



Comparative Study of Heat Transfer Rate in Solar Water Heater by Varying the Sun Incoming Angle and Flow Rate of Sun Heat Absorbing Fluid

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ABSTRACT

The issue of Green Energy, which is about clean and environmentally friendly energy, is a very important issue at this time. Energy that has the above properties is renewable energy. Optimization of energy absorption needs to be done and this is usually done by conditioning or manipulating several parameters so that the energy absorption rate is more effective and efficient. Therefore, the authors conducted a study that is expected to know at the angle of arrival and the rate of flow what is the most optimal absorption of heat from solar energy for the installation and seeding of Solar Water Heater in Pontianak City. And it is expected that with this research can be a recommendation of energy absorption rate, especially those who use solar energy for the Pontianak City area of West Kalimantan to be optimal and efficient. Based on the results of research and analysis conducted in this study for the setting of the sun's coming angle of 450 and coolant fluid flow rate setting, namely the Solar Collector Loop side of 1250 ccm and on the Domestic Heater Water Loop of 1000 ccm in solar water heater. The setting of angles and flow rate settings in the conditions mentioned are very suitable for the condition of Pontianak city area which provides a very stable efficiency value and the value is close to 100% and the value of heat transfer is quite optimal both the absorption of solar heat and heat absorption by heated water

INTRODUCTION

The issue of Green Energy, which is about clean and environmentally friendly energy, is a very important issue in this time. Energy that has the above characteristics is renewable energy. Many new renewable energy (EBT) forms and uses are available in Indonesia. Some are used based on their motion energy, for example water energy, wind energy. And there are also those that are used because of their Electro Magnetic waves and heat like solar energy. The form of its utilization can be used to produce electrical energy, it can be used to extract heat or other forms in an effort to simplify and improve human welfare.

One form of energy that is currently widely used to facilitate and improve human welfare is the use of solar energy. At this time there are 2 uses of solar energy as a new renewable energy source:

1. Converting sunlight into electrical energy using photovoltaic cells. The production and development of photovoltaic cells is currently very rapid along with the increasing need for energy, especially energy that is clean and environmentally friendly. This Photo Voltaic absorbs sunlight and moves the electrons contained in the panel to generate electricity. The stronger the sunlight the greater the energy that can be produced.
2. Utilization of solar energy by absorbing energy using a Solar Collector. It's usually used for water heating and has low operating costs. The working principle is by passing water to the solar collector so that heat transfer occurs from the solar collector to the water. The amount of energy that can be utilized also depends on the intensity of the solar energy emitted, so it's very dependent on climate and weather conditions.

In this thesis, the author discusses the utilization of solar thermal energy as an energy source that will be used to heat water. As we also know that this utilization is very dependent on climate and weather conditions according to the geographical location of the place. Optimization of energy absorption needs to be done and this is usually done by conditioning or manipulating several parameters so that the level of energy absorption is more effective and efficient.

By looking at the background mentioned above, the authors are interested in conducting research by conditioning or adjusting the flow rate of the fluid in the Solar Water Heater and the angle of incidence of the sun so that optimal absorption and heat transfer rates are obtained in the climate and weather conditions in Pontianak City, Kalimantan. West.

Formulation of the Problem

As we know, almost all water heaters that utilize solar energy sources are fixed in nature. Setting the angle of incidence of sunlight is very important to determine the absorption of heat energy coming from sunlight. It's likely that each region will be different, depending on it's geographical location.

By looking at the background mentioned above, apart from the angle of incidence, the flow rate of the fluid that absorbs heat from the sun is very influential because theoretically it is said that the flow rate of the fluid greatly influences the rate of heat transfer.

So with this the author is interested in conducting a research which is expected to provide recommendations about the angle of incidence of the sun

and the flow rate of heat absorbing fluid in an effort to optimize the absorption of heat energy in Solar Water Heaters.

Restricting the Problem

To keep the discussion in this research focused and not expanded, because there are other possibilities that also affect the rate of heat absorption in Solar Water, the authors provide several problem boundaries for this research:

1. This research was conducted in the City of Pontianak, West Kalimantan, so that the climatic and geographical conditions are the climate and geographical conditions of the city of Pontianak.
2. The fluid used in solar collectors to absorb heat energy is coolant and does not differentiate between brands.
3. Setting the direction of the angle of incidence of the sun in this study, the variations are limited in the range where theoretically it is estimated that the amount of heat energy is very large or at peak conditions and in this study at an angle of 30° and 45°.
4. The fluid flow rate that is varied in this study is the heat absorbing fluid flow rate in the Solar Collector, not the heated water fluid flow rate.

Research Purposes

The aim of this research is:

1. To find out at what angle of incidence and flow rate heat absorption from solar energy is the most optimal for installing and setting up Solar Water Heaters in Pontianak City.
2. It is hoped that this research can become a recommendation for the level of absorption of energy, especially those that use solar energy for the Pontianak City area of West Kalimantan to be optimal and efficient.

Benefits of Research

The benefits of this research are:

1. Optimizing the absorption of heat energy from renewable energy sources, namely solar energy which is used for heating water in order to meet the needs of human life.
2. Contribute to the development of science and technology, especially in maximizing the rate of heat transfer in Solar Water Heaters by considering the angle of incidence and flow rate of the heat absorbing fluid in the Solar Collector.
3. Maximizing the function of the Solar Water Heater, especially those installed in the Pontianak City area, West Kalimantan.

THEORETICAL REVIEW

At this time, the development of science and the use of thermal systems is very rapid, where it is known that fluid flow and energy transport play a very important role [1; 1]. The use of this thermal system is very broad in engineering fields such as for manufacturing processes, energy generation, air conditioning, automotive to the use of new and renewable energy such as Solar Water Heaters (SWH) by utilizing solar energy.

Solar Water Heater whose energy comes from solar energy is a complex system in which there are several sub-systems and one of them is a thermal

system. But in general, for solar water heaters, there are 2 major parts, namely the solar collector loop and the domestic water loop. The two loops transfer heat energy to the heat exchanger section.

In this thesis, the author will try to optimize the absorption of heat energy by adjusting the Solar Collector Loop. The arrangement is made at the angle of incidence of sunlight which is related to geographical location and climate. Meanwhile, setting the flow rate of the heat-absorbing fluid in the solar collector loop, namely the coolant fluid, is related to the thermal sub-system which is quite complex as a result of the influence of fluid flow and the heat and mass transfer mechanisms involved in the system [1; 22]. One of the thermal sub-systems in SWH is a heat exchanger. This heat exchanger functions to exchange heat energy originating from the sun and is absorbed by the coolant fluid and transferred to the water fluid which will be used as hot water. The role of the heat exchanger here as a thermal sub-system is very important to maximize the rate of energy exchange, especially heat energy.

For SWH whose energy source comes from the sun, several variables involved in the absorption of heat energy from the sun and the rate of heat transfer can be regulated or conditioned. Variables that can be adjusted are the angle of incidence of the sun and the heat transfer coefficient which is highly dependent on the flow rate. For other factors such as the desired heat and the area of heat transfer are relatively constant.

From the foregoing, to maximize the heat transfer rate for SWH, the variable that we can adjust is the angle of incidence and adjust the flow rate of the fluid flowing in the Solar Collector Loop. For this reason, the author will try to carry out an experiment where it is hoped that the results will be able to maximize the rate of heat transfer by adjusting the angle of incidence of the sun to maximize the absorption of heat energy from the sun directly and the flow rate of the fluid at input temperature conditions that change due to the emission of energy by the sun which depends on the weather. And climate. The fluid that is regulated here is only the fluid in the Solar Collector Loop (Fluid Coolant) while the fluid in the Domestic Water Loop (Water Fluid) is fixed.

Basic Theory

a. Solar Water Heater

According to the McGraw-Hill Dictionary of Architecture and Construction, Solar Water Heater is a system where solar heat is collected by a solar collector and used to increase the temperature of a heat transfer fluid (water or anti-freezing fluid) flowing through the pipes in the collector; the heat contained in this fluid is then conveyed and transferred to domestic water.

Solar Water Heater has two components, a solar collector which is placed in a sunny place and usually on the roof of a building, and a storage tank to collect the hot water. Pipes filled with liquid flow through collectors to storage tanks inside the building, transferring heat from the liquid to the water in the tanks. The cooled heat transfer fluid is returned to the collector to be heated again.

So in principle Solar Water Heater is a tool that converts solar energy into heat energy which is then used to heat water and a process of heat transfer always occurs. It can be said that the Solar Water Heater is a Heat Exchanger. The following is a picture showing the working principle of a Solar Water Heater.

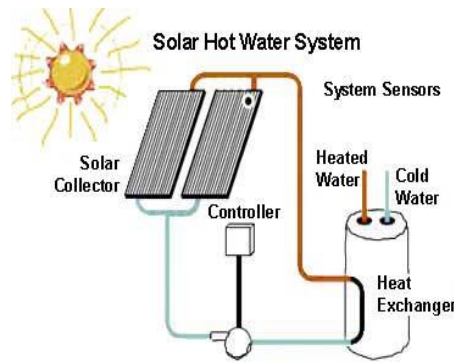


Figure 1. The Process of Heat Absorption in the Solar Collector and Heat Transfer in the Heat Exchanger

b. Solar Water Heater Series and Components

The following is a complete diagram of a solar water heater that will be used to conduct research on the influence of the water fluid flow rate (DHW Loop) as shown in Figure 2[2;14]. While the components contained in the solar water heater are as follows;

1. Solar Collector Panel
Solar Collector Panel serves to collect heat energy from the sun.
2. Circulating pumps and piping for heating fluids (Ethelyn Glycol)
This pump and piping function to circulate Ethelyn Glycol with closed circulation and pass it through the Solar Collector Panel and function to absorb the heat absorbed by the Solar Collector Panel which comes from solar thermal energy.
3. Circulating pumps and piping for water fluids
This pump and piping function to circulate water and are in the form of open circulation where during this circulation the water will absorb heat from Ethelyn Glycol so that the water temperature will rise and be used as hot water for user needs.
4. Heat Exchanger or Heat Exchanger
This Heat Exchanger functions to exchange heat between Ethylin Glycol fluids and water fluids
5. Heat Coil or Heating Coil
This Heat Coil serves to preheat the water fluid which will enter the heat exchanger by utilizing heat from the surrounding air which is exhaled using a fan.
6. Fan or Fan
This fan functions to blow air around which has a certain temperature to be passed on to the water fluid before entering the heat exchanger. This fan also functions to accelerate heat transfer that occurs between air and water fluids
7. Measuring instrument for measuring flow rate, pressure and temperature

