The experimental performance of the semi-cylindrical type of solar concentrator collector on the addition of heat storage material

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Abstract. The heat absorbability and the efficiency of water heaters are increased by adding phase change material as heat storage in solar water heaters known as cylindrical through collectors type. It used to absorb heat from solar energy and will concentrate towards an absorber pipe containing water, so it can increase the water temperature that flows through the tube. In this study, two absorber copper pipes used with Ø 2.54 and Ø 1.91 cm, respectively. The copper pipes arranged parallel and placed the heat storage materials with different conditions. A drum with a diameter of 55.5 cm and a length of 10 cm is split vertically into two parts which will be used as a cylindrical type of solar collector — the solar intensity measured during the experiment. Results show the highest water out temperature is 65 °C at 13:00 WIB that the position of paraffin inside pipe 2 with a solar intensity is 1195 W/m² and the efficiency is 13.5%. The water inside of pipe 2 found the water out temperature is 62 °C and the efficiency is 12.31%. The position of air inside of pipe 2 recorded the water out temperature is 60 °C, and the efficiency is 10.21%. It can be concluded that the effect of adding paraffin inside of pipe 2 is better than water and air.

1. Introduction

Solar energy is alternative energy that can be used to replace fossil fuels that will run out over the time. Solar energy is potential energy to manage and further develop as an alternative energy source, especially for countries that located on the equator such as Indonesia, where the sun shines all the year. Water heaters consume almost 20% of total energy consumption for daily human needs [1]. When the sun's light radiated the absorber on the solar collector, some of the light will be reflected the environment, while most of light absorbed and converted to heat energy, then the heat transferred to the fluid circulating in the solar collector for various next applications [2]. Potential of solar intensity for water heater applications has been observed for Inland Norway housing. Observations for water heater household needs, it supplied about 62%, save around 182GWh of electrical energy, reduced 15,690 tons of oil energy and CO₂ emissions with tabular collectors is 48.6 kt [3]. Nano-fluid that essentially a dispersion of liquid colloid-nanoparticles for working fluids has been widely applied to water heaters, room heating, and cooling. Thermal efficiency using nano-fluid with flat plate solar collectors reaches up to 30 percent [4]. Solar water heater system has been analyzed in detail by inducing supercritical CO₂ natural convective flow as working fluid, performance parameters such as
heat recovery efficiency, effective energy efficiency ratio, effective energy efficiency, highest water temperature, and the amount of hot water supplied. The highest heat efficiency reaches 90.4%, and it is higher than other conventional solar water heating systems, and the highest temperature reaches 78 °C during summer [5]. The highest solar intensity at 13:00 WIB was measured in Aceh-Indonesia after the tsunami [6-7].

The performance of solar water systems with 4 m² stainless steel flat plate collectors in Dublin, Ireland has been studied. The result shows the maximum collector temperature of 70.4 °C, the average daily energy collected is 19.6 MJ/day, and the pipe loses about 3.2 MJ/d, the collector efficiency is 45.6% and the system efficiency around 37.8 % [8-9]. The shot peening process can improve the properties of stainless steel [10]. Performance of solar water systems with heat pipe tube collectors evacuated has been analyzed in Dublin, Ireland [11]. Optimization of an integrated solar collector geometry with a truncated compound parabolic concentrator (CPC) reflector with three independent parameters particularly height, tilt axis, and absorbent tank length has been modeled [12]. Tube solar water heaters that evacuated with two types of collectors particularly water-in-glass and heat-pipes have been observed in Hong Kong. The energy acquisition performance results of the heat-pipe collector design were found to be slightly better rather than glass water collectors [13]. The flat plate collector plate has investigated the heat transfer process with the model built in Te'touan (Morocco) to support the decision in the optimal definition of water flow and optimal flat collector area [14]. Solar collector photovoltaic Thermal-PV (T-PV) with double-glazed has been designed, built and tested [15] and a turbine ventilator application [16]. The aim of this experiment is performance tested of the semi-cylindrical type of solar concentrator collector by adding heat storage material with different conditions.

2. Experiment Method
Performance testing of a half-cylindrical concentrator collector was observed. Paraffin wax is a mixture of hydrocarbons fulfilled with high molecular mass, produced during refining from oil/petroleum. It has most commercial value with C_{25}H_{52} octane and better to use as material for storing heat [17]. So that in this study paraffin has been used as a heat storage material applied in the water heater system. Paraffin wax is a solid object and when the heated, the form changes to the liquid. The change in form is called melting, the melt temperature about 40-50 °C and when cooled the liquid wax turns into a solid shape. Two copper pipe with Ø 2.54 cm (1 inch) and Ø 1.91 cm (3/4 inch) is an absorber tube with both lengths is 190 cm. The drum with 55.5 cm diameter is split vertically into two parts then the end of those drums welded to obtain 170 cm of length, it is used for cylindrical collector frame. The stainless steel plate used as a reflector with thick, wide and length are 0.06, 170, 85 cm, respectively. Black Styrofoam sheets use as a heat-retardant insulator that is 0.9 cm thick. A measuring glass to measure water coming out, thermometers to measure water and air temperature, a K-type thermocouple to observe plate temperature, solar power meter to measure solar intensity during experiments. The assistive equipment used were a reservoir, ball valves, PVC pipe, plastic pipe, solar tracking device, outcomes water tank, reservoir support frame, collector support frame (Figure 1).

