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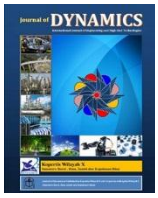

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Experimental Study of Heat Pipe Solar Collector for Energy Supply to Heat Pump

Dian Wahyu

Department of Mechanical Engineering, Politeknik Negeri Padang

Kampus Limau Manis, Limau Manis, Pauh, Padang, Sumatera Barat 25163, Indonesia

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Academic Editor: Asmara Yanto (asmarayanto@yahoo.com)

Correspondence should be addressed to dianwahyuitb@gmail.com

Abstract

Heat pipe solar collectors with heat absorber with a size of 1.13 m x 2 m x 0.12 m with 1.87 m2 aperture area has been created and tested to produce hot water which will be used for energy supply to heat pump. Heat pipes are made using water as the heat carrier medium and use stainless steel mesh wick 100 as a tool that helps accelerate the flow of condensate inside the heat pipe. Tests conducted heat pipe heat pipe first before selected and assembled into a solar water heating collectors. Testing is done by using heat pipes 1.000 mL 100 ^{o}C temperature hot water as a heat source and a heat pipe evaporator also tested by direct solar radiation. The tests are done to see the response speed (τ) heat pipe in heat transfer. Filling ratio obtained from testing the best heat pipe is 10%. Testing of solar collector with heat pipe absorber has been conducted during the month of June 2013 in the laboratory of solar Institut Teknologi Bandung (ITB) using the standard American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE 93-2003). The efficiency of solar water heating collectors is strongly influenced by solar irradiance and the temperature difference between incoming fluid collector with the environment (Tfi-Ta). The test results showed the highest efficiency of 35.8% is obtained when the temperature difference between incoming fluid and ambient temperature is close to zero. To get hot water at a flow rate of at least 50^{o}C 0,25 L / min, the necessary irradiance of 750 W / m^2. Generally, during the trial obtained water output temperature solar heating collectors from 8:30 - 9: 40 pm and 15: 40 - 17: 30 pm is below 50 °C, while at 9:40 - 15: 40 obtained collector output water temperatures above 50 ° C , Thus, it can be concluded that the heat pipe solar collectors are designed can be used to replace the evacuated tube collector in supplying heat for the heat pump. An advantage of using heat pipe solar collectors tend to be more economical and can be domestically produced.

Keywords: Solar collector, Heat pipe, Heat Pump

1. Introduction

The existence of solar energy has been used by everyone in the world since the first. The map of the intensity of solar radiation on Earth has been studied and measured by the researchers. Based on Meteonorm program can be known annual irradiance value every Country in the world is in the range of 300 kWh / m^2-2500 kWh / m^2 [1]. Based on its location, Indonesia is in tropical climates where this area is rich in solar energy outpouring. The Ministry of Energy and Mineral Resources provided data on the average daily solar energy potential in Indonesia of 4.5-6.8 kWh/m^2/day [1]. Bandung is located at coordinates 107^{o}36 'East Longitude and 6^{o}55' South Latitude. Based on the daily average daily radiation of meteonorm program ranges from 4.5-5.4 kWh/m^2/day [2].

The areas on the island of Sumatra and the island of Borneo, as well as some areas in Eastern Indonesia have low solar radiation energy compared to some areas of Java, Sulawesi and some areas in NTB and NTT, as well as in the Maluku archipelago. The amount of solar radiation energy is taken from 6:00 to

18:00. Based on this condition, consideration to utilize solar energy is very possible.

Solar energy utilization efforts to contribute to the fulfillment of energy needs since long been done but not optimal. The direction of energy policy from the Ministry of Energy of Human Resources in Indonesia has been made based on Presidential Regulation No. 5 of 2006. The PRESCR has become the basis for the issuance of Law No. 30 of 2007 on energy. The law regulates all the energy potentials in the territory of Indonesia. One of the goals is energy conservation and energy utilization efficiently in all sectors.

At present solar energy utilization has been done in two ways, namely by using solar photovoltaic technology and thermal solar technology. Solar photovoltaic technology is usually used for small-scale electricity needs such as home lighting, water pump suppliers, LCD and LED television suppliers, and others. While thermal solar technology can be used directly such as for dryers and water heaters.

