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Effect of TiO_2/Al_2O_3 Hybrid Nanofluid and Irradiation Time on Solar Photovoltaic Thermal Performance

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Abstract. Photovoltaic thermal (PVT) is a technology capable of converting solar energy into energy in the form of electricity and thermal (heat). Absorption of solar thermal energy can cause PVT to experience a high temperature increase which affects the efficiency of electricity that can be generated by PVT. Nanofluid is a fluid with high thermal conductivity that can be used as a coolant to absorb the high temperature generated by PVT and recover some of the energy lost as heat to increase the efficiency of PVT. The combination of two nanoparticles as a hybrid nanofluid was produced by mixing 1000 ml distilled water with TiO_2/Al_2O_3 hybrid nanoparticles (80:20) of 0.1% with irradiation time for 60 minutes using light intensity of 1200 W/m2. The results showed that TiO_2 nanofluid had the best thermal and electrical efficiency compared to hybrid nanofluid, Al_2O_3 nanofluid, and distilled water. Thermal efficiency decreased due to the long irradiation time with constant intensity causing ineffective cooling over time, while electrical efficiency increased due to heat reduction on the PVT surface, but after 15 minutes there was a decrease in electrical efficiency caused by the PVT surface overheating.

1 Introduction

Energy is one of the most important needs for human life in various aspects of life. The increase in energy consumption is directly proportional to population growth and economic growth [1]. Fossil fuels have become the main source of energy for the global economy. Non-renewable fossil energy even causes several problems for the environment such as air pollution in the form of carbon dioxide (CO_2) emissions of more than 10 gigatons, causing climate change [2]. The sun can be a promising alternative energy source for the future because it is an environmentally friendly energy that does not cause pollution and availability that will not run out [3]. Utilization of solar energy using the application of the latest technology can convert solar thermal energy into energy in the form of electricity and thermal [4]. Indonesia has the potential to utilize solar energy which is very abundant, reaching 112,999 GWp, but has only been utilized by 71 MW [5]. Solar energy that is converted into electrical energy using photovoltaic technology can be used to meet electricity and communication needs, while the utilization of solar energy into thermal energy using thermal technology is used to provide warm water. The device that connects the two uses is called photovoltaic thermal (PVT) [4]. The decrease in photovoltaic efficiency caused by higher temperatures is one of the problems with the use of PVT. The use of coolers can be a solution to absorb temperature so as to increase photovoltaic efficiency and recover some of the energy lost as heat [6][7]. The utilization of cold water as the easiest form of energy conversion is done by radiative cooling, for example, as a fluid that carries thermal energy and converts it into an electromagnetic form that can be reused or thrown to the ceiling by working fluid that flows through the fluid wall heat transfer between surfaces that continuously emit radiation [8]. Nanofluids have high thermal conductivity compared to the base fluid. There are TiO_2 nanofluids with excellent absorption of solar radiation [9], as well as Al_2O_3 nanofluids that have heat resistance reaching 1700°C and are suitable for use as insulators because they have low electrical thermal conductivity [10]. This research aims to obtain alternatives to increase the efficiency of thermal photovoltaic by using cooling fluids through experimental methods.

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1.1 Nanofluid

Nanofluid is an innovative combination of the base fluid with nanoparticles measuring 1-100 nanometers (nm) which are suspended together due to certain treatments. There are several types of nanofluids, such as Al_2O_3, ZrO_2, SiO_2, and TiO_2 which are oxide types, Ag and Cu which are metal nanofluids and Teflon which are polymer nanofluids. Nano particles are generally made of chemically stable metals. The very small size makes nanofluids have the advantage of high heat transfer capability and does not cause corrosion so that nanofluids are widely used as a cooling medium [11]. The interesting thing about the characteristics of nanofluids is the comparison of thermal conductivity which is very different from the base fluid, nanofluids have a much higher thermal conductivity even though the number of nanoparticles dispersed into them is very relative [12].

1.1.1 Aluminum Oxide (Al_2O_3)

Aluminum oxide (Al_2O_3 or alumina) is an affordable structural engineering material that is widely applied as a ceramic material based on the local mineral bauxite. Alumina is a high-performance ceramic material that can be produced cost-effectively, resulting in good alumina grades. Alumina is widely applied in industries such as electronics, metallurgy, and ceramic composites. The use of alumina in engineering is spread in various fields such as sacrificial anodes, coatings, synthesis, and matrix composites because alumina has characteristics such as corrosion-free, can withstand acids and bases, resistance to high temperatures and high levels of hardness [13]. The temperature of alumina resistance to high temperatures can reach 1700°C [14].