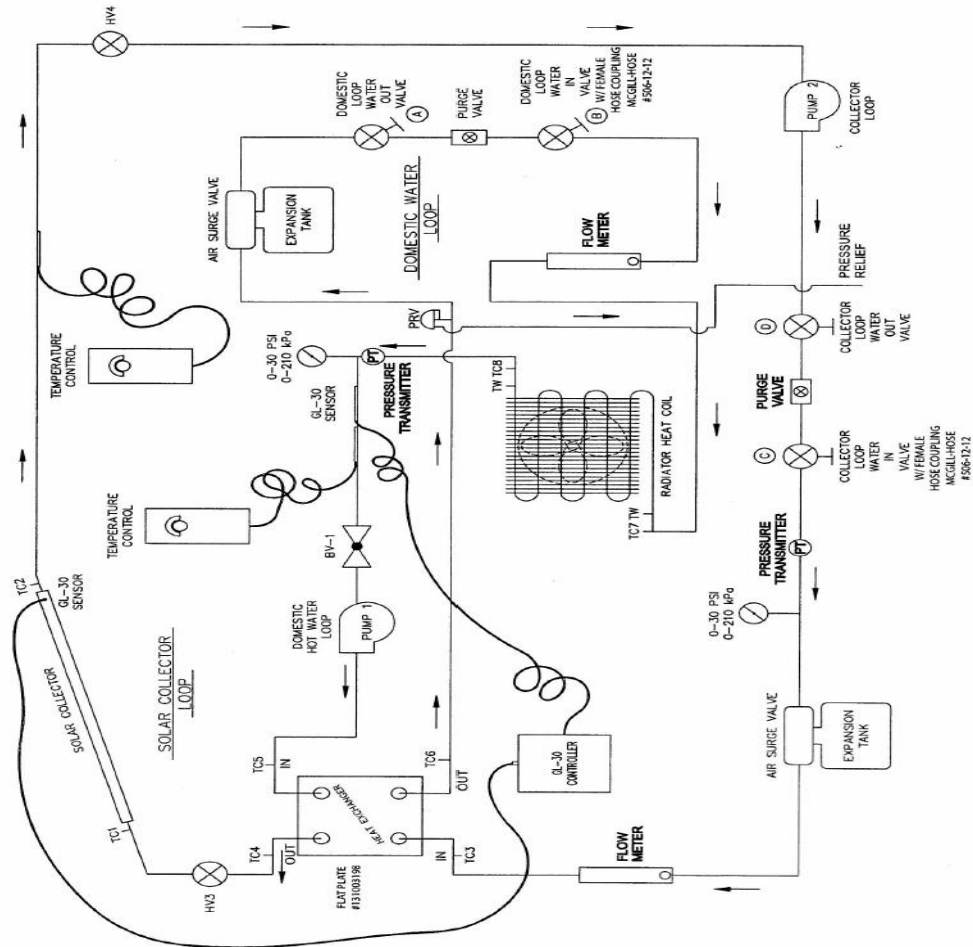


Figure 2. Hampden H-SST-1A Installation Diagram

c. Heat Transfer

Many things in this world happen because of the flow of heat. For example, when a room is filled with many people, the room will feel hot, during the dry season when the room in the house will feel hot or when we are close to the stove, our bodies feel hot. These incidents were all things people knew about. This means that everyone knows that there will always be a flow of heat from hotter objects to cooler objects.

But not everyone knows what the flow mechanism is like, what flows, how big the flow is and other things related to the flow. If we know all that then we can control the heat according to our wishes and can be used for human welfare. From the science of thermodynamics, we have learned that energy can be transferred by the interaction between the system and its environment. This interaction is called work and heat. But thermodynamics can only predict the end of the process, but does not provide any information about what the process is like or how long it will take to complete the process. In the science of heat transfer we can know that. Heat transfer can be defined as the transfer of energy as a result of a temperature difference in the direction of transfer from higher temperature to lower temperature.

d. Heat Transfer Mechanism

After we know the definition of heat transfer, the next question is "how does it (heat) move?".

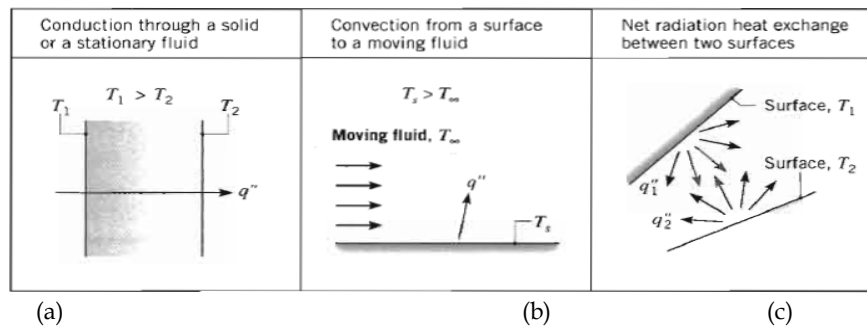


Figure 3. Heat Transfer Processes

As shown in Figure 3 [3;2], there are three heat transfer processes. These three processes have forms of heat transfer with different physical mechanisms. In Figure 1 part (a) it can be seen that heat transfer occurs due to temperature differences in a fixed medium, whether solid or liquid, which is known as Conduction.

Whereas in part (b) heat transfer occurs as a result of a temperature difference on a surface with the media in the form of a moving fluid and this process is known as convection.

And in part (c) is the heat transfer process in the form of thermal radiation (Thermal Radiation). In this process, it is seen that there is a process of transmitting energy by the surface in the form of electromagnetic waves. So that in this process it can occur without going through media or other conducting substances, heat transfer is carried out by radiation between 2 surfaces that have different temperatures.

1. Conduction

The conduction heat transfer process is a heat transfer process that involves the activity of atoms or molecules. Conduction can be viewed as a form of energy transfer from high energy to low energy as a result of interactions between particles.

As an illustration to describe the process of conduction heat transfer is heating from the end of a metal as can be seen in Figure 4 below.

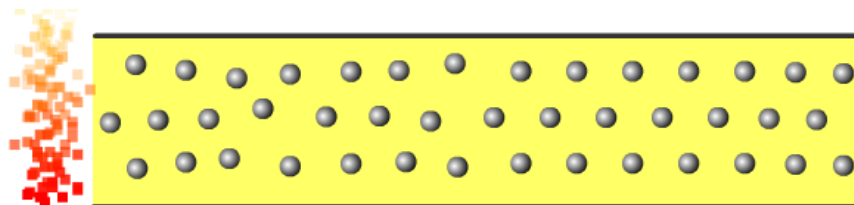


Figure 4. Illustration of Conduction Heat Transfer Process for Hot Metal Rod Ends

Metal is a material composed of atoms where each atom is surrounded by electrons and is free to move. When a metal rod is cold or at ambient temperature and there is no difference in temperature between the two ends and the middle, the atomic particles and those contained in the metal will have the same energy level. In these conditions there is no energy transfer between the particles, which means that there is also no heat transfer that occurs.

Then at one end of the metal rod, it's heated so that there is an increase in the energy of the particles at the heated end. As a result of this increase in energy, the particles will vibrate. The vibrating particles are initially the particles in the heated part. This vibration causes the next particle to vibrate, followed by the next and so on until it reaches the other end of the metal rod. As a result, there is an increase in energy starting from the heated end to the other end and if we hold it, all parts of the metal rod become hot. Such is the description of the physical mechanism that occurs from conduction heat transfer.

The total rate of heat transfer can be calculated by an equation. This equation calculates the amount of energy transferred per unit time. For heat of conduction, the rate equation is known as Fourier's Law. For a one-dimensional plane with a temperature distribution $T(x)$ as shown in Figure 5, the equation is [3;4]:

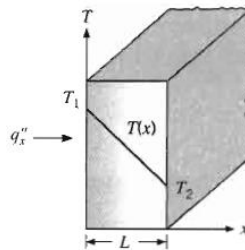


Figure 5. One-Dimensional Conduction Heat Transfer

$$q_x'' = -k \frac{dT}{dx}$$

The heat flux q_x'' (W/m²) is the rate of heat transfer in the x direction per unit area perpendicular to the direction of displacement. The heat flux is directly proportional to the temperature gradient dt/dx . Meanwhile, k is the thermal conductivity (W/m.K) and depends on The minus sign (-) indicates that the heat transfer occurs towards a lower temperature.

2. Convection

Convection is a type of heat transfer that occurs due to 2 types of mechanisms. The first is energy transfer due to random movement of molecules or also known as diffusion and the second is energy transfer caused by macrocosmic movement of fluids or commonly known as bulk. This fluid motion is related to the instantaneous movement of a large number of molecules together. In addition to this movement, convection heat transfer is also caused by temperature differences. Because these molecules move together in random motion, the amount of heat that can be transferred depends on the superposition of energy carried by the molecules as a result of the random motion as well as by the bulk motion of the fluid.

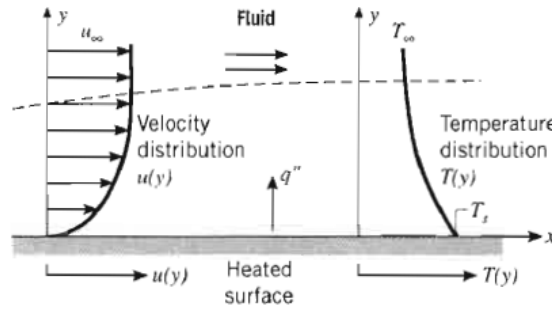


Figure 6. Boundary Layer on Convection Heat Transfer

Above depicts a fluid moving over a heated surface. This illustration is made to illustrate the convection heat transfer mechanism that occurs between a moving fluid and a surface where there is a temperature difference. As a result of the interaction between the fluid and the surface, an area will be formed in the fluid with a velocity variation from 0 on the surface to ∞ which is related to the flow. This area is called the hydrodynamic or velocity boundary layer. In addition, if there is a temperature difference between the fluid and the surface, a region will be formed in the fluid whose temperature varies, namely T_s at $y=0$ to T_∞ in the outermost flow. This area is called the thermal boundary layer.