There are many processes that require temperatures above 100°C, among others are the process of distillation of oil using steam hot water, the process of making bioethanol assisted by steam hot water, sanitation processes in the health environment and others. Based on the above, the desire to utilize solar energy for these processes. In order to meet temperatures above 100°C required heat pump is required. This tool utilizes the heat collected by the solar collector as the energy enters the heat pump and on the condenser, a high temperature heat is generated. The heat of the condenser can be used as a producer of hot air or steam heat that can be used later for various purposes. Solar heater assisted solar pump system has been created and tested by Djuanda by using four collectors of ETC (Evacuated Tube Collector) solar heater. The ETC solar collector is a vacuum tube collector using a U-shaped pipe placed inside the glass tube. The test results show that the collector is capable of supplying heat pump energy to generate steam, and hot vapor will form on the steam generator side if the hot water coming out of the solar collector is at least 50°C. The energy flow rate of the solar collector coming into the heat pump evaporator area is 2600 J / s and the steam temperature generated on the steam generator (condenser replacement) is 102°C. Solar-assisted solar heating pump system in the study is considered not enough economic, because the price of solar heating collector is very expensive where it takes Rp 135 million to provide four collectors.

Based on the above problems, collectors are required to replace the ETC collector function in the heat pump system and able to produce hot water temperature of at least 50°C for heat pump energy suppliers. The fluctuating solar irrandiance requires collectors to rapidly transfer solar radiation energy but it is economical. According to theory, heat pipe is a very fast heat transfer device that has high thermal conductivity. Therefore collectors are made using heat pipe as absorber. The solar pipe solar collector is expected to collect energy well, and can be used as a heat pump energy supplier.

2. Material and Methods

A. Working Principle of Heat Pipe

Heat pipe is a hollow pipe whose ends are closed after a number of working fluids are placed inside them. In general, heat pipe works utilizing the latent heat of the working fluid. The heat transfer process in the heat pipe occurs in the three delivery regions, the evaporator, the adiabatic and the condenser where it can be illustrated as shown in Figure 1.

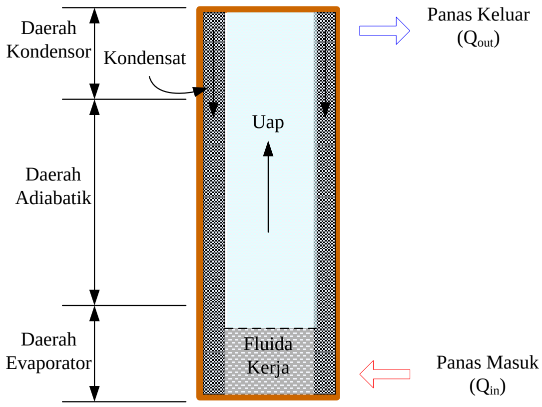

Figure 1. Heat transfer in heat pipe [3].

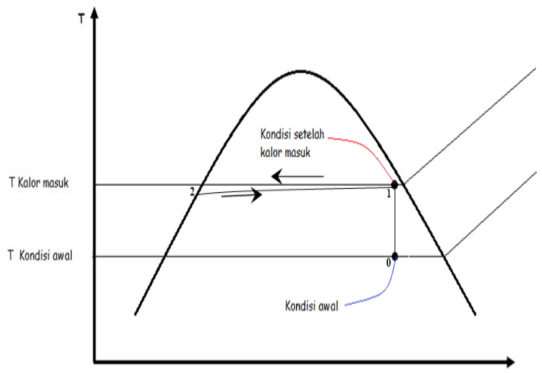

Figure 2. Work cycle in heat pipe [3]

The wick structure is used to help accelerate condensate flow in the pipe. In Figure 2, we can see the phase conditions of the working fluid before and after the heat entering the heat pipe evaporator area. When the heat enters along the evaporator side, where the incoming heat temperature exceeds the working fluid saturation temperature, it causes the amount of liquid the working fluid evaporates. Steam will flow into the condenser area due to an increase in vapor pressure. In the condenser section, the latent heat of the vapor is transferred to the surrounding environment, causing the temperature and vapor pressure to fall down so that condensate is formed. The condensate goes back to the evaporator area through the wick, while the vapor pressure drop will evaporate again the amount of working fluid under the evaporator. This process will take place continuously along the heat received in the evaporator section. A simple cycle of heat pipes can be summarized according to Figure 2, as shown below [4]:

Table 1. Simple cycle of heat pipes [4]

Process	Description
0-1	Evaporation event is first incoming heat
1-2	Condensation event because heat is transferred out heat pipe
2-1	Evaporation events

B. Working Fluid of Heat Pipe

Working fluid serves to move heat from the evaporator to the condenser [3]. For this purpose a working fluid must be selected which has a liquid point temperature below the operating temperature and has a critical temperature above the operating temperature and has a high latent heat.