1.1.2 Titanium Dioxide (TiO_2)

Titanium dioxide (TiO_2 or titania) is a semiconductor material that does not exist in nature naturally. Titanium dioxide has a molecule weighing 79.90 g/mol with a density of 4.26 g/cm^{-3} which is able to absorb UV radiation so as to cause hydroxyl radicals in pigments as photocatalysts. Titanium dioxide is also a good semiconductor material when viewed from optical properties with a wide energy band gap value of 3.2 Ev which is active when exposed to ultraviolet light [15]. The inability to absorb visible light or light with long waves is a shortcoming of titanium dioxide when viewed in the potential application of visible light photocatalysts and electrochemical devices as well as sensors and photovoltaics [16][17]. Titanium dioxide produces high stability when dispersed in base fluids even without surfactants, chemically titanium dioxide also has good stability compared to other pure metal particles [18].

1.1.3 Hybrid Nanofluid

Hybrid nanofluids are fluids with 2 or more nanoparticles added to the base fluid or hybrid base fluid. Hybrid nanofluids are able to generate specific heat with a higher capacity than conventional or ordinary nanofluids. The specific heat capacity of a fluid indicates the ability of a fluid to absorb heat, thus affecting the heat transfer performance of the heat exchanger. Thermal conductivity and fluid parameters in conducting heat are influenced by several factors, namely particle size, type of particles used, stability, type of base fluid, and fluid temperature resistance [19][20].

2 Materials and Methods

2.1 Experimental Configuration and Methods of the PVT System

Experiments were conducted with thermal photovoltaic testing to determine and analyze the efficiency performance that can be generated in the presence of nanofluid cooling media. The thermal photovoltaic used is monocrystalline type. The shape of the thermal photovoltaic working tool for this test is shown in Figure 1. The specifications of the solar panels used can be seen in Table 1. The tilt of the PVT during testing is 0°.

Fig. 1. Photovoltaic thermal equipment.

Table 1. Solar panel specifications.

Specifications	**Description**
Brand	Maysun Solar
Model	MS50M-18
Voltage Max	18 V
Current Max	5,5 A
Dimmensions	760 × 680 × 30 mm
Power	100 W

Photovoltaic thermal is equipped with a copper tube and plate as shown in Figure 2, which is placed on the back of the PV as a means to drain the cooling fluid which aims to absorb the heat contained in the photovoltaic thermal. The plate has a thickness of 1 mm with dimensions of 760 mm × 680 mm.

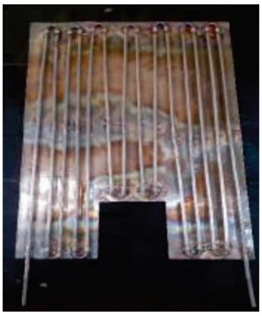


Fig. 2. Copper Tube and Plate.

This study uses halogen lamps as a substitute for sunlight. Tests were carried out with variations in cooling fluid and time. The test data is obtained from thermocouple sensor for fluid heat and flow meter sensor for fluid flow rate. The PVT testing scheme is shown in Figure 3.

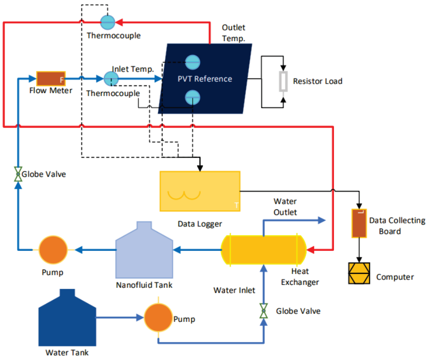


Fig. 3. Schematic diagram of PVT.

2.2 Nanofluid Preparation

TiO_2 and Al_2O_3 nanoparticles with TiO_2 mass fraction of 0.08 gram and Al_2O_3 of 0.02 gram mixed with 1000 ml of base fluid in the form of distilled water were processed using a magnetic stirrer for 60 minutes. The stirring process is carried out with a rotating speed of 650 rpm, then the fluid solution is carried out an ultrasonic process for 30 minutes per 500 ml to obtain a homogeneous solution. Solutions that have been subjected to magnetic stirrer and ultrasonic dispersion processes can be applied in testing photovoltaic thermal devices.