Convection heat transfer itself can be classified based on the nature of the flow. The classification is:

- Free/natural convection heat transfer (Natural Convection)

This type of convection heat transfer is caused by buoyancy due to density differences due to temperature variations in the fluid.

- Forced convection heat transfer

Fluid flow in convection is caused by external sources such as fans, pumps or wind speed from outside. An example of forced convection is the cooling of a car radiator by a fan or wind due to the movement of the car.

For convection heat transfer (free/natural) the rate of heat transfer can be found using the equation[3;8]:

$$q'' = h(T_s - T_\infty)$$

Where q'' is the convection heat flux (W/m^2) directly proportional to the temperature difference between the surface and the fluid. This equation is known as Newton's Law of Cooling, and is directly proportional to the convection heat transfer coefficient, h ($W/m^2.K$) This coefficient depends on the boundary layer which includes the surface geometry, fluid motion and thermodynamic properties and fluid conductivity.

If the equation above is the convection heat flux, it is assumed to be positive if heat is transferred from the surface $T_s > T_\infty$ and negative if heat is transferred to the surface ($T_\infty > T_s$. When heat transfers to the surface, Newton's Law of Cooling becomes [3;9] :

$$q'' = h(T_\infty - T_s)$$

3. Radiation

Thermal radiation is the process of emitting energy by materials at temperatures above zero (0). Although we focus on radiation from solid surfaces, it does not mean that liquids and gases do not emit radiation. Regardless of the shape of the material, it is certain that emission affects changes in the configuration of electrons in the arrangement of atoms and molecules. Energy originating from radiation is transferred by electromagnetic waves so that radiation does not require a medium for transfer unlike conduction or convection. And in fact, energy transfer in radiation is much more effective in a vacuum.

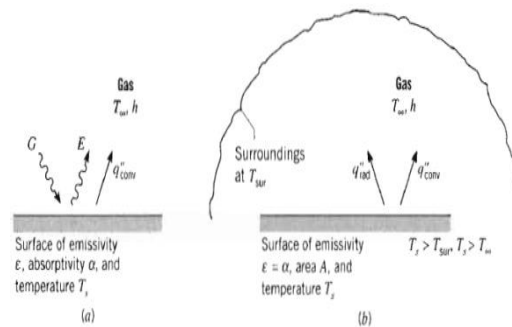


Figure 7. Radiation (a) On the Surface; (b) Between the Surface and the Surroundings

Figure 7 [3;8] is an image illustrating the process of transferring radiation from a surface. The radiation emitted by the surface comes from the energy of a material bounded by the surface and the rate of energy released per unit area is called the surface emissive power, denoted by E (W/m^2). The emission power can be found by using the Stefan-Boltzmann Law, namely [3;9]:

$$E_b = \sigma \cdot T_s^4$$

With T_s being the absolute temperature (K) of the surface and σ the Stefan Boltzmann constant which is $5.67 \times 10^{-8} W/m^2.K$. The surface is considered as the ideal radiator or blackbody.

The heat flux emitted by the surface is actually smaller than that of a perfect black surface (blackbody) at the same temperature and is expressed by equation [3:10]:

$$E_b = \epsilon \cdot \sigma \cdot T_s^4$$

The constant ϵ is also called the Emissivity which shows the emission properties of the surface. The value is in the range $0 \leq \epsilon \leq 1$, this value indicates the level of efficiency of the surface for emitting energy relative to the blackbody.

Radiation can also come from the surrounding surface as illustrated in the figure below [2;563]:

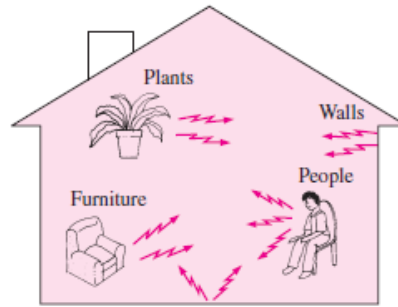


Figure 8. Illustration That the Surrounding Surface Can Emit Radiation

Radiation may also come from certain sources such as the sun or from other surfaces that are intentionally allowed to radiate energy to other surfaces. Regardless of the source, we call the overall rate of radiation over a given area as Irradiation. Part or all of the irradiation may be absorbed by the surface thereby increasing the heat energy or thermal energy of the material or materials.

The rate of radiation energy absorbed by per unit area can be found by using a surface radiation property called absorptivity (α) or by the following equation [3;9]:

$$G_{abs} = \alpha \cdot G$$

With $0 \leq \alpha \leq 1$. If $\alpha < 1$ and the surface is opaque, some irradiation will be reflected.

If the surface is semi-transparent, some irradiation may be continued. The occurrence of absorption (absorption) and emission (radiation) respectively causes an increase or decrease in heat energy or thermal energy of the material. Meanwhile, the light that is reflected (reflection) or transmitted (transmission) has no effect on this thermal energy. As a note, the value of α depends on the nature of the irradiation that hits the surface. For example, the α value of solar radiation will be different from the α value for radiation originating from the wall of a factory's kitchen/stove.

In most engineering problems (except for solar radiation or radiation from high-temperature sources), liquids may be considered as opaque surfaces and gases as materials that are considered to be transparent in radiation heat transfer. Meanwhile, solid materials can be considered opaque if they are metals or semi-transparent if they are thin sheets of polymers and some semiconductor materials.

In this special case, which often occurs, involves the exchange of radiation between a small surface on T_s and a larger surface, which is an isothermal surface surrounding the small surface. The surroundings for example could be the walls of a kitchen or furnace room where the temperature T_{sur} is different from the surface it surrounds ($T_{sur} \neq T_s$). In a later section, for some conditions, the irradiation can be approximated as emission from a blackbody at T_s , in this case $G = \sigma \cdot T_{sur}^4$. If the surface is assumed to be one for $\alpha = \epsilon$ (on a gray surface), the rate of radiant heat transfer from the surface per unit unit of surface becomes [3.9]:

$$q_{rad}'' = \frac{q}{A} = \varepsilon \cdot E_b(T_s) - \alpha \cdot G = \varepsilon \cdot \sigma(T_s^4 - T_{sur}^4)$$

e. Heat Exchanger

The transfer of energy in the form of heat between fluids is one of the most important and most widely used parts of engineering applications. Heat transfer is usually used in a device called a heat exchanger. Heat exchangers are commonly used in nuclear fields, boilers, cooling fans, heat exchangers for water coolers and condensers.

Heat exchangers are usually designed for 2 types of fluids that have different temperatures separated by a certain conducting medium. One of the fluids flows through the metal tube and the other fluid surrounds the tube. On both sides of the tube, heat is transferred by convection. While on the tube wall heat is transferred by conduction.

Heat exchangers are usually divided into several categories or classifications. The heat exchangers that are generally used or used are 2 types of fluids with different temperatures flowing in a room separated by a tube wall. Heat transfer occurs through convection and conduction through the walls. This type is called an ordinary heat exchanger compared to the other 2 types, which are classified as regenerators and cooling towers.

The heat exchanger usually consists of single phase or two phase. In a single phase heat exchanger, the two fluids change phase during the heat exchange process. The steam generator or main boiler and condenser of a nuclear facility is another example of a two-phase heat exchanger. Single phase heat exchangers are usually of the tube and shell type where the exchange occurs in a set of pipes in a container called the shell. The next picture will provide this illustration [5;33].

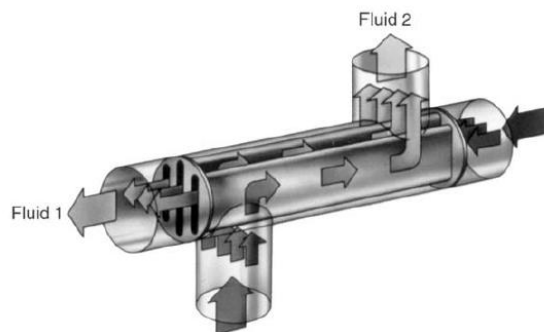


Figure 9. Tube And Shell Type Heat Exchanger

f. Design of Direct and Counter Flow Heat Exchangers

Although heat exchangers are usually different in design, construction and type, the working principle and effectiveness of the heat exchanger still depend on the direction of fluid flow during heat exchange. The heat exchanger, as discussed earlier, consists of unidirectional flow and counterflow. In a one-way flow heat exchanger, the two fluids flow in the same direction. Whereas in counterflow, the cooled fluid flows in the opposite direction to the cooling fluid. Figure 2.10 below shows the direction of flow in the heat exchanger both in one direction and in the opposite direction [4;668].

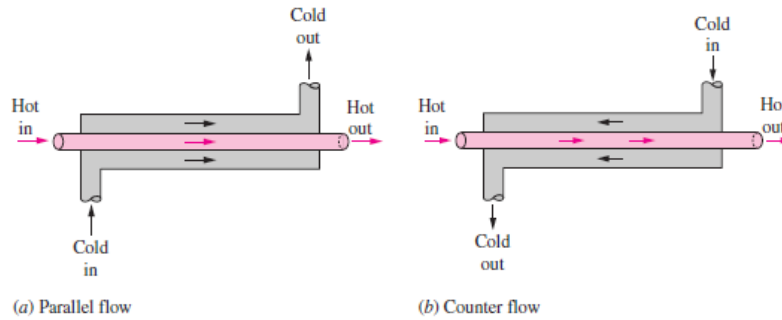


Figure 10. Flow Direction in Heat Exchanger

The heat transfer in the counterclockwise heat exchanger is greater than in the one-way heat exchanger. The temperature profiles of the 2 types of heat exchangers show that there are 2 major losses in unidirectional flow. First, a large temperature difference at the ends of the heat exchanger will result in thermal stresses in the materials. Expansion and contraction in construction materials as a result of differences or variations in fluid temperature will cause material failure. The second disadvantage is that the temperature of the cold fluid leaving the heat exchanger will never exceed the lowest temperature of the hot fluid. This will cause losses if the design of the heat exchanger is to increase the temperature of the cold fluid [4;668].

