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Efficiency of a Photovoltaic Thermal (PVT) System using Bio-nanofluid based on Virgin Coconut Oil-Graphene with Additive Surfactant: An Experimental Study

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ABSTRACT

This study explores the efficiency of photovoltaic thermal (PVT) system using bio-nanofluid based on virgin coconut oil (VCO). This research proposes bio-nanofluid as dispersion media because of their potential in medium to high temperature applications in terms of thermal output, biodegradable, and renewable. Graphene nanoplatelets (GNP) were prepared in a mass fraction of 0.1% wt. Then, the ratio for the surfactant was a 1:1 nanoparticle. The surfactants used in this study were Polyvinylpyrrolidone (PVP), Sodium dodecyl sulfate (SDS), and Cetyltrimethylammonium bromide (CTAB). The two-stage method was used for the bio-nanofluid synthesis. Further, the samples were tested for physical and thermophysical properties. From the stability test, we discovered stable dispersion from VCO-GNP-PVP bio-nanofluid sample during the 30 days of testing. The bio-nanofluid samples also presented an increase in thermal conductivity following its stability, with the highest conductivity value (0.158 W/m.K) observed on the VCO-GNP-PVP sample. The efficiency test results on additive surfactant and flow rate show the optimum flow rate of 7 mL/s on VCO-GNP-PVP bio-nanofluid, with thermal and electric efficiency of 25.169% and 8.632%, respectively.

1. Introduction

Following the increasing demands for renewable energy, deteriorating environmental issues, and dependency on electrical power, solar energy has become one of the promising renewable energy alternatives [1,2]. The sun releases relatively considerable heat energy to the earth, reaching 17.491.015 watts [3]. The instrument which convert solar energy into electrical energy is known as a

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photovoltaic system (PV) [4]. This module adopts a solar cell made from silicon material, classified as an abundantly available semiconductor material [5].

Before being converted, the solar energy within the PV module is absorbed by the PV cell, increasing the temperature of the PV module and reducing the amount of semiconductor band gap energy. Consequently, the PV module's efficiency also subsides [6]. The primary factor determining the effectiveness of the system is the temperature of the PV modules and solar radiation. The PV module attached to the photovoltaic thermal (PVT) is commonly equipped with a cooling system to lower the PV cell's temperature so it generates maximum heat and electrical power [7-9].

Most of the cooling agents adopted in many PVT research are conventional fluids, such as water and air [10] . These common fluids present lower thermal conductivity than solid metal, so it inhibits the system's efficiency. Therefore, its efficiency should be enhanced by improving the heat transfer from the heat media. The issues with the system's efficiency can be resolved through the construction of a nanofluid using different nanoparticle materials to escalate its thermophysical properties [11,12]. This application is also promoted by the urgent need to maintain the PV cell's temperature below 100˚C [13].

The PVT efficiency study using Al_2O_3/water nanofluid conducted by Tang and Zhu [14] showed an increase in overall efficiency of 29.47% due to the better thermal characteristics of the nanofluid compared to water, while the electrical efficiency decreased by -3.73% due to light absorption. appear larger by the nanofluid. Xu and Kleinstreuer [15] studied Al_2O_3/water nanofluid flowing through a single rectangular flow channel in a CPV/T system. The results show that the nanofluid used increases the overall efficiency by 1.49%. Al-Shamani *et al.,* [16] investigated TiO_2/water, SiO_2/water, SiC/water as refrigerants in a PVT system which has a serpentine absorber design with a rectangular cross section. They concluded that the SiC/water nanofluid led to the highest overall efficiency of 18.47%. Khanjari *et al.,* [17] conducted a study on the efficiency of sheet and tube PVT systems using Al_2O_3/water and Ag/water nanofluids. The results of their research showed that the overall efficiency of the PVT system using Al_2O_3/Air and Ag/water nanofluids was 4.26% and 11.54%, respectively.