C. Solar Water Heater

Utilization of solar energy for water heating is not a new idea. More than a hundred years ago, the black-painted water tank has been used as a simple solar water heater in various countries. Solar water heater technology has evolved in recent decades [5]. Now more than 30 million m^2 of solar water heater collectors have been installed all over the earth's surface. The advantage of using solar water heaters is the cost savings in water heating, as some solar water heaters do not require power supplies to operate. During enough solar irradiance, hot water is still produced like swimming pool water heating directly.

Heat Pipe Solar Collector

In general, this design solar collector includes a flat plate solar collector type. What distinguishes lies in the type of absorber used. The collector's absorbers, using heat pipe technology. The heat pipe is mounted on an aluminum plate as shown in Figure 3. The pipe heat pinned is inserted into the solar collector manifold through the heat pipe condenser as shown in fig. 4 and 5. The working principle of the collector in the heating process is by the phase change Takes place inside the heat pipe [6]. The solar radiation energy that falls on the collector surface will be absorbed by the heat pipe on the evaporator side. The temperature of the heat pipe will increase slowly, causing the working fluid in the heat pipe to change the phase to steam. Steam will flow from the evaporator side to the condenser side. On the condenser side, the latent heat of the vapor will be transferred to the water stream to be heated in the manifold as shown in Figure 6. The collector cover uses 1 layer of glass. This collector is manufactured and tested to see the collector's performance, whether this collector can replace the evacuated tube type collector that has been used as a heat pump supplier in the Djuanda dissertation research. It is expected that the solar pipe solar collector, can provide results that meet the requirements as a heat source supplier of heat pump energy.

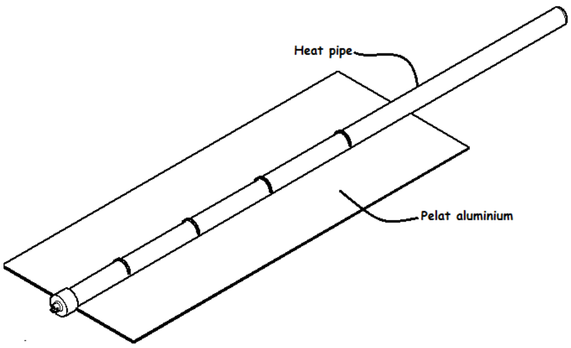

Figure 3. Heat pipe in an absorber plate [7]

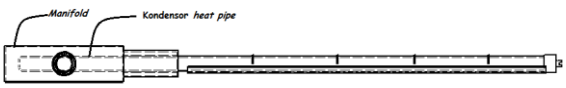

Figure 4. Stucture of heat pipe solar collector

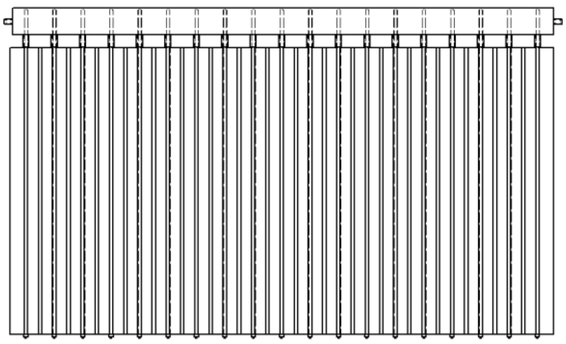
Figure 5. Aranggement of heat pipe in solar collector

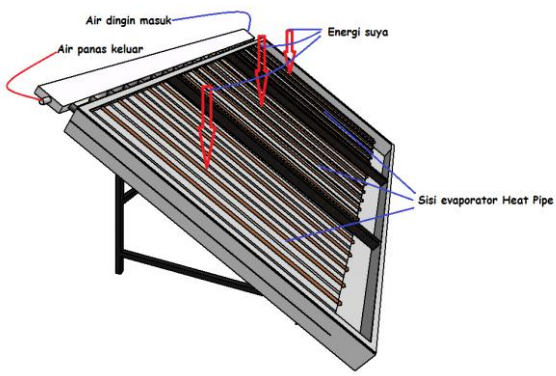

Figure 6. Heat pipe solar collector design

D. Energy Balance in Solar Collector

The first step to perform solar collector analysis is to apply the law of thermodynamics I which speaks of conservation of energy. This energy equilibrium is useful for seeing incoming energy, utilized energy and thermal energy losses. Assuming the collector operates at steady state, this scheme can be seen in Figure 7 below:

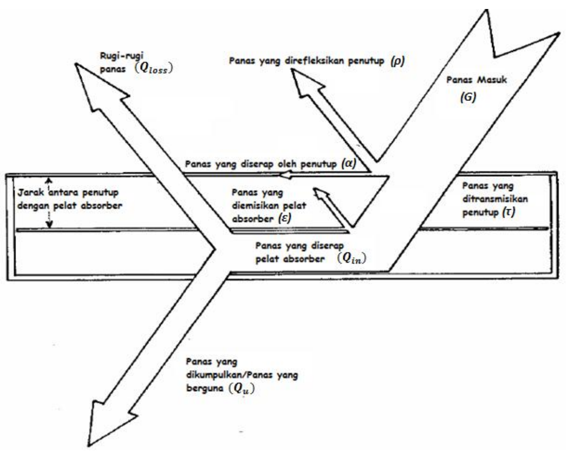

Figure 7. Energy balance [8]

If G is the sun irradiance (W / m2), if the solar collector has the aperture area (Aa) shown in Figure 7. The amount of radiant energy received by the solar collector can be searched by equation 1 below:

$$Q_i = A_a G \quad (1)$$

However there is a part of the radiation that is reflected back into space and some are absorbed through the cover glass and the absorber plate. The inlet energy (Q_{in}) after the absorption event of the cover and the collector absorber can be written as equation 2 where the incoming energy is the multiplication of A_a, the absorption-transmission value (τ_α) with the incoming solar irradiance (G)

$$Q_{in} = A_a \tau_\alpha . G \quad (2)$$

Because the collector absorbs heat, the collector temperature will be high when compared to ambient temperature and heat will be lost to the environment by convection and radiation. The average heat loss depends on the heat transfer coefficient (U_L) and the difference between the average temperature of the absorber plate, $T_{p,m}$ and ambient temperature, T_a. The thermal loss equation can be determined according to equation 3 below:

$$Q_{loss} = U_L . A_g \, (T_{p,m} - T_a) \quad (3)$$

The useful energy Q_u extracted from the collector under steady conditions is equivalent to the incoming energy of collector absorption reduced by the energy lost to the environment, and can be written like the equation below:

$$Q_u = \tau_\alpha G - U_L A \, (T_{p,m} - T_a) \quad (4)$$

The above equation is very difficult to implement because of the difficult process in determining the average collector plate temperature. The actual way to calculate the useful energy, can also be calculated as the average heat extracted from the collector transferred to the fluid flowing in the manifold as shown in Figure 8. Generally the energy utilized for heating water can be calculated using equation 5 :

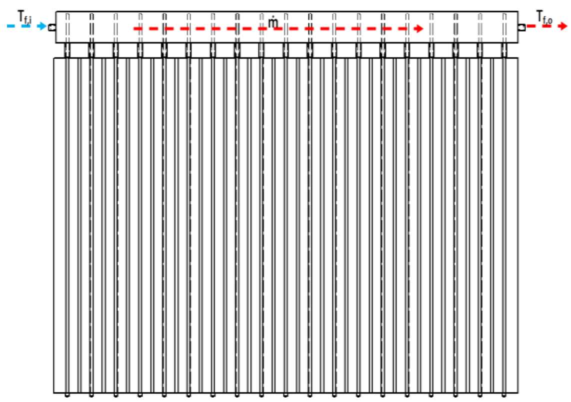

Figure 8. Water Flow in Solar Collector [9]

$$Q_u = m \; C_p \, (T_{f,o} - T_{f,i}) \quad (5)$$

Where C_p is the type heat of water, m is the mass flow rate of water, $T_{f,i}$ and $T_{f,o}$ the inlet and outgoing fluid temperatures. According to Hottel Whillier-Bliss useful energy as the acquisition of solar energy into the field of collectors can be written as equation 6:

$$Q_u = F_R \, A_a \, G \, \tau_\alpha - U_L \, (T_{f,i} - T_a) \quad (6)$$

Where F_R is the heat transfer factor. The collector performance indicator is efficiency, defined as the ratio of the amount of heat utilized to the amount of heat entering the collector plane. Mathematically can be written like equation 7:

$$\eta_a = \frac{\int_{t_1}^{t_2} Q_u \, dt}{A_a \cdot \int_{t_1}^{t_2} G \, dt} \times 100\ \% \qquad (7)$$

Where t is the time interval, data retrieval taken every second while processing data in interval of 5 minutes.