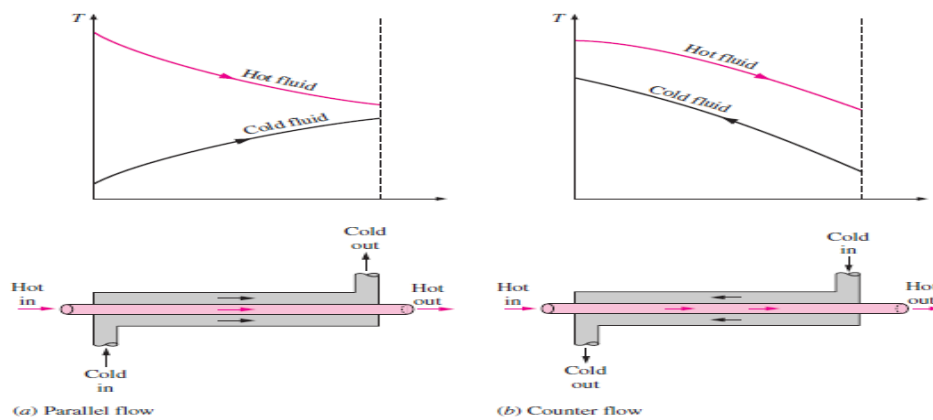


Figure 11. Profile Temperature on Heat Exchanger

In a counter flow heat exchanger there are 3 main advantages over a direct flow heat exchanger. First, a more uniform temperature between the two fluids minimizes heat stress occurring from the heat exchanger. Second, the exit temperature of the cold fluid can approach the highest temperature of the hot fluid (inlet temperature). Third, the more uniform the temperature difference, the more uniform the heat transfer rate will be in the heat exchanger.

Both unidirectional and counter flow heat exchangers, heat transfer in heat exchangers definitely involves 2 methods of heat transfer, namely convection and conduction. The hot fluid will experience convection heat transfer to the tube wall. From the tube wall, the heat transfer mechanism changes to conduction. After passing through the tube wall where the heat transfer mechanism is

conduction, it is continued with the convection heat transfer mechanism, namely from the wall to the cold fluid. Because this process takes place over the entire length of the heat exchanger, the temperature of the fluid involved is generally not constant but varies along the length of the heat exchanger as shown in the figure. The rate of heat transfer also varies along the tube heat exchanger as a result of temperature variations along the heat exchanger.

g. Application of Log Mean Temperature Difference in Heat Exchangers

It may be easier to solve the heat exchanger problem by analyzing the balance of the system as a whole or using integrals. The analysis is carried out by taking into account the overall energy balance from fluid entry to fluid discharge. In this study, this balance is analyzed to calculate the heat absorbed by the Ethylene Glycol fluid from entering the solar panel collector to leaving the solar panel collector. The total amount of heat absorbed by the fluid can be found by equation [4;680]:

$$q = \dot{m} \cdot c_p \cdot \Delta T$$

Where \dot{m} , c_p , ΔT are the mass flow rate, specific heat and temperature change of the heat absorbing fluid, respectively.

The heat flow rate that occurs in the heat exchanger can be found by equation [4;681]:

$$q = U \cdot A \cdot \Delta T_{lm}$$

To solve some problems in heat exchangers, the log mean temperature difference (LMTD or ΔT_{lm}) must be found to calculate heat transfer in the heat exchanger. To find LMTD or ΔT_{lm} can be searched by equation [4;681]:

$$\Delta T_{lm} = \frac{\Delta T_{in} - \Delta T_{out}}{\ln \left(\frac{\Delta T_1}{\Delta T_2} \right)}$$

With ΔT_{in} and ΔT_{out} is the difference in temperature at the inlet and outlet of the heat exchanger.

f. Overall Coefficient of Heat Transfer

When it comes to heat transfer in heat exchanger tubes, the overall heat transfer coefficient (U) must be calculated. The overall heat transfer coefficient value can be calculated by the equation [4;672]:

$$U = \frac{1}{\frac{1}{h_i} + \frac{\ln(D_o/D_i)}{2\pi kL} + \frac{1}{h_o}}$$

According to lit. 1 p. 672, if the wall of the heat exchanger pipe is thin and the heat conductivity value (k) of the pipe material is high then the value of $\frac{\ln(D_o/D_i)}{2\pi kL}$ can be ignored so that the overall heat transfer coefficient equation becomes [4;672]:

$$U = \frac{1}{\frac{1}{h_i} + \frac{1}{h_o}}$$

METHODOLOGY

A. Tools and Materials Used

The tool used for this research is the Hampden H-SST-1A Solar System Trainer [2]. Completeness of measuring tools owned by this test tool are:

a. Pressure gauge

Pressure measurement using a manometer. There are 2 pressure gauges, namely 1 (one) is used to measure the pressure in the circulation pump for Ethelyn Glycol and the other is used to measure the pressure in the water circulation pump.

b. Flow rate meter

There are 2 flow rate measuring instruments used, namely to measure the Ethelyn Glycol fluid flow rate and the water fluid flow rate. The measurement scale used is Cubic Centimeters per Minute or CCM.

c. Temperature Gauge

The temperature measuring device used is a type of thermocouple. The temperature scale used is Celsius (0C). The temperature measured there are 9 positions, namely at:

- Solar Collector Panel inlet or T_1 which serves to measure the incoming fluid from Ethelyn Glycol that enters the Solar Collector Panel
- Solar Collector Panel or T_2 outlet which functions to measure the fluid coming out of Ethelyn Glycol coming out of the Solar Collector Panel
- When entering the Heat Exchanger on the fluid side of Ethelyn Glycol or T_3 which serves to measure the temperature of the Ethelyn Glycol fluid that enters the Heat Exchanger
- When exiting the Heat Exchanger on the fluid side of Ethelyn Glycol or T_4 which serves to measure the temperature of the Ethelyn Glycol fluid leaving the Heat Exchanger after exchanging heat with water fluid
- When entering the Heat Exchanger on the fluid side of water or T_5 which serves to measure the temperature of the water fluid that enters the Heat Exchanger
- When exiting the Heat Exchanger on the fluid side of water or T_6 which functions to measure the temperature of the water fluid that comes out of the Heat Exchanger after absorbing heat from the Ethelyn Glycol fluid
- When entering the water heating coil or T_7 which functions to measure the temperature of the water fluid that enters the heating coil
- When the water heater coil comes out or T_8 which functions to measure the temperature of the water fluid that comes out of the heating coil
- Ambient temperature or T_9 which functions to measure the ambient temperature

Of all the equipment and measuring instruments contained in the Hampden H-SST-1A Solar System Trainer, it is actually divided into 2 loops, namely the Domestic Hot Water (DHW) Loop and the Collector Loop [2].

The material used for this research consists of 2 types of fluid, namely:

- Heating fluid, namely the type of Ethelyn Glycol which is usually used as a heat absorbing fluid or coolant for Solar Water Heaters or also commonly used in radiators. For this study, the coolant used was the TOP 1 brand with an ethylene glycol content of 20%.
- Water fluids

B. Research Equipment Schematic

The research installation of the Hampden H-SST-1A Solar System Trainer is shown in Figure 2

C. Research Variables and Stages

a. **Research variable**

The research was carried out by varying the flow rate of the heated fluid, in this case, water. While the flow rate of the Ethelyn Glycol fluid is fixed. The flow rate setting for each fluid is carried out at the faucet located on the fluid flow rate meter. The unit used in this study for the flow rate of both heating fluid and heated fluid is CCM or cubic centimeters per minute.

The variables of this study are:

a. The independent variable is the variable that causes the dependent variable to change. In this study, the independent variable is the collant fluid flow rate.

b. Dependent variable, is a variable that is influenced by the existence of independent variables. The dependent variable in this study is T_3 and T_4 .

c. Control Variables, are variables whose values are regulated so that the effect of the independent variables on the dependent variable can be known. The control variable in this study is the flow rate of the heating fluid, in this case Ethylin Glycol.

The combination of research variables is shown in table 1

Table 1. Combination of research variables

Sunlight Incident Angle	Temperature T_3 and T_4 ($^{\circ}\text{C}$)	Flow Rate	
		Heating Fluid (CCM)	Heated Fluids (CCM)
30°, 45°	Variative	1000, 1250	1000

Table 2. Hampden H-SST-1A Solar Water Heater experimental data

Solar water heater experimental data								
Day/Date	:							
Time Start	:							
Time End	:							
The Angle Of The Sun	:							
	Start	Data Collection Period						
		10	20	30	40	50	60	70
Loop Flow Rate (CCM)								
Collector Loop								
Domestic Heater Water (DHW)								
Temperature (°C)								
Collector In (T1)								
Collector Out (T2)								
Heat Exchanger Collector In (T3)								
Heat Exchanger Collector Out (T4)								
Heat Exchanger DHW In (T5)								
Heat Exchanger DHW Out (T6)								
DHW Heat Coil In (T7)								
DHW Heat Coil Out (T8)								
Ambient Temperature								

b. Research Stages

The goal to be achieved in this study is to determine the angle of incidence of sunlight and the optimal flow rate of the heating fluid (fluid coolant) to obtain maximum heat absorption in Solar Water Heaters and the research flow chart Figure 12 on the next page.