A number of basic fluids, such as water, glycol (ethylene and propylene), and ionic fluid, have been used as a dispersing media for establishing nanofluid [18]. In recent studies, many reported oil-based nanofluids used as working fluids in thermal energy storage (TES) because of their potential thermal output in moderate to high temperature applications. Meanwhile, the vegetative oil-based nanofluid is preferable for thermal absorption media since it is biodegradable, presents excellent thermal stability, renewable, and carries lower environmental effects than the other conventional toxic liquid, such as ethylene glycol, ionic fluid, and others. Various studies on the heat transfer properties of nanofluids in PVT have confirmed their availability as a thermal medium for heat transfer, but because the desired goals have not been achieved, further research is needed to achieve the efficiency of using nanofluids as a thermal medium in solar energy systems [19].

The PVT system with a serpentine-shaped absorber design was built in this study. To evaluate the efficiency of the PVT system, a comparative experiment was carried out using nanofluid based on vegetable oil (virgin coconut oil) and graphene with the addition of surfactants as a heating medium on PVT efficiency. Surfactants are added to lower the surface tension of the base fluid to increase the suspension period of the nanoparticles. Nanofluid studies with the addition of PVP and SDS surfactants conducted by Mingzheng *et al.,* [20] confirmed that the addition of surfactants affected the viscosity and thermal conductivity values. Their results found the effect of surfactant additives on the thermal conductivity of single base fluids to be within a negligible range with respect to the surfactant concentration limit.

In designing the PVT cooling system, the working fluid's flow rate should be controlled as it directly affects the operational temperature and the system performance, primarily on the obtained power. Bambrook and Sproul [21] uncovered that altering the air mass flow rate within the PVT system can enhance its thermal and electric efficiency, as well as enhance the flow rate. Meanwhile, Liang *et al.,* [22] analyzed the performance of the solar concentrator system in a conical shape based on its working fluid's mass flow rate. The study concluded the increasing tendency of thermal efficiency followed the higher flow rate, but it decreased as the optimum flow rate had passed [19]. This study explores the concept of a PVT heat transfer media based on bio-nanofluid. The results are expected to generate better efficiency using renewable material from different treatments.

2. Methodology

2.1 Experimental Configuration of The PVT System

This study used flat plate PVT, consisting of a PV module, thermal absorbing tube, water storage tank, bio-nanofluid, and pump. The solar cell within the PV module was monocrystalline silicon. The glass cover above the PV module functioned to reduce the thermal energy lost. Meanwhile, the absorbing tube below the PV model was constructed from the copper pipe in a serpentine shape [22-25]. The pump and censor flow controlled the working fluid flow rate during the cooling circulation. The storage tank stored and contained the thermal energy from working fluid circulated within the PVT absorbing tube. The PV module's specification is summarized in Table 1.

Table 1
Specification of PV module

Model	MS50M-18
Rated maximum power (P_m)	50 W
Dimension	400 x 625 x 25 mm
Mass	2.52 kg
Cell technology	SHINGLED
Operating temperature	-40°C – 85°C
Voltage at P_{max} (V_{mp})	18 V
Current at P_{max} (I_{mp})	2.78 A
Maximum voltage system	1000 V DC
Maximum series fuse rating	10 A
Open circuit voltage (V_{oc})	22.11 V

In the beginning, the initial temperature and voltage were examined. The PVT system received a beam from a 575.8 W/m^2 halogen lamp, producing thermal and electrical energy. The halogen lamp lit up until the PVT reached 100°C temperature since it was the working temperature of the oil-based fluid. After reaching that temperature, the working fluid was stored in the storage tank and circulated throughout the pump for two minutes, heading to the absorbing tube to attain the thermal energy from the flow rate. The data were obtained from the thermocouple type DS18B20 attached to the inlet and outlet sides of the thermal absorbing tubes. Meanwhile, PVT current, voltage, and power were attained from the Watt meter. The working fluid flow rate was regulated through the censor flow type YF-S401 attached on the inlet side of the thermal absorbing tube, with flowrates of 5,6,7, and 8 mL/s. The cooling cycle within the PVT system is illustrated in Figure 1.

