data on day II (04-04-2012) (3) the average temperature was 31.62624oC (4) the average solar radiation was 564.8615 W/m² (5) the average humidity was 82.121%. HOBO data on day III (05-04-2012) (1) the average temperature was 31,79447oC (2) the average solar radiation was 447,6978 W/m². (3) the average humidity of the environment is 82.191%.

Table 1. Data from HOBO Test Results Day I, Day II and Day III

Pengujian	Temperatur Rata-rata	Rata-rata Radiasi Matahari	Rata-rata Kelembaban Lingkungan
Hari I	31,58065 °C	438,0991 W/m ²	82,380 %
Hari II	31,62624 °C	564,8615 W/m ²	82,121 %
Hari III	31,79447 °C	447,6978 W/m ²	82,191 %

Table 4.1 shows that on days I, II and III the average temperature of the sun ranges from 31.58065oC to 31.79447oC. Where the maximum temperature obtained on the third day is 31.79447oC. The minimum temperature obtained on the first day is 31.58065oC. The highest solar radiation was obtained on the second day, namely 564.8615 W/m². While the lowest solar radiation was obtained on the first day, namely 438,0991 W/m². The highest environmental humidity on the first day is 82.38 %. Meanwhile, the lowest humidity during the day occurs on the second day, which is 82.121%.

3.2. Data analysis

The analysis of data from tests carried out at the Refrigeration Laboratory of the Department of Mechanical Engineering, Faculty of Engineering, University of North Sumatra are:

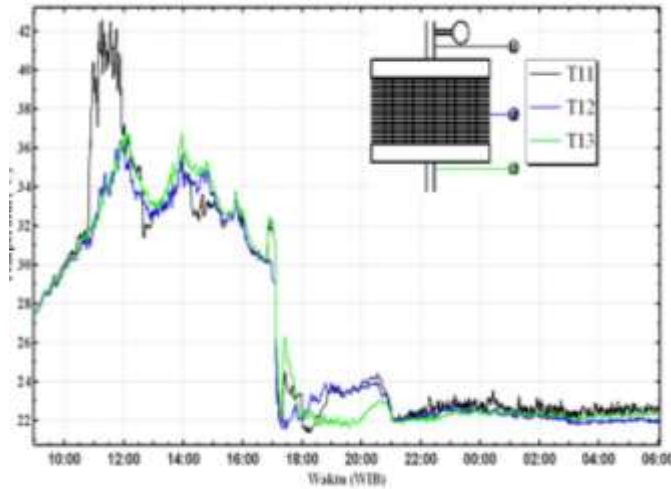


Figure 2. Graph of Temperature VS Time in the Condenser on Day I

From Figure 4.1 it is known:

T11 the highest temperature is 42.57oC at 11:16 WIB

T11 the lowest temperature is 21.36oC at 18:10 WIB

T11avg= 26.74973 oC

T12avg= 26.22478 oC

T13avg= 26.3274 oC

The equations that apply to this heat transfer are as follows:

The thickness of the boundary layer with the equation:

$$\delta = 3,936y \left(\frac{0,952 + Pr}{Pr^2} \right)^{0,25} x Gr_y^{-0,25}$$

. Fluid velocity profile on a vertical plate:

$$v = V_{c(y)} \left(\frac{x}{\delta} \right) \left(1 - \frac{x}{\delta} \right)^2 \tag{1}$$

Where the equation to get the characteristic velocity is the mass flow rate with the equation:

$$V_{c(y)} = \frac{Pr}{3(20/21 + Pr)} x \frac{\rho \beta g |T_s - T_\infty|}{\mu} \delta^2 \tag{2}$$

. Mass flow rate with the equation

$$\dot{m} = \frac{\rho^2 g \beta D^3 L (T_s - T_\infty)}{12 \mu} \tag{3}$$

. Heat transfer rate for each plate:

$$Q = \dot{m} C_p (T_s - T_\infty) \tag{4}$$

The nature of the ambient air in the test refers to the average temperature (T_{avg}) between the ambient temperature (T_{∞}) and the condenser surface temperature (T_s).

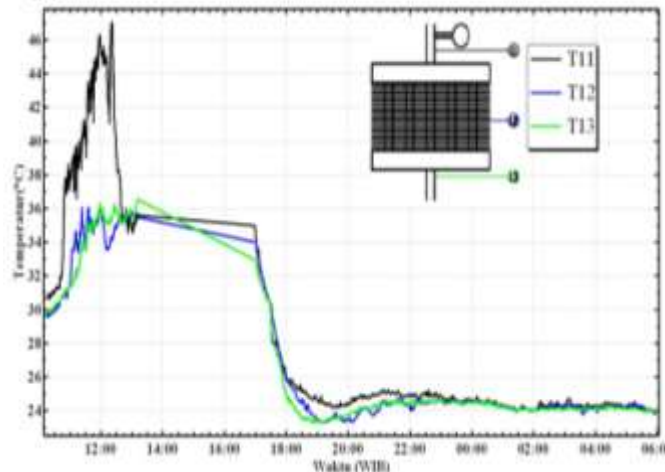


Figure 3. Graph of Temperature Vs Time in the Condenser on Day II

From Figure 4.2 it is known:

T11 the highest temperature is 47.06 oC at 12:21 WIB

T13 the lowest temperature is 23.23 oC at 19:12 WIB

T11avg= 27.45218 oC

T12avg= 26.34033 oC

T13avg= 26.25108 oC

The nature of the ambient air in the test refers to the average temperature (T_{avg}) between the ambient temperature (T_{∞}) and the condenser surface temperature (T_s).