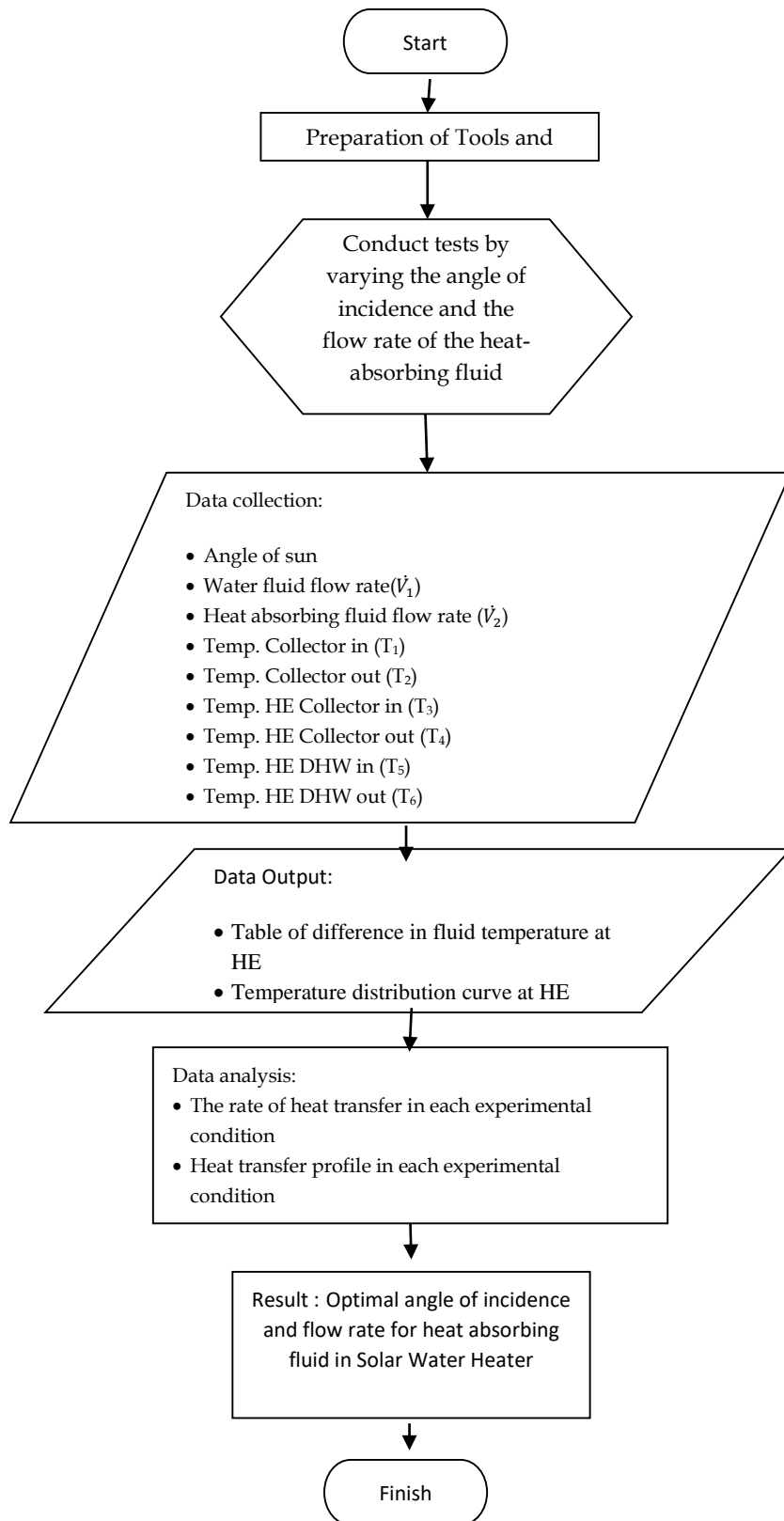


Figure. 12 Research flow chart

D. Data Analysis

Data analysis in this study is to use descriptive quantitative analysis techniques, namely techniques used to describe or convey research results in graphical form.

The data taken in this study is the flow rate on the DHW Loop and Solar Collector Loop. The flow rate in the DHW Loop will be fixed while in the Solar Collector Loop it will be varied. In addition to fluid flow rate data and temperature data at 9 points, in this study also variations in the angle of incidence of sunlight.

The research data will be presented in tables for temperature differences in HE and in graphical form for the temperature distribution in HE. The graphs obtained are then compared, so that the effect of heat absorption will be seen on changes in the angle of incidence of sunlight and changes in heat transfer due to the influence of changes in flow rate in the Solar Collector Loop.

RESULT AND DISCUSSION

A. Research Conditions

Research on the effect of regulating the flow rate of water fluid on heat transfer in Solar Water Heaters has been carried out at the Mechanical Engineering Laboratory, Department of Mechanical Engineering, Pontianak State Polytechnic.

This research was conducted using a Solar System Trainer brand Hampden H-SST-1A which has been equipped with several measuring devices, namely flow rate and temperature at 9 points. This tool has an angle-adjustable Solar Panel, and in this study experiments were carried out at an angle of 300 and 450. In this research, fluid flow regulation has been carried out where the heating fluid in the form of a mixture of Ethelyn Glycol or in the market known as coolant fluid is set at a speed of 1000 ccm and 1250 ccm. Meanwhile, the water fluid whose path is known as the Domestic Water Heater Loop is fixed at a flow rate of 1000 ccm.

In each experiment with variations in the flow rate of the heating fluid in different Solar Collector Loops and the flow rate in the DHW Loop was kept constant, the data were obtained as shown in table 2 the measurement results from the experiment are presented in Table 3 to Table 6 below:

Table 3. Table of experimental data for Solar Water Heater Hampden H-SST-1A with a flow rate of 1000 ccm Collector Loop at an angle of 450 and 1000 ccm DHW Loop

Solar water heater experimental data											
Day/Date	:Wednesday/29 December 2020										
Time Start	:08.15 WIB										
Time End	:12.45 WIB										
Angle Comes	:45°										
	Star t	30 min	60 min	90 min	120 min	150 min	180 min	210 min	240 min	270 min	
Loop Flow Rate (CCM)											
Solar Collector Loop	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Domestic Heater Water (DHW)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Temperature (°C)											
Collector In (T1)	27	29	30	30	29.7	28	29.4	29	29	29	29
Collector Out (T2)	33.3	34.5	37	38	44.2	50.2	60	62.2	65	62	62
Heat Exchanger Collector In (T3)	33	34.2	37	37.6	42.9	50.2	59.3	62	64	61.5	61.5
Heat Exchanger Collector Out (T4)	27.3	30	31	30.6	29.9	28.5	29.8	29.2	30.6	30.6	30.6
Heat Exchanger DHW In (T5)	29.6	30.2	30	29.5	29.2	29.4	29.8	29.6	29.6	29.6	29.8
Heat Exchanger DHW Out (T6)	33.0	32.7	33.8	34.2	37.9	44.4	50.5	51.6	52.6	49.9	49.9
DHW Heat Coil In (T7)	28.5	28.8	29	28.9	28.6	28.5	29.1	29	29	29	29
DHW Heat Coil Out (T8)	29.4	29.8	30	29.5	29.5	29.3	29.8	29.5	29.5	29.5	29.5
Ambient Temperature	30	31	30.8	31.2	30.4	30.5	31.1	31.5	30.5	31.1	31.1

Table 4. Table of experimental data for Solar Water Heater Hampden H-SST-1A with a flow rate of 1250 ccm Collector Loop at an angle of 450 and 1000 ccm DHW Loop

Solar water heater experimental data											
Day/Date	:Monday/4 January 2021										
Time Start	:08.15 WIB										
Time End	:12.45 WIB										
Angle Comes	:45°										
	Star t	30 min	60 min	90 min	120 min	150 min	180 min	210 min	240 min	270 min	
Loop Flow Rate (CCM)											
Collector Loop	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
Domestic Heater Water (DHW)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Temperature (°C)											
Collector In (T1)	28	29.2	31	30	29.8	28	28.9	29.3	29	29.3	29.3
Collector Out (T2)	34	33.3	38.2	46	49.6	60.4	62	68.2	72	72.7	72.7
Heat Exchanger Collector In (T3)	34	33	38.1	45.8	49.3	60.3	61.9	66.9	71.7	70.9	70.9
Heat Exchanger Collector Out (T4)	27.4	27.7	27	27.3	27	27.3	27	27.6	27.9	27.9	27
Heat Exchanger DHW In (T5)	27.2	27	27.2	27.5	27.6	27	26.6	27.4	27.7	27.4	27.4
Heat Exchanger DHW Out (T6)	32.2	31.0	35.4	41.0	44.4	52.2	52.8	56.9	60.7	60.3	60.3
DHW Heat Coil In (T7)	26	26.2	26	26.4	26.2	26.2	26	26.7	26.6	26.6	26.6
DHW Heat Coil Out (T8)	27.3	27	27.4	27.7	27.9	27.3	26.6	27.5	27.7	27.5	27.5
Ambient Temperature	28	28.5	28.3	29	31	30	29.4	30.2	30.5	31.1	31.1

Table 5. Table of experimental data for Solar Water Heater Hampden H-SST-1A with a flow rate of 1250 ccm Collector Loop at an angle of 300 and 1000 ccm DHW Loop

Solar water heater experimental data										
Day/Date	:Wednesday/6 January 2021									
Time Start	:08.15 WIB									
Time End	:12.45 WIB									
Angle Comes	:30°									
	Star t	30 min	60 min	90 min	120 min	150 min	180 min	210 min	240 min	270 min
Loop Flow Rate (CCM)										
Collector Loop	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
Domestic Heater Water (DHW)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Temperature (°C)										
Collector In (T1)	27.6	27.1	27.8	27.9	27.4	28	28.4	27.4	28.3	28.6
Collector Out (T2)	32	34	37.5	43	45.3	50	52.2	54	56.3	59.1
Heat Exchanger Collector In (T3)	31.8	33.4	37.1	42.8	44.7	49.6	52	53.4	55.9	58.9
Heat Exchanger Collector Out (T4)	27.4	27	27.6	27.7	27.3	27.8	28.2	27.3	28.1	28.4
Heat Exchanger DHW In (T5)	26.9	26.8	26.9	27.2	27.1	27.1	27.7	27.1	27.4	27.9
Heat Exchanger DHW Out (T6)	29.4	31.1	33.8	37.4	40.1	43.3	44.7	47.1	48.7	50.8
DHW Heat Coil In (T7)	26.1	26.4	26.5	26.4	26.7	26.7	26.9	26.7	27	27.1
DHW Heat Coil Out (T8)	26.5	26.6	27.1	26.8	26.9	27.3	27.3	26.9	27.6	27.5
Ambient Temperature	29.3	29.3	30.1	30.3	30	29.8	30.2	30.3	30.5	30.7