E. Heat Pipe Testing

The heat pipe test is performed prior to the installation of heat pipe absorber in the solar heating collector. Tests are performed on various fluid replenishment ratios. The filling ratio is the ratio of fluid volume in the heat pipe to the volume of the cavity in the heat pipe. In this case the tested filling ratios are 5%, 10%, 20%, 30%, 40% and 50%. This test aims to see the speed of heat pipe response in heat transfer. The indicator seen is the time required to reach steady state or known as thermal time constant (τ). This can be determined by measuring the temperature of the heat source in the heat pipe evaporator and the energy temperature moved on the side of the heat pipe condenser. This test is carried out with two heat sources, first by heating the heat pipe with 1000 mL of water at a temperature of 100 °C, the next heating with direct solar radiation. By doing this test is expected to get the right heat pipe to be installed on the solar heating collector.

F. Heat Pipe Testing with Heat Pipe Heating with Water 1L at Temperature 100 °C

The procedures for testing are:

1. Heat pipe with various fill ratio has been made and prepared.
2. Heat water with a volume of 1,000 mL with a water heater
3. Place the heat pipe absorber to the test spot as shown in Figure 9.
4. Install the thermocouple on the evaporator side and the heat pipe condenser.
5. Connect the thermocouple cable to the aquisition data.
6. Insert boiling hot water on the heat pipe evaporator side.
7. Record evaporator and condenser temperature data with laptop.

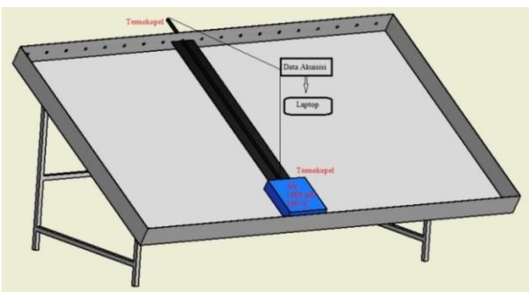

Figure 9. Heat pipe position in solar collector

G. Heat Pipe Testing With Direct Radiation

This test is conducted to predict whether a heat pipe can work to heat water on a solar collector. This test is carried out for 8 minutes at an average radiation of 700 W / m2.

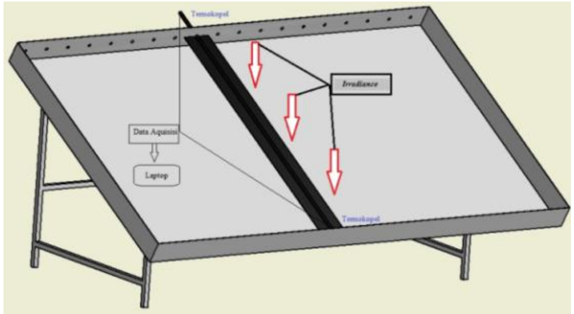

Figure 10. Heat pipe position in solar collector

The procedure for testing is

1. Heat pipe tested is a heat pipe that has been selected on heat pipe test with a heat source of 1,000 mL of water at a temperature of 100 °C.
2. Testing is done at the same place, same day and hour.
3. Place the heat pipe absorber to the test spot as shown in Figure 10
4. Install the thermocouple on the evaporator side and the heat pipe condenser.
5. Connect the thermocouple cable to the aquisition data.
6. Before recording temperature data, cover the absorber heat pipes so that radiation does not enter.
7. If the test preparation is mature, open the cover and record the evaporator and condenser temperature data with the laptop

H. Collector Performance Test

For the perfomance of flat plate plate heat pipe, it is necessary to test. Testing can be done outdoors with natural solar radiation as well as indoors using artificial radiation. In order to obtain experimental results close to the actual state, in this thesis the testing is done outdoors. Collector testing can be done in two ways, namely calorimetric testing and instantaneous testing. Calorimetric testing is used for close loop systems, and usually the system comes with a storage tank. In a momentary test, the test is focused solely on the collector, and simultaneous measurements, fluid mass flow rate, difference of collector entry and exit temperature, and radiation intensity coming in the collector field. Because the test will only focus on the performance of the collector, then in this thesis is applied a momentary test. This collector test follows the standards set by

ASHRAE 93. Other agencies developing the test are ISO 9806, UNE-EN 12975-2, ASTM E 905-87. Commonly measured parameters are the same:

1. Intensity of solar radiation
2. The fluid temperature goes into the collector
3. The fluid temperature comes out of the collector
4. The ambient temperature
5. Mass flow rate of fluid

With these parameters the efficiency of the solar pipe solar collector can be calculated.