2.3 Test Procedure

This research method is an experimental method carried out in several stages. First, TiO_2/Al_2O_3 nanoparticles will be characterized by SEM, XRD, and FTIR. Furthermore, material preparation will be carried out consisting of TiO_2 with a mass of 0.1%, Al_2O_3 with a mass of 0.1%, and TiO_2/Al_2O_3 nanofluid hybrid with a mass ratio of 0.08%/0.02%. The material preparation process is carried out by mixing nanoparticles with a base fluid in the form of distilled water using a magnetic stirrer followed by an ultrasonic dispersion process to obtain a homogeneous solution. Nanofluids that have been dispersed will be tested for thermophysical properties in the form of density, viscosity, thermal conductivity, and specific heat. Then the nanofluid is tested on PVT with a comparison of cooling media testing, namely distilled water, distilled water nanofluid + TiO_2 0.1%, distilled water + Al_2O_3 0.1%, and distilled water + hybrid nanofluid TiO_2/Al_2O_3 0.08%/0.02% with variations in irradiation time of 15 minutes, 30 minutes, 45 minutes, and 60 minutes for all cooling media.

2.4 Efficiency Calculation

2.4.1 Thermal Efficiency

Thermal efficiency is the amount of heat energy from sunlight absorbed by the PV collector. This is due to the high temperature found on the surface of the panel due to solar radiation [21]. Han et al. (2021) provide an equation to obtain thermal efficiency by knowing the mass flow rate of nanofluids as follows [22].

$$\dot{m}_{nf} = \rho_{nf} \times V_{nf} \tag{1}$$

where, $\dot{m}_{nf}$ is the mass flow rate of nanofluid (kg/s), ρ_{nf} is nanofluid density (kg/m^3), and V_{nf} is the nanofluid discharge (m^3/s).
Next, calculate the value of heat absorbed by the solar panel with the following equation.

$$Q = \dot{m}_{nf} \times c \times (T_o - T_i) \tag{2}$$

Q is the total thermal energy obtained by the PV panel, c is the heat capacity of fluid (J/kg.K), T_o and T_i are outlet temperature and inlet temperature in Kelvin, respectively.
So that thermal efficiency can be obtained with the following equation.

$$\eta_h = \frac{Q}{A_c \times G} \tag{3}$$

η_h is the thermal efficiency in percent, A_c is the cross-sectional area, and G is the solar radiation in W/m^2.

2.4.2 Electric Efficiency

Electrical efficiency shows the ability of the PVT system to produce electricity from the absorption of energy derived from sunlight. The main factor affecting electrical efficiency is the PVT surface temperature, the higher the PVT surface temperature, the electrical efficiency results will be inversely proportional [21]. The value of PVT electrical efficiency can be known by the equation given by Ghadiri et al. (2015) as follows.

$$\eta_{el} = \frac{V_{OC} \times I_{SC} \times FF}{A_c \times G} \tag{4}$$

where, η_{el} is the electrical efficiency of PVT, V_{OC} is the voltage produced by PV, I_{SC} is the current generated, FF is the filled factor which can be obtained by the following equation.

$$FF = \frac{P_m}{V_{OC} \times I_{SC}} \tag{5}$$

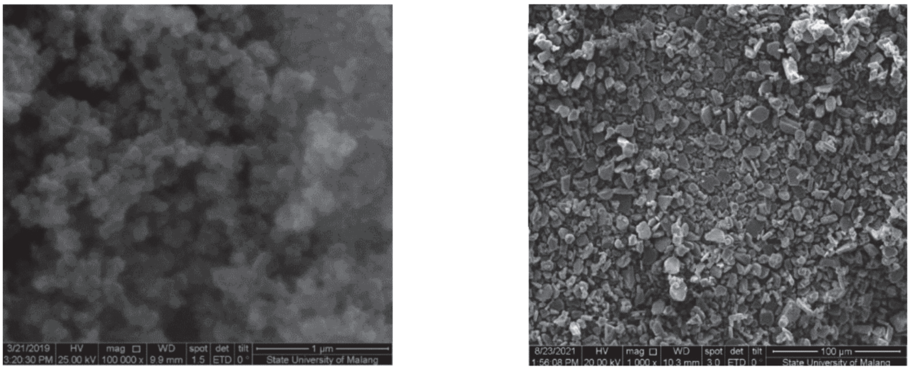
$$P_m = V_m \times I_m \tag{6}$$

P_m is the maximum power generated by the PV in Watt.