Two cylindrical collectors with the same surface area developed to place copper pipe with different conditions on two testing stages as shown in Figure 2. The first condition called collector A, it is two copper pipes arranged in parallel, pipe 2 (the smallest diameter is 1.91 cm) inserted into pipe 1 (the largest diameter is 2.54 cm). Paraffin is placed in pipe 2 while water flows in the pipe (between pipe 1 and pipe 2). The second condition is collector B, where pipe 2 only contains air while water flows through tube 1. This experiment conducted to investigate the ability of paraffin wax to store and release heat. The first stage test is collector A (paraffin in pipe 2), and collector B (air in pipe 2). In the second test is collector A (paraffin in pipe 2), and collector B (water in pipe 2).
Figure 1. Water heater system scheme.

Figure 2. The configuration of the double absorber pipe arrangement with paraffin, air and water filling.

Figure 3. The position of temperature collected.
The position of temperature measurement on the solar collector apparatus can be seen in Figure 3. Temperature collected at the outer of the pipe surface outside the collector (water in) were TA1 and TB1. The temperature collected at the outer of the pipe surface inside the collector are TA2, TB2, TA3, TB3, TA4, and TB4. The temperature collected at the outer of the pipe surface outside the collector (water comes out) are TA5 and TB5. TPA is the position of temperature measure at plate collector. Room collectors measured at TRA and TRB. The point of water in temperature is Tf1, while the temperature of the water coming out are Tfa, Tfb.

The number of useful heat can determine by Equation 1.

\[ Q_u = m \cdot C_p \cdot (T_o - T_i) \]

where:

- \( Q_u \) = useful heat (Watt)
- \( m \) = mass flow rate (kg/s)
- \( C_p \) = heat capacity based on fluid type (J/kg oC)
- \( T_o \) = water out temperature (oC)
- \( T_i \) = water in temperature (oC)

The efficiency of the collector is the comparison of heat absorbed by the fluid, and the intensity of the sun which affects to the collector, the collector's performance can be determined by Equation 2.

\[ \eta = \frac{Q_u}{A \cdot I_T} \]

where:

- \( \eta \) = the efficiency of the collector
- \( Q_u \) = useful heat (Watt)
- \( A \) = collector area (m²)
- \( I_T \) = solar intensity (W/m²)

3. Results and Discussion

Concentrator collector types cylindrical trough collectors by comparing the absorber pipe between paraffin, air, and water in pipe 2 have been observed (Figure 4). The velocity of the flow rate at each collector is kept constant at 100 ml/ minute.

Figure 5 shows the temperature and solar intensity distribution in paraffin in pipe 2, water in pipe 2, and air in pipe 2 during experimental. The intensity of the sun strongly influences the increase and decrease in the temperature of the water out during data collection. It causes of the heat storage material placed in pipe 2, so if the solar's intensity decreases then the temperature of water out does not decrease significantly because of inside pipe 2 there has a heat storage material. At 13:00 WIB (western Indonesia time) the temperature of water out (paraffin in the pipe 2) reach 65 °C, while the temperature of the water inside pipe 2 achieve 62 °C and the air temperature in pipe 2 is 60 °C.

Figure 6 shows that the value of the useful energy obtained can be affecting to increase of the temperature of the water out, where the higher temperature of the water out then influence to increase the useful energy. The highest useful energy occurs in Collector A with paraffin inside pipe 2 at 13.00 WIB is 237.91 Watts, while the useful energy at water inside pipe 2 is 216.92 Watts and water inside pipe 2 is 167.94 Watts.
Figure 4. Placement of paraffin, air and water position in the absorber pipe.

Figure 5. Distribution of water out temperature, which occurs in pipe 2.
Figure 6. The distribution of useful energy against times on the half-cylindrical type of concentrator collector.

Figure 7. Efficiency distribution at a semi-cylindrical type of concentrator collector.

Figure 7 can be seen that the value of efficiency also influenced by the amount of useful energy that produced, where the greater useful energy can improve the heat efficiency. The highest heat efficiency obtained on paraffin placed inside of pipe 2 at 13:00 WIB with the efficiency about 13.5%, while water inside pipes 2 the efficiency is 12.31, and air inside pipes 2 is recorded with 10.21%.

4. Conclusions
The experimental results on the concentrator collector type of Cylindrical Trough Collectors, it can be concluded that:
1. The highest temperature of water out found with three conditions of heat storage: first, paraffin inside pipe 2 at 13:00 WIB with water out temperature is 65 °C; second, the water inside pipe 2 obtained 62 °C of water out temperature, and the air inside pipe 2 found 60 °C of water out temperature.
2. The useful energy obtained, temperature differences strongly influence it. The greater the
temperature difference will increase the energy produced, at the paraffin collector inside pipe 2 at
13:00 WIB then energy useful is 237.91 Watts, the water inside pipe 2 found 216.92 Watts of
useful energy and while the air inside pipe 2 is 167.94 Watts of energy.

3. Paraffin position inside pipe 2 at 13:00 WIB reach the highest efficiency (13.50%), the
water inside pipe 2 is 12.61% efficiency, while the air inside the pipe 2 is 10.21% efficiency. It can
be seen from the three experimental tests that paraffin shows the highest efficiency because paraffin
has better to absorb and store heat rather than water and air.

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