I. Schematic and Systematic Testing

Systematic testing is as follows:

1. Enable the constant head tank to adjust the flow rate of the water to be heated.
2. Once the discharge is regulated, water is flowed into the collector through a conduit that contains a heat pipe condenser.
3. Once the steady state is achieved, measurements are made include:
   - The measurement of the intensity of solar radiation
   - Measurement of the incoming collector fluid temperature
   - Measurement of outlet collector fluid temperature
   - Measuring ambient temperature

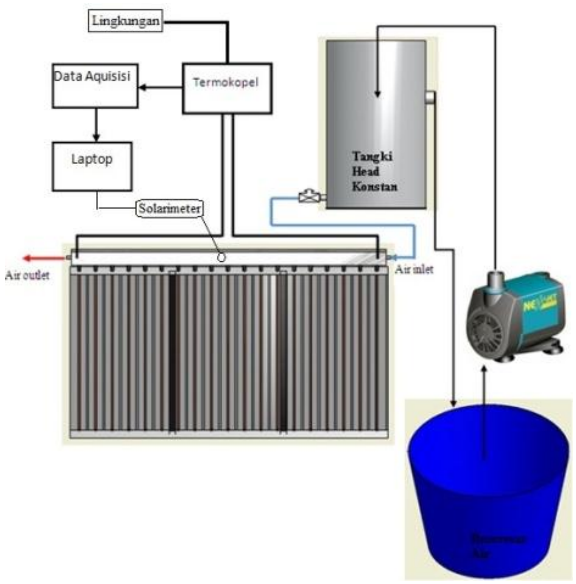

Figure 11. Testing Schematic

The tools required in this test are:

1. Solar heater collector is a collector to be tested the self-performance.
2. Water, used as an indicator of the absorption of energy from the absorber heat pipe to water, which is indicated by the increase in water temperature.
3. Constant head tank, serves to regulate the flow rate of water to the collector.
4. Water reservoir, accommodating the excess water supplied by the pump to the constant head tank.
5. Pump serves to drain water from the water reservoir to the constant head tank.
6. Temperature sensor, used to measure the inlet and collector water temperature and environmental temperature.
7. Measuring intensity of solar radiation, used to measure the intensity of solar radiation.
8. Data acquisition, analog signal modifier generated temperature sensor to digital signal.
9. Laptop, serves as a recorder and data processor.

3. Results and Discussion

A. Testing Data for Heat Pipe Selection

To draw the conclusion of the heat pipe to be selected, Figure 12 shows the heat pipe response speed (τ). The value of the response speed of this heat pipe, can be determined in the amount of time specified for both types of testing. The speed of this heat pipe response, indicating the time required to achieve steady state. As can be seen clearly in Figure 12, the overall heat pipe made can work in heat transfer at any filling ratio created except at a 100% filling ratio.

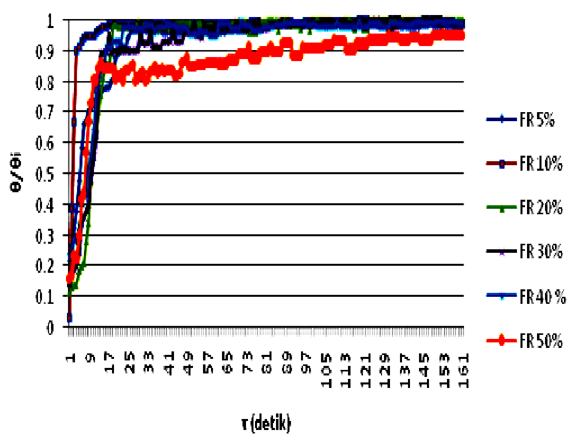

Figure 12. The heat pipe response speed

Based on the results of both types of testing, got the type of heat pipe that has a pretty good response, the heat pipe with heat pipe filling ratio of 10%. Other considerations include the dryout problem on the evaporator side. Where this dryout condition should be avoided as it affects the operation of heat pipes. If this condition occurs, then the process of heat transformation was stopped, because no more fluid to be evaporated.

Considering that the heat source on the heat pipe evaporator side is sourced from solar radiation, the heat pipe requirement for the solar collector with a 10% filling ratio is selected. This selection is based on the heat pipe characteristics that best respond to incoming energy and greater heat transfer capacity compared to all other filling ratios and heat pipes with a 10% filling ratio in preventing dry out.

B. Solar Heat Pipe Collector Test Data

Testing of solar heating collectors has been done so that the test results data can be plotted. The conditions at which the test affects the resulting data, in which the radiation begins to enter the collector field effectively and significantly at 8:30. In fact, when taken in other positions actually radiation data can already be taken, this is because the solar radiation obstructed trees that grow next to the solar laboratory building. From the results of the data during the test it can be concluded that the collector designed to produce hot water passing temperature 50°C for more than 6 hours and this can be achieved if the weather conditions are not rain or cloudy thick and radiation of at least 750 W/m^2.