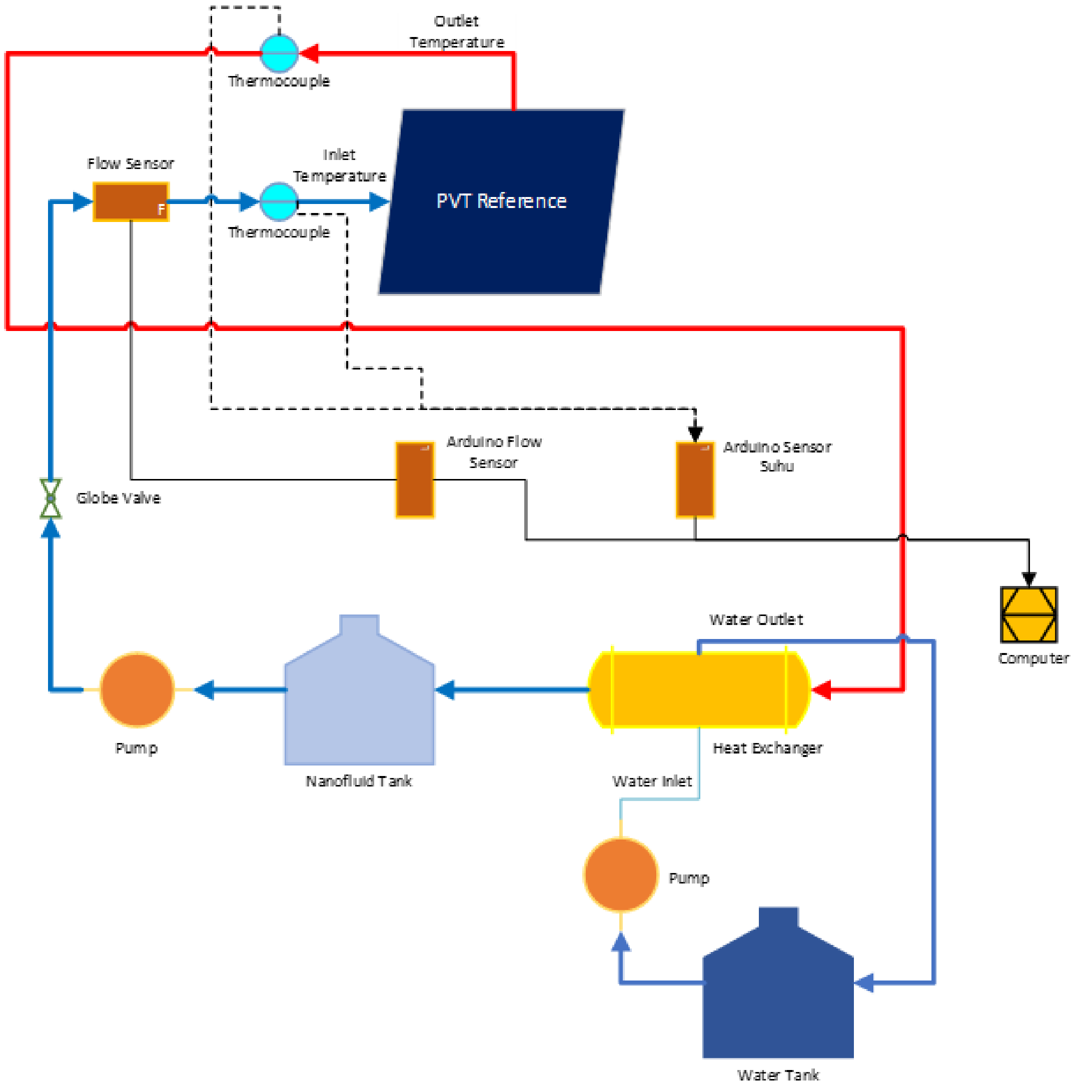


Fig. 1. Schematic of the experimental layout

2.2 Preparation of Bio-Nanofluid

The two-stage method was used for the bio-nanofluid synthesis, as shown in Figure 2. The 0.1% wt concentration of graphene nanoplatelets (GNP) KNG-150 and different surfactants (PVP non-ionic, SDS anionic, and CTAB cationic) was measured at a 1:1 ratio and mixed with the base fluid of virgin coconut oil (VCO) using a magnetic stirrer at 1500 rpm for 60 minutes in room temperature [26,27]. Furthermore, the sonication process was carried out for 40 minutes using the KG-MT3N sonicator to increase the stability of the nanoparticles in the base fluid. The detailed material is presented in Table 2.