Table 6. Table of experimental data for Solar Water Heater Hampden H-SST-1A with a flow rate of 1000 ccm Collector Loop at an angle of 300 and 1000 ccm DHW Loop

Solar water heater experimental data										
Day/Date	:Tuesday/5 January 2021									
Time Start	:08.15 WIB									
Time End	:12.45 WIB									
Angle Comes	:30°									
	Star t	30 min	60 min	90 min	120 min	150 min	180 min	210 min	240 min	270 min
Loop Flow Rate (CCM)										
Solar Collector Loop	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Domestic Heater Water (DHW)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Temperature (°C)										
Collector In (T1)	28.1	29	29	29.3	29.6	28	28.9	29	28.8	29
Collector Out (T2)	31.2	33	33.8	40.2	49	50.3	52	52.3	54	57
Heat Exchanger Collector In (T3)	31	32.9	33.4	40	48.9	49.9	51.8	52.2	53.6	56.8
Heat Exchanger Collector Out (T4)	27.1	29.9	30.6	30.4	29.8	28.1	29.6	29.1	30.2	30.4
Heat Exchanger DHW In (T5)	26.4	28.3	28.4	27.3	28.1	28.8	28.7	28.3	29.2	28.8
Heat Exchanger DHW Out (T6)	28.7	30.1	30.3	33.5	40.5	43.4	42.9	42.1	45.3	45.2
DHW Heat Coil In (T7)	26.2	27.1	27	27.1	27.6	28.2	28.5	28	28.6	28.6
DHW Heat Coil Out (T8)	27.1	28.2	28	28.1	28	28.4	28.7	28.2	28.8	29
Ambient Temperature	29	29.3	29.2	29.7	30	29.3	29	29.6	30	30.6

B. Experimental Data Processing

From the experiments carried out, data was obtained and data processing was carried out as follows:

1. This temperature difference is the difference between the temperature of the heating fluid entering the Solar Collector Panel (T_1) and the temperature of the heating fluid leaving the Solar Collector Panel (T_2). There is a temperature difference between T_1 and T_2 because as long as it flows through the Solar Collector Panel the fluid in this case is Ethelyn Glycol with a content of 20% will absorb heat, resulting in an increase with an increase difference of:

$$\Delta T_{SCP} = T_2 - T_1$$

2. Difference in fluid temperature entering the Heat Exchanger on the Collector Loop side (ΔT_{HEC})

This is the temperature difference from the fluid on the Collector Loop side that enters the Heat Exchanger, namely the temperature entering HE (T_3) and the temperature leaving HE (T_4). The farther the difference means the more heat energy that can be transferred to the water fluid to be heated. The equation for this temperature difference is

$$\Delta T_{HEC} = T_3 - T_4$$

3. The difference in the temperature of the water fluid entering the Heat Exchanger on the Domestic Hot Water side (ΔT_{HEW})

This is the difference in temperature of the water fluid on the DHW side that enters the Heat Exchanger, namely the temperature entering HE (T_5) and the temperature leaving HE (T_6). The farther the difference means the more heat energy that can be absorbed by the water fluid. The equation for this temperature difference is

$$\Delta T_{HEW} = T_6 - T_5$$

4. Specific Heat (cp)

The specific heat sought here is the specific heat of 20% concentration of Ethylene Glycol used in this study. This specific heat is sought to find the amount of heat transported by the Ethylene Glycol fluid before entering the Heat Exchanger. The specific heat for Ethylene Glycol is 2.42 kJ/kg.0C.

5. Mass flow rate on the Collector Loop (m)

The mass flow rate sought is the mass flow rate of Ethylene Glycol on the Collector Loop side. This mass flow rate is used to find the heat carried by Ethylene Glycol entering the Heat Exchanger. The specific mass of Ethylene Glycol is 1,1 g/cm³.

6. Heat energy in the Collector Loop (q)

The heat energy sought here is the heat energy transported by the Ethylene Glycol fluid which will be transferred to the water fluid which takes place in the Heat Exchanger. This heat energy can be found by multiplying the mass flow rate (m) with cp and the difference in inlet and outlet temperatures at the Solar Panel Collector.

The following is a table of experimental data processing using the Hampden SST 1 Solar Water Heater Brand.

Table 7. Temperature difference in the Solar Collector Loop and DHW Loop

The Angle of Incidence of Sunlight	Experiment	Fluid Flow Rate on DHW Loop (ccm)	Fluid Flow Rate on DHW Loop (ccm)	Temp.Solar		Temperature Difference									
				Panel Collector (°C)	Temperatur Heat Exchanger (°C)	ΔT (C°)									
				T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	ΔT_{top}	ΔT_{out}	ΔT_{in-out}	(kJ/kg°C)	(kg/min)	kJ/min
45	1	1000	1000	27	33.3	33	27.3	29.6	33.0	6.3	5.7	3.42			
				29	34.5	34.2	30	30.2	32.7	5.5	4.2	2.52			
				30	37	37	31	30	33.8	7	6	3.78			
				30	38	37.6	30.6	29.5	34.2	8	7	4.69			
				29.7	44.2	42.9	29.9	29.2	37.9	14.5	13	8.71			
				28	50.2	50.2	28.5	29.4	44.4	22.2	21.7	15			
				29.4	60	59.3	29.8	29.8	50.5	30.6	29.5	20.7			
				29	62.2	62	29.2	29.6	51.6	33.2	32.8	22			
				29	65	64	30.6	29.6	52.6	36	33.4	23			
				29	62	61.5	30.6	29.8	49.9	33	30.9	20.1			
	28	34	34	27.4	27.2	32.1	6	6.6	4.9						
	29.2	33.3	33	27.7	27	30.9	4.1	5.3	3.9						
	31	38.2	38.1	27	27.2	35.4	7.2	11.1	8.2						
	30	46	45.8	27.3	27.5	41	16	18.5	13.5						
	29.8	49.6	49.3	27	27.6	44.4	19.8	22.3	16.8						
	28	60.4	60.3	27.3	27	52.2	32.4	33	25.2						
	28.9	62	61.9	27	26.6	52.8	33.1	34.9	26.2						
	29.3	68.2	66.9	27.6	27.4	56.9	38.9	39.3	29.5						
	29	72	71.7	27.9	27.7	60.7	43	43.8	33						
	29.3	72.7	70.9	27	27.4	60.3	43.4	43.9	32.9						
30	3	1000	1000	28.1	31.2	31	27.1	26.4	28.7	3.1	3.9	2.3			
				29	33	32.9	29.9	28.3	30.1	4	3	1.8			
				29	33.8	33.4	30.6	28.4	30.3	4.8	2.8	1.9			
				29.3	40.2	40	30.4	27.3	33.5	10.9	9.6	6.2			
				29.6	49	48.9	29.8	28.1	40.5	19.4	19.1	12.4			
				28	50.3	49.9	28.1	28.8	43.4	22.3	21.8	14.6			
				28.9	52	51.8	29.6	28.7	42.9	23.1	22.2	14.2			
				29	52.3	52.2	29.1	28.3	42.1	23.3	23.1	13.8			
				28.8	54	53.6	30.2	29.2	45.3	25.2	23.4	16.1			
				29	57	56.8	30.4	28.8	45.2	28	26.4	16.4			
	27.6	32	31.8	27.4	26.9	29.4	4.4	4.4	2.5						
	27.1	34	33.4	27	26.8	31.1	6.9	6.4	4.3						
	27.8	37.5	37.1	27.6	26.9	33.8	9.7	9.5	6.9						
	27.9	43	42.8	27.7	27.2	37.4	15.1	15.1	10.2						
	27.4	45.3	44.7	27.3	27.1	40.1	17.9	17.4	13						
	28	50	49.6	27.8	27.1	43.3	22	21.8	16.2						
	28.4	52.2	52	28.2	27.7	44.7	23.8	23.8	17						
	27.4	54	53.4	27.3	27.1	47.1	26.6	26.1	20						
	28.3	56.3	55.9	28.1	27.4	48.7	28	27.8	21.3						
	28.6	59.1	58.9	28.4	27.9	50.8	30.5	30.5	22.9						

Table 8. Calculation of Mass Flow Rate Calculation and Heat Energy Absorbed in the Solar Collector Loop