3 Result and Discussion

3.1 Captions/numbering Characterization of Titanium Dioxide (TiO_2) and Aluminum Oxide (Al_2O_3) Nanoparticles

3.1.1 Scanning Electron Microscopy (SEM)

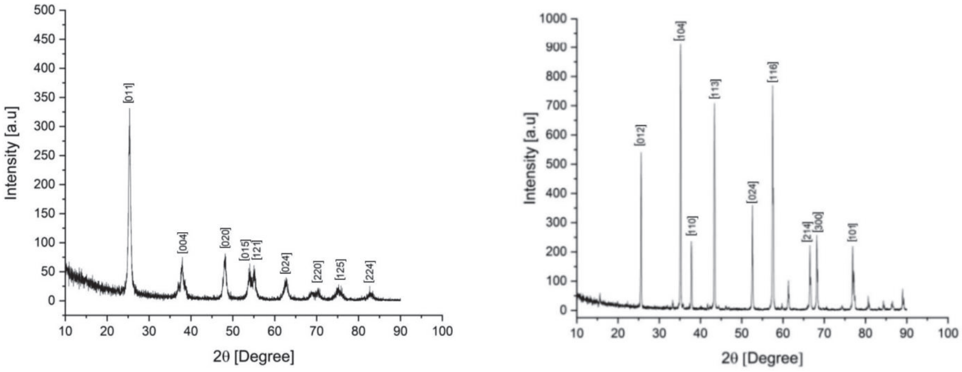


(a) (b)

Fig. 4. Scanning Electron Microscopy (SEM) results with 100000× magnification of nanoparticles (a) TiO_2 (b) Al_2O_3.

Figure 4 (a) shows the results of SEM testing of TiO_2 which shows that the shape of TiO_2 particles tends to have an almost spherical or spherical shape with a tendency to agglomerate [23]. These results are also reinforced by proving that the shape of the TiO_2 particle test results which tend to be round is almost the same as the morphology of TiO_2 [24]. Figure 4 (b) is the morphology of the surface of Al_2O_3 nanoparticles produced based on SEM testing which shows irregular shapes and insignificant interconnection between nanoparticles [25].

3.1.2 X-Ray Diffraction (XRD)



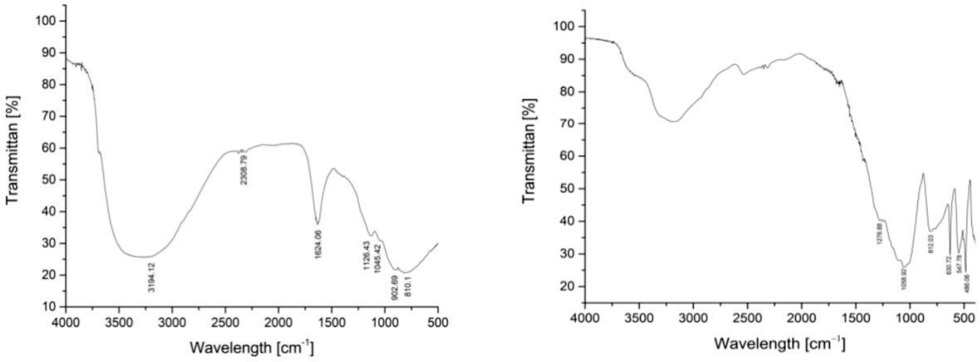
(a) (b)

Fig. 5. X-Ray Diffraction (XRD) graphs of (a) TiO_2 (b) Al_2O_3.

Figure 5 (a) is a graph of XRD results showing that TiO_2 nanoparticles have a structure with a tetragonal crystal pattern. The most visible diffraction peaks are 25.3520° and 48.0901° with miller index peaks [011] and [020] so that the candidate phase in the TiO_2 nanoparticles is anatase phase structure [26].