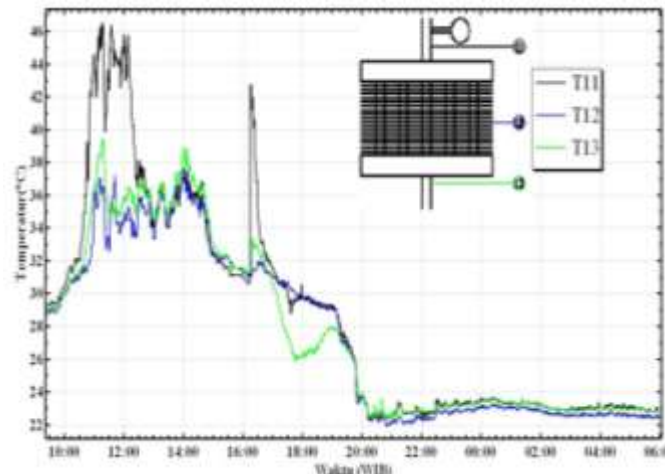


Figure 4. Graph of Temperature in VS Condenser Time on Day III

From Figure 4.3 it is known:

T11 the highest temperature is 46.57oC at 11:16 WIB

T12 the lowest temperature is 21.89oC at 20:52 WIB

T11avg= 28.55966oC

T12avg= 27.39669oC

T13avg= 27.59137oC

The nature of the ambient air in the test refers to the average temperature (T_{avg}) between the ambient temperature (T_{∞}) and the condenser surface temperature (T_s).

$T_s = 34.43 + 273 = 307.43 \text{ K}$

$$T_{\infty} = 32.36 + 273 = 305.36 \text{ K}$$

$$T_{avg} = \frac{T_s + T_{\infty}}{2} = \frac{307.43 + 305.36}{2} = 306.395^{\circ} \text{C}$$

The prandtl number for air is: 0.707

$$\rho = 1,1544 \text{ kg/m}^3$$

$$C_p = 1,0061 \text{ kJ/kgK}$$

$$\mu = 1,994 \times 10^{-5} \text{ kg/m s}$$

$$\beta = \frac{1}{(32,36 + 273)} = 3,27 \times 10^{-3} \frac{1}{\text{K}}$$

$$y = 0,4 \text{ m}$$

$$g = 9,81 \text{ m/s}^2$$

$$L = 0,1 \text{ m}$$

$$D = 12,7 \times 10^{-3} \text{ m}$$

$$x = 0,02 \text{ m}$$

Calculating Grashof's number with the equation

$$Gr_y = \frac{\rho^2 g \beta (T_s - T_{\infty}) y^3}{\mu^2} \quad (5)$$

$$Gr_y = \frac{(1,1544)^2 (9,81) (3,27 \times 10^{-3}) (307,43 - 305,36) (0,4)^3}{(1,994 \times 10^{-5})^2} = 14,264 \times 10^6$$

Calculating the thickness of the boundary layer, namely:

$$V_{c(y)} = \frac{\text{Pr}}{3(20/21 + \text{Pr})} x \frac{\rho \beta g |T_s - T_{\infty}|}{\mu} \delta^2$$

(6)

$$V_{c(y)} = \frac{0,707}{3(20/21 + 0,707)} x \frac{(1,1544)(3,27 \times 10^{-3})(9,81)|307,43 - 305,36|}{1,994 \times 10^{-5}} (0,034)^2$$

Calculating the thickness of the boundary layer, namely:

$$V_{c(y)} = \frac{\text{Pr}}{3(20/21 + \text{Pr})} x \frac{\rho \beta g |T_s - T_{\infty}|}{\mu} \delta^2 \quad (7)$$

$$V_{c(y)} = \frac{0,707}{3(20/21+0,707)} x \frac{(1,1544)(3,27 \times 10^{-3})(9,81) | 307,43 - 305,36 |}{1,994 \times 10^{-5}} (0,034)^2$$

$$V_{c(y)} = 0,653 \text{ m/s}$$

. Calculating fluid velocity profile

$$v = V_{c(y)} \left(\frac{x}{\delta} \right) \left(1 - \frac{x}{\delta} \right)^2 \quad (8)$$

$$v = V_{c(y)} \left(\frac{x}{\delta} \right) \left(1 - \frac{x}{\delta} \right)^2 \quad (9)$$

$$v = (0,653) \left(\frac{0,02}{0,034} \right) \left(1 - \frac{0,02}{0,034} \right)^2$$

$$v = 0,067 \text{ m/s}$$

. Calculate the mass flow rate:

$$\dot{m} = \frac{\rho^2 g \beta D^3 L (T_s - T_\infty)}{12 \mu} \quad (10)$$

$$\dot{m} = \frac{(1,1544)^2 (9,81) (3,27 \times 10^{-3}) (12,7 \times 10^{-3})^3 (0,1) (307,43 - 305,36)}{12 (1,994 \times 10^{-5})}$$

$$\dot{m} = 7,586 \times 10^{-5} \text{ kg/s}$$

. Calculate the heat transfer rate for each plate:

$$Q = \dot{m} C_p (T_s - T_\infty) \quad (11)$$

$$Q = (7,586 \times 10^{-5}) (1006,1) (307,43 - 305,36)$$

$$Q = 0,157 \text{ W}$$

So, the total heat transfer rate is $17 \times 2 \times 0,157 = 5,3 \text{ W}$

Calculating engine cooling performance (COP):

$$m_w = 1 \text{ kg}$$

$$C_{pw} = 4,184 \text{ kJ/kgK}$$

$$T_{wawal} = 296,59 \text{ K}$$

$$m_w = 1 \text{ kg}$$

$$C_{pw} = 4,184 \text{ kJ/kgK}$$

$$T_{wawal} = 296,59 \text{ K}$$

$$COP_{aktual} = \frac{Q_c}{Q_{solar}} \quad (12)$$

$$COP_{aktual} = \frac{m_w \cdot C_{pw} \cdot (T_{wawal} - T_{wakhir})}{G_i \cdot A_{kolektor}} \quad (13)$$

$$COP_{aktual} = \frac{(1kg)(4,184kJ / kgK)(296,59 - 282,04)K}{(14.505,40kJ / m^2)(0,25m^2)}$$

$$COP_{aktual} = 0,0167$$

So, the performance of the cooling engine on the third day of testing is 0.0167

Table 2.Cooling Engine Test Results

Tgl.	Luas Kolektor (m ²)	Jumlah Karbon Aktif (kg)	Massa Air (kg)	Jumlah Metanol (Liter)	Temp. Lingk. Rata-rata (°C)	Intensitas Radiasi Rata-rata (W/m ²)	Chan	Temperatur						COP	Tahun Penelitian		
								Absorber		Kondensator		Evaporator					
								Max (°C)	Min (°C)	Max (°C)	Min (°C)	Max (°C)	Min (°C)				
02 April 2012	0,25	8	1	2	33,541	438,8991	T5	105,77	21,44								2012
							T6	105,07	21,61								
							T7	93,74	21,07								
							T8	27,05	21,95								
							T9	96,42	21,32								
							T10	117,91	23,67								
							T11			42,57	21,36						
							T12			36,44	21,52						
							T13			36,76	23,60						
							T16					24,24	9,87	0,023			
							T17					28,32	9,21	0,012			
							T18					28,66	9,27	0,013			
							T19					32,82	9,34	0,026			
T20					31,73	9,22	0,027										
04 April 2012	0,25	8	1	2	35,849	564,8618	T5	85,75	22,83							2012	
							T6	84,87	23,14								
							T7	95,13	22,95								
							T8	33,79	23,49								
							T9	86,48	22,76								
							T10	118,86	25,12								
							T11			47,06	23,88						
							T12			36,13	23,38						
							T13			36,56	23,33						
							T16					25,11	11,21	0,013			
							T17					24,13	11,16	0,012			
							T18					24,66	11,13	0,012			
							T19					23,87	11,28	0,011			
T20					23,88	11,17	0,011										
05 April 2012	0,25	8	1	2	32,891	447,8978	T5	87,76	22,35							2012	
							T6	103,46	22,31								
							T7	111,82	21,54								
							T8	34,21	23,12								
							T9	104,72	21,43								
							T10	118,59	23,97								
							T11			46,57	22,27						
							T12			37,67	21,89						
							T13			39,47	22,39						
							T16					23,59	9,16	0,016			
							T17					22,80	9,04	0,016			
							T18					-	-	-			
							T19					22,66	9,25	0,015			
T20					22,63	9,10	0,015										

4. CONCLUSION

The conclusions in this study are: (1) The rate of heat transfer that occurs in the condenser: Test Day I: 0.55 W, Test Day II: 7.5 W, Test Day III: 5.3 W. The highest heat transfer rate occurred on the second day of testing, this was influenced by a larger temperature change as well. (2) Mass flow rate of methanol in the condenser : Test Day I : 2,437 x 10-5 kg/s, Test Day II : 8,935 x 10-5 kg/s. Testing Day III: 7.586 x 10-5 kg/s. 3. Performance of the cooling engine (COP): Testing Day I: 0.027, Testing Day II: 0.0127, Testing Day III: 0.0167, The highest performance occurs on test day I, influenced by the difference between the final temperature and the initial temperature. and lower solar radiation. Suggestions in this study are: (1) To avoid leakage in the condenser, the welding technique should be carried out more thoroughly and neatly. (2) For the continuation of the next research, it is better to analyze the causes of the non-achievement of ice so that it is considered.

ACKNOWLEDGEMENTS

We would like to thank all those who have contributed to this research, so that the research can be carried out properly.

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