In Fig. 13, the data residing on the purple line of elip is processed as an example to calculate the instantaneous collector efficiency.

In the calculation of efficiency, the data is processed into segments with intervals of 5 minutes. Then, for each segment, the collector's instantaneous efficiency is calculated by using equation 6. These data are processed into a graphical form commonly used for solar heating collectors and shown in Figure 14.

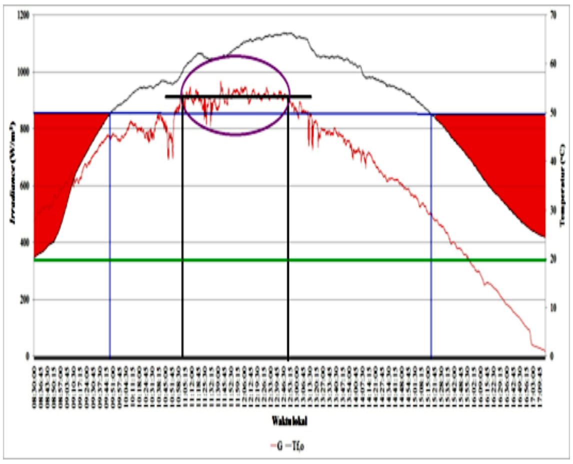

Figure 13. Testing graphic of solar collector

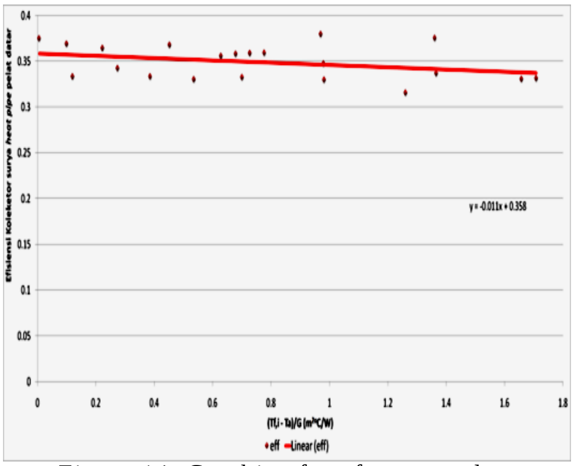

Figure 14. Graphic of performance data

From the results of solar pipe solar collector testing, it is obtained that the temperature rise that occurred at 33°C. This is obtained under test conditions: the average radiation intensity is 900 W / m^2, the average temperature of the incoming fluid is 30°C, the average temperature of the circumference is 29°C, and the wind speed is 0 to 5 m/s. In this condition, the intermittent efficiency of solar collectors varies depending on the conditions of the solar radiation fluctuations and the difference in temperature of the incoming fluid with the ambient temperature ($T_{f,i}$-T_a). The collector's instantaneous efficiency will decrease if the value ($T_{f,i}$-T_a) increases. The highest collector efficiency was found to be 35.8%. This occurs when the temperature difference of the fluid enters with the near-zero environmental temperature. The results of this collector test also provide a useful energy flow rate at the collector of 591.8 J/s.

Not all solar collector output fluids can be utilized to supply heat pump energy. This is caused, because sometimes the collector fluid temperature of at least 50°C has not been reached. In Fig. 13 the collector output fluid temperature is at least 50 ° C, reached at 9:45 until 15:20. This means the heat pump system can work at that time range because the collector output can be directly utilized to supply the heat pump energy. However, the solar heating collector's output before 9:40 am and after 15:20 is not yet eligible to supply the heat pump energy because the collector's output fluid temperature is less than 50 °C. The addition of a small amount of incoming energy from another source is required to increase the temperature of the collector output fluid not reaching a temperature of 50 °C. The orange area in Fig. 13 is a picture of the energy that must be added to the collector output fluid to reach a temperature of 50 °C. The minimum energy that must be added to the temperature of the solar collector's minimum output of 50ºC is 0.355 kWh before 9:45 and 0.402 kWh after 15:20.