The XRD results graph in Figure 5 (b) shows that the Al_2O_3 nanoparticles have a structure with a trigonal crystal pattern with correlation peak data of 25.5877°, 35.1590°, 37.7873°, 43.3549°, 52.5575°, 57.6457°, 57.4924°, 66.5148° 68.2008°, and 76.8687° [27]. Aluminum Oxide nanoparticles produce Miller Index (hkl) at each peak, namely [012], [104], [110], [113], [024], [116], [214], [300], and [101] which are candidates for corundum phase [28].

3.1.3 Fourier Transform Infrared (FTIR)



(a) (b)

Fig. 6. Fourier Transform Infrared (FTIR) graphs of nanoparticles (a) TiO_2 (b) Al_2O_3.

Based on the main peak identified along the wavelength from 3194 – 754 in Figure 6 (a), an analysis of the functional groups contained in the TiO_2 nanoparticles can be obtained. The results of the main peak analysis that occurs along the wavelength identify that the functional groups of TiO_2 nanoparticles are O-H, Ti-OH, C=O, Ti-O-Ti, and O-Ti-O.

The FTIR graph in Figure 6 (b) shows the main peak at 1276 – 486 along the wave, so that an analysis of the functional groups contained in Al_2O_3 nanoparticles can be obtained. The results of the main peak analysis that occurs along the wavelength identify that the functional groups of Al_2O_3 nanoparticles are O-H, Al-O-H, Al-O-Al, and Al-O.

3.2 Photovoltaic Thermal (PVT) System Performance

3.2.1 Thermal Efficiency

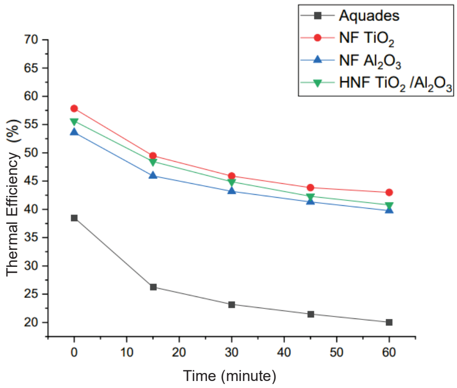


Fig. 7. Thermal Efficiency of PVT.

Figure 7 shows that the thermal efficiency of PVT decreases with time. Different nanofluids and nanoparticle concentrations produce different thermal efficiency values. Nanofluid TiO_2 with a mass fraction of 0.1% produces a thermal efficiency of 49.472% at minute 15, nanofluid Al_2O_3 with a mass fraction of 0.1% produces a thermal efficiency of 45.917% at minute 15, and hybrid nanofluid $TiO_2 + Al_2O_3$ produces a thermal efficiency of 48.454% at minute 15, while the lowest thermal efficiency of all fluids is at minute 60. Thermal efficiency nanofluid TiO_2 higher than the nanofluid Al_2O_3 influenced by the agglomeration of nanoparticles Al_2O_3 and because of this also thermal efficiency hybrid nanofluid $TiO_2 + Al_2O_3$slightly higher than nanofluid Al_2O_3 [29]. Thermal efficiency decreases due to the influence of the inlet temperature, where the inlet temperature of the fluid channel can affect the thermal efficiency which results in an increase or decrease in thermal efficiency [29]. The decrease in thermal efficiency is also influenced by an increase in fluid temperature caused by the duration of irradiation for 60 minutes so that the thermal conductivity of the fluid has decreased [30].

3.2.2 Electrical Efficiency

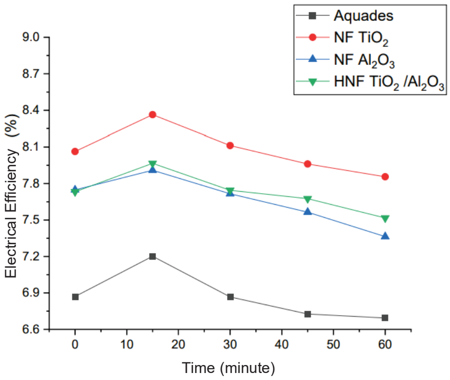


Fig. 8. Electrical Efficiency of PVT.