The Angle of Incidence of Sunlight	Experiment	Fluid Flow Rate on DHW Loop (ccm)	Fluid Flow Rate on DHW Loop (ccm)	Temp.Solar Panel Collector (°C)						Temperature Heat Exchanger (°C)			temperature difference ΔT (°C)	specific heat of ethylene glycol (c _p)	collector loop time flow rate(m)	heat energy in the collector loop (q)					
				T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	ΔT _{SCP}	ΔT _{coil}	ΔT _{HE Out}									
																	(kJ/kg.°C)	(kg/min)	kJ/min		
45	1	1000	1000	27	33.3	33	27.3	29.6	33.02	6.3	5.7	3.42	4.07	28.47	1.1100			28.47			
				29	34.5	34.2	30	30.2	32.72	5.5	4.2	2.52	4.08	24.88							
				30	37	37	31	30	33.78	7	6	3.78	4.08	31.72							
				30	38	37.6	30.6	29.5	34.19	8	7	4.69	4.09	36.28							
				29.7	44.2	42.9	29.9	29.2	37.91	14.5	13	8.71	4.10	66.06							
				28	50.2	50.2	28.5	29.4	44.37	22.2	21.7	14.973	4.12	101.58							
				29.4	60	59.3	29.8	29.8	50.45	30.6	29.5	20.65	4.15	141.02							
				29	62.2	62	29.2	29.6	51.58	33.2	32.8	21.976	4.16	153.25							
				29	65	64	30.6	29.6	52.65	36	33.4	23.046	4.17	166.51							
				29	62	61.5	30.6	29.8	49.89	33	30.9	20.085	4.16	152.30							
				28	34	34	27.4	27.2	32.1	6	6.6	4.9	4.07	33.91				1.3875			23.16
				29.2	33.3	33	27.7	27	30.9	4.1	5.3	3.9	4.07	40.82							
	31	38.2	38.1	27	27.2	35.4	7.2	11.1	8.2	4.09	91.23										
	30	46	45.8	27.3	27.5	41	16	18.5	13.5	4.11	113.20										
	29.8	49.6	49.3	27	27.6	44.4	19.8	22.3	16.8	4.12	186.70										
	28	60.4	60.3	27.3	27	52.2	32.4	33	25.2	4.15	190.95										
	28.9	62	61.9	27	26.6	52.8	33.1	34.9	26.2	4.16	225.42										
	29.3	68.2	66.9	27.6	27.4	56.9	38.9	39.3	29.5	4.18	249.86										
	29	72	71.7	27.9	27.7	60.7	43	43.8	33	4.19	252.32										
	29.3	72.7	70.9	27	27.4	60.3	43.4	43.9	32.9	4.19	13.99	1.1100			18.07						
	28.1	31.2	31	27.1	26.4	28.7	3.1	3.9	2.3	4.07	21.70										
	29	33	32.9	29.9	28.3	30.1	4	3	1.8	4.07	49.51										
	29	33.8	33.4	30.6	28.4	30.3	4.8	2.8	1.9	4.07	88.69										
	29.3	40.2	40	30.4	27.3	33.5	10.9	9.6	6.2	4.09	102.05										
29.6	49	48.9	29.8	28.1	40.5	19.4	19.1	12.4	4.12	105.84											
28	50.3	49.9	28.1	28.8	43.4	22.3	21.8	14.6	4.12	106.78											
28.9	52	51.8	29.6	28.7	42.9	23.1	22.2	14.2	4.13	115.63											
29	52.3	52.2	29.1	28.3	42.1	23.3	23.1	13.8	4.13	128.76											
28.8	54	53.6	30.2	29.2	45.3	25.2	23.4	16.1	4.13	24.83	1.3875						39.00				
29	57	56.8	30.4	28.8	45.2	28	26.4	16.4	4.14	54.97											
27.6	32	31.8	27.4	26.9	29.4	4.4	4.4	2.5	4.07	85.91											
27.1	34	33.4	27	26.8	31.1	6.9	6.4	4.3	4.07	102.02											
27.8	37.5	37.1	27.6	26.9	33.8	9.7	9.5	6.9	4.08	125.82											
27.9	43	42.8	27.7	27.2	37.4	15.1	15.1	10.2	4.10	136.33											
27.4	45.3	44.7	27.3	27.1	40.1	17.9	17.4	13	4.11	152.57											
28	50	49.6	27.8	27.1	43.3	22	21.8	16.2	4.12	160.87											
28.4	52.2	52	28.2	27.7	44.7	23.8	23.8	17	4.13	175.59											
27.4	54	53.4	27.3	27.1	47.1	26.6	26.1	20	4.13												
28.3	56.3	55.9	28.1	27.4	48.7	28	27.8	21.3	4.14												
28.6	59.1	58.9	28.4	27.9	50.8	30.5	30.5	22.9	4.15												

Table 9. Calculation of Heat Exchanger Efficiency in Solar Water Heaters

Angle of Incidence of Sunlight (...°)	experiment	fluid flow rate in the collector loop (ccm)	fluid flow rate in the DHW loop (ccm)	temperature difference at HE (°C)		collector loop mass flow time (m)	collector loop mass DHW loop (m)	specific heat of the coolant fluid	specific heat of water fluid	the heat absorbed by the collector loop	heat taken up by dwh loop	heat efficiency on HE	
				ΔT_{HEC}	ΔT_{HEW}								
45	1	1000	1000	5.7	3.42	1.11	1	2.42	4.18	15.31	14.30	93.39	
				4.2	2.52					11.28	10.54	93.39	
				6	3.78					16.12	15.80	98.06	
				7	4.69					18.80	19.61	104.28	
				13	8.71					34.92	36.42	104.28	
				21.7	15					58.29	62.60	107.40	
				29.5	20.7					79.24	86.34	108.95	
				32.8	22					88.11	91.88	104.28	
				33.4	23					89.72	96.36	107.40	
				30.9	20.1					83.00	83.98	101.17	
				6.6	4.9					22.16	20.49	92.45	
				5.3	3.9					17.80	16.31	91.63	
	11.1	8.2	37.27	34.28	91.99								
	18.5	13.5	62.12	56.44	90.86								
	22.3	16.8	74.88	70.24	93.81								
	33	25.2	110.81	105.36	95.09								
	34.9	26.2	117.19	109.54	93.48								
	39.3	29.5	131.96	123.34	93.47								
	43.8	33	147.07	137.97	93.81								
	43.9	32.9	147.41	137.55	93.32								
	30	3	1000	1000	3.9	2.3	1.1100	1	2.42	4.18	10.48	9.62	91.79
					3	1.8					8.06	7.53	93.39
					2.8	1.9					7.52	7.94	105.62
					9.6	6.2					25.79	25.92	100.52
19.1					12.4	51.31					51.84	101.05	
21.8					14.6	58.56					61.04	104.24	
22.2					14.2	59.63					59.37	99.56	
23.1					13.8	62.05					57.70	92.98	
23.4					16.1	62.86					67.31	107.09	
26.4					16.4	70.92					68.57	96.69	
4.4					2.5	14.77					10.45	70.75	
6.4					4.3	21.49					17.98	83.66	
9.5		6.9	31.90	28.85	90.44								
15.1		10.2	50.70	42.65	84.11								
17.4		13	58.42	54.35	93.03								
21.8		16.2	73.20	67.73	92.53								
23.8		17	79.91	71.08	88.94								
26.1		20	87.64	83.62	95.42								
27.8		21.3	93.35	89.06	95.40								
30.5		22.9	102.41	95.74	93.49								

C. Analysis of the difference in temperature rise at the inlet (T_1) and exit (T_2) of the solar collector

Good heat absorption from the heat-absorbing fluid in the solar collector can be seen from the increase in inlet and outlet temperatures. If the temperature rise is high, resulting in a large temperature difference between the inlet and outlet sides, it means that the level of heat absorption is good.

This analysis was actually carried out to see the effect of setting the angle of incidence and flow rate on the optimal level of heat absorption. The following shows a graph of the temperature difference at the inlet and outlet of the Solar Collector.

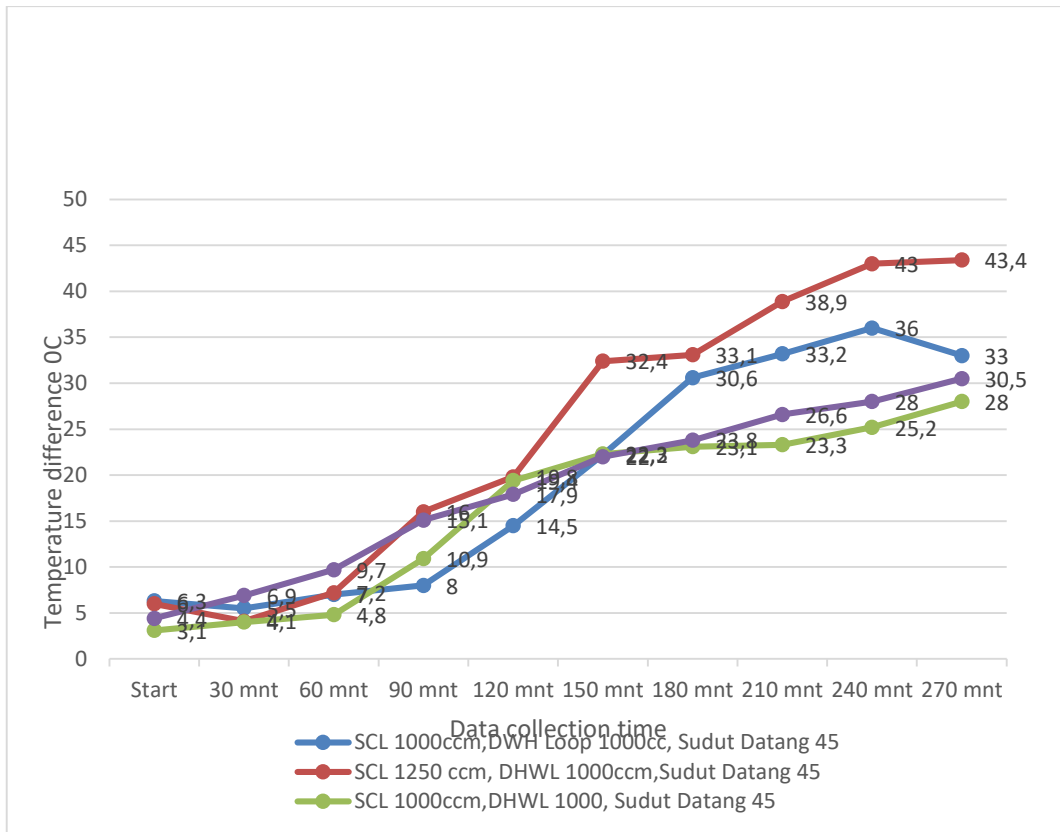


Figure 13. Temperature Difference in the Solar Collector at each Flow Rate and Incident Angle

From figure 13 above, it appears that for experiments using an angle of incidence of 45° , it shows a higher upward trend compared to an angle of incidence of 30° . For the same angle of incidence, namely 45° , a greater coolant flow rate indicates a greater ability to absorb heat. so that it can be said that the flow rate of 1250 cm for an angle of incidence of 45° is better at absorbing heat energy than other flow rates.

Meanwhile, if you look at the fluid flow rate, for both 45° and 30° angles, a higher flow rate indicates a higher absorption of heat transfer.

D. Analysis of Absorption of Heat Energy in Solar Collector Panels

Below is a figure showing the level of absorption of heat energy in the Solar Collector Panel which can be used as a basis for analysis to determine the effectiveness of heat absorption for each incident angle and flow rate.