Another step in meeting the lack of energy when the hot water collector output is less than 50ºC is by making thermal energy storage and the addition of a little electrical energy from the PLN. For more details the system is shown as Figure 15 below:

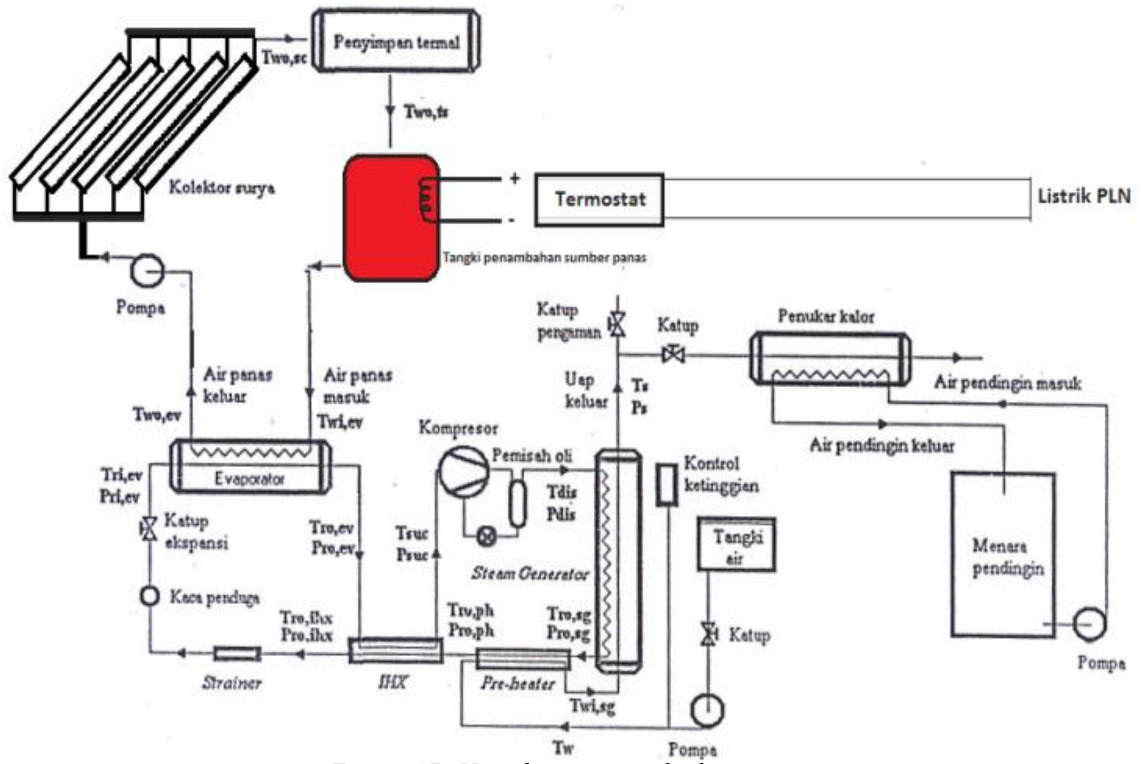

Figure 15. New design to make hot vapor

The hot water generated by the heat pipe solar collector prior to entering the heat pump evaporator is flowing first through the thermal energy storage. The energy storage technique is to utilize the phase variable material. Hot water from solar collectors goes into thermal energy storage, where the construction is Shell and Tube type heat exchanger with hot water flowing in pipes and phase-shifting materials in the shell. When the hot water generated by the solar collector exceeds the melting point temperature of the phase material, the phase variable material will melt as the energy from the hot water has been applied to the material, and when the water coming out of the solar collector is below the melting point temperature of the phase material, Of the material will be transferred again to the flowing water. The handover of this energy will continue, and stop if things are balanced. The collector test results can be used as a prediction for the number of flat plate pipes heat pipes used. Because the solar pipe solar collector will be used as a heat pump energy supplier, where one collector unit can produce an average flow rate of energy of 591.8 J / s then the number of collectors required is as much as 5 pieces such as installation of the system above.

4. Conclusion

After conducting literature studies, designing, creating, testing, and analyzing this research, it can be concluded that:

1. Solar collectors that meet DR & O with heat pipe absorber have been designed measuring 1.13 m x 2 m x 0.12 m, made and tested and can produce water with a minimum temperature of 50ºC at a minimum radiation of 750 W / m^2 for 20 minutes.
2. The efficiency of the collector is strongly influenced by the fluctuations in solar radiation and the value of the temperature difference of the collecting fluid in the collector with the ambient temperature ($T_{f,i}$-T_a). The highest collector efficiency was obtained at 35.8% when the value ($T_{f,i}$-T_a) was close to zero.
3. The average collector's energy flow rate is 591.8 J / s
4. It takes five solar pipe solar collectors measuring 1.13 m x 2 m to supply high temperature heat pump energy in Djuanda dissertation research with input 2600 J / s at 50ºC hot water temperature.

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