The electrical efficiency produced by PVT increases maximally at 15 minutes and the next minute decreases. The results of the greatest electrical efficiency obtained by the TiO_2 nanofluid at minute 15 amounted to 8.364%, while the lowest electrical efficiency results obtained by the base fluid amounted to 6.694% at minute 60. The results of the greatest electrical efficiency obtained by nanofluids compared to the base fluid are due to nanofluids being able to absorb heat better than the base fluid because heat transfer with a high capacity is directly proportional to the power produced and nanofluids also affect the decrease in the operating temperature of the PV panel [31]. The results of electrical efficiency that has increased due to the use of nano-based cooling as a cooling system can reduce the surface temperature followed by an increase in electrical efficiency [32]. Maintaining PVT temperature also affects electrical efficiency, low PVT temperature is inversely proportional to electrical efficiency [33]. The decrease in electrical efficiency is due to the temperature of the PVT which is overheated and the heat absorption by the cooling medium is not effective. PVT devices are made of semiconductor materials that are sensitive to changes in temperature, so that when PVT experiences excessive temperature it can cause a decrease in electrical efficiency [29].

The addition of nanoparticles into the base fluid shows a significant effect in increasing the heat transfer that occurs, the increase that occurs in heat transfer is directly proportional to the thermal conductivity of the cooling fluid, but the increase in PVT temperature causes a reduction in heat transfer so that cooling is reduced due to an increase in viscosity to the addition of nanoparticles into the base fluid followed by a decrease in specific heat so that nanoparticles tend to agglomerate [29]. Agglomeration is an important factor in maximizing the heat transfer performance of nanoparticles, because agglomeration can cause loss of nanoparticle suspension and reduced viscosity and conductivity. The addition of nanoparticles to the base fluid with increasing concentration has a positive impact because it causes the nanoparticles to be closer together and the collision ratio between nanoparticles is greater [31]. The size of nanoparticles also affects the results of PVT efficiency, the smaller the size of nanoparticles, the efficiency results will be directly proportional to the increase in thermal conductivity and heat transfer that occurs [29]. The use of nanofluids as coolants provides better cooling results than using basic fluids, this is because the effectiveness of the thermal conductivity possessed by nanofluids is higher than by basic fluids and the effect of nanoparticle concentration is also an important factor in the results of PVT efficiency obtained [34].

4 Conclusions

This study was conducted to compare the thermal efficiency and electrical efficiency that can be produced by PVT with nanofluids as a coolant. Nanofluids used in this study are 4 kinds, namely, the basic fluid in the form of distilled water, TiO_2 nanofluid, Al_2O_3 nanofluid, and hybrid nanofluid TiO_2 + Al_2O_3. The results show that the hybrid nanoparticles TiO_2 + Al_2O_3 have some influence on the resulting thermophysical properties. Density and thermal conductivity tend to increase but do not exceed TiO_2 nanofluids, this is due to the clumping that occurs in Al_2O_3 nanoparticles and the size of nanoparticles also affects the thermophysical properties obtained from combining the two nanofluids. The hybrid nanofluid TiO_2 + Al_2O_3 has the greatest viscosity due to the good suspension between TiO_2 nanoparticles as a filler of empty space from Al_2O_3 nanoparticles.

The effect of nanoparticles on the performance of hybrid nanoparticles TiO_2 + Al_2O_3 can help improve the performance efficiency of PVT compared to single nanoparticles, this is because there are two advantages that can be obtained from two different nanoparticles. Hybrid nanofluids are not always higher than single nanoparticles, due to the influence of nanoparticle size as well as the degree of agglomeration of the nanoparticles combined or combined. The hybrid nanofluid TiO_2 + Al_2O_3 can produce greater efficiency than the Al_2O_3 nanofluid and the base fluid, this is due to the thermophysical properties that support and are more favorable than the Al_2O_3 nanofluid and the base fluid.

Hybrid nanoparticles $TiO_2 + Al_2O_3$ are highly functional as a slightly effective cooling fluid, this is due to the advantage of two nanoparticles obtained in one fluid so that there are more advantages obtained. The ratio of more TiO_2 nanoparticles with a smaller size than Al_2O_3 makes cooling efficient, but not for a long time due to the nature of nanoparticles that undergo agglomeration. This makes the nanofluid as a coolant does not last long and the overheat temperature of the PVT makes heat transfer to the fluid ineffective.

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