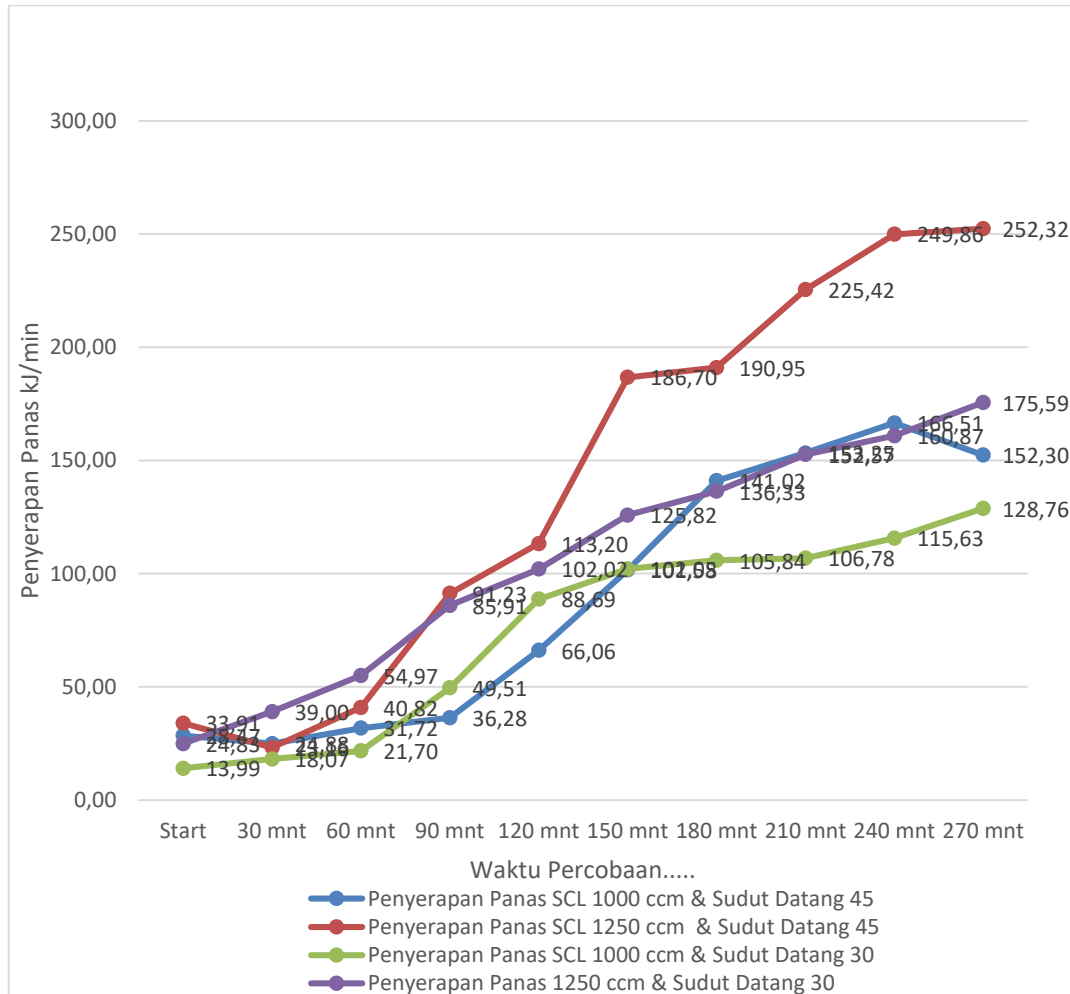


Figure 14. Absorption of Heat Energy in Solar Collector Panels

From figure 14 above, it appears that the highest heat absorption value is at an angle of incidence of 45° and the flow rate of the collant fluid in the Solar Collector Loop is 1250 ccm. Even heat absorption can reach 252.32 kJ/min.

E. Effectiveness Analysis of Heat Transfer Rates in Heat Exchangers

In a heat exchanger, apart from the type, the direction of flow, the flow rate also greatly influences the rate of heat transfer. In this study, the type and direction of flow were not the object of research and were considered to be in accordance with the tools used to carry out the experiment. The type of heat exchanger used in this experiment is a plate type with a unidirectional flow type. In this experiment, what is done to see the effectiveness of the heat transfer rate is the flow rate. And the flow rate that is changed is the coolant fluid flow rate on the Solar Collector Loop side, while on the Domestic Heater Water Loop side the amount or flow rate is conditioned to be constant.

The following is a graph showing the heat transfer efficiency that occurs in the Plate Heat Exchanger in the Solar Water Heater by changing the flow rate in the Solar Collector Loop. As we know, the efficiency of a heat exchanger can be seen from the amount of heat absorbed by the fluid being heated compared to the amount of heat released by the fluid providing the heat. The results of

calculating the efficiency of the Heat Exchanger on the Solar Water Heater have been shown previously in tabular form, namely table 9.

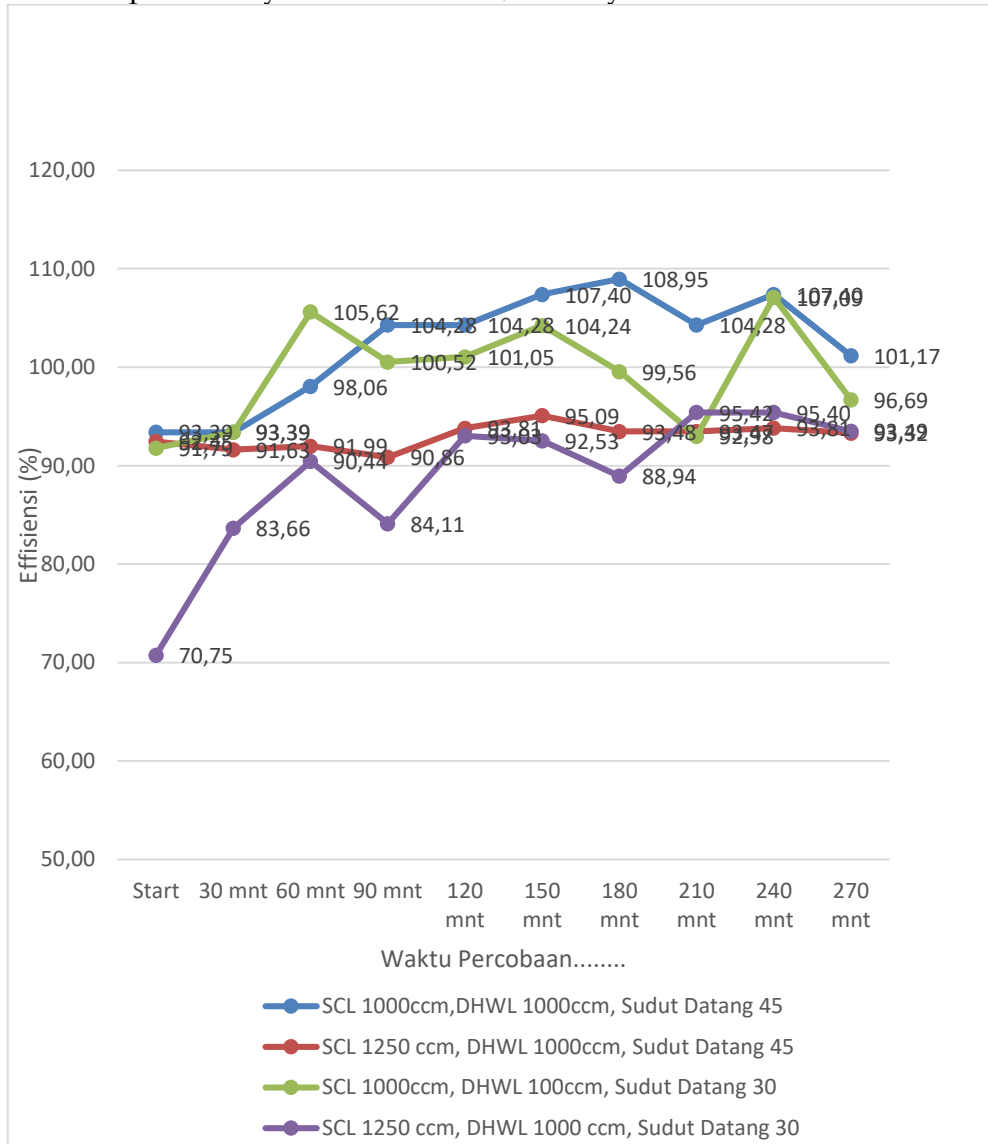


Figure 15. Heat Exchanger Efficiency in Solar Water Heater

From the heat transfer efficiency graph, it can be seen that the high level of efficiency even has a low flow rate of 1000 ccm but is not stable. Whereas at a flow rate of 1250 ccm the efficiency level is more stable and the figure is close to 100% efficiency.

From figure 13 and graph 14, in terms of the magnitude of the temperature difference and the magnitude of the heat absorption capability on the Solar Collector Loop side, it can be said that setting the angle of incidence of sunlight at an angle of 45° with a flow rate of 1250 ccm for the coolant fluid is very well done for Solar Water Heaters in the area Pontianak City. Meanwhile, if you look at the efficiency of the Heat Exchanger for a 1250 ccm flow, the coolant is also very good because the value is close to 100% and the efficiency value is stable.

CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

Based on the results of the analysis and discussion carried out in the research in writing this thesis to regulate the Coolant fluid flow rate, namely the Solar Collector Loop side of the Solar Water Heater, several conclusions can be drawn as follows:

1. The effective angle of incidence for the Solar Collector Panel to absorb heat energy from the sun for the Pontianak City area is 45).
2. Coolant fluid flow rate of 1250 ccm for the Solar Collector Loop on the Solar Water Heater has a large difference in temperature and absorption of heat energy for the Solar Collector Loop.
3. Coolant fluid flow rate of 1250 ccm for the Solar Collector Loop and for the Domestic Heater Water Loop side of 1000 ccm, provides a very stable efficiency value and a value close to 100%.

B. Recommendations

Research in this thesis can be carried out in different areas both geographically and climatically considering that the West Kalimantan region for several cities and regencies has very different geographical conditions.

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