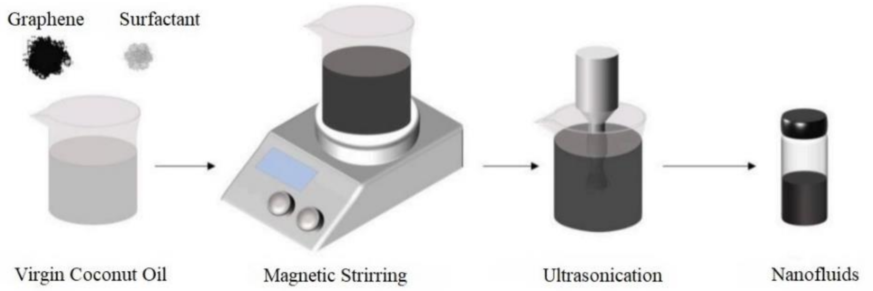


Fig. 2. Preparation of Bio-Nanofluid

Table 2
The details of the material used in the present study

Name	Category	Function	Supplier/Product Code	Molecular Weight
Virgin coconut oil (VCO)	Dispersion medium	Base fluid	Botanica	-
Graphene Nanoplatelets (GNP)	Dispersed phase	Nanoparticle	KNG-150	12.01 g/mol
Polyvinylpyrrolidone (PVP)	Dispersed phase	Surfactant	Merck 5295-100GM	114,4 g/mol
Sodium dodecyl sulfate (SDS)	Dispersed phase	Surfactant	Future Chemical CAS:151-21-3	288,38 g/mol
Cetyltrimethylammonium bromide (CTAB)	Dispersed phase	Surfactant	Himedia MB101-100G	364,45 g/mol

2.3 Measurement of Physical Properties

SEM is a technique for analyzing a specimen's size and morphology [28]. In this study, we used SEM from FEI type Inspect-S50. Meanwhile, XRD analysis was used to identify the crystallinity, elemental deviations from the ideal composition, and the samples' structural condition [29]. We used PANalytical. Lastly, we also used FTIR analysis to find the organic, inorganic, and polymer material using scanning through infrared rays. We used the FTIR from Shimadzu. For visual observation, a studio with an LED-lit backdrop was used to capture the photos. This technique speeds up the results obtained and clearly shows agglomeration and sedimentation in the sample beaker [30,31].

2.4 Measurement of Thermophysical Properties

The bio-nanofluid density can be calculated by dividing the mass by its volume. The sample's mass was attained by weighing the bio-nanofluid using a digital scale, while the volume was measured using the measuring glass. The thermal conductivity and specific heat were assessed using the KD2-Pro instrument at room temperature (25°C) after the samples had been cooled down using the sonification technique. The dynamic viscosity value was gained from the viscometer instrument by placing the fluid on the rotor following its type. Ain this study, we used NDJ-8S with rotor 1 since results of the viscosity of oil-based fluids can be detected using the rotor 1 on the viscosity testing machine. The viscosity test was carried out at temperature 25°C with a shear rate of 22.2 s^{-1} – 111.2 s^{-1} [32]. Shear rate can be found using Eq. (1). The thermophysical data of virgin coconut oil-graphene based bio-nanofluid with surfactant variations are summarized in Table 3.

$$Shear\ rate\ (s^{-1}) = \frac{2\omega {R_c}^2 {R_b}^2}{{R_b}^2\left({R_c}^2 - {R_b}^2\right)} \quad (1)$$

where, ω is the angular speed of the rotor (rad/s), R_c is the radius of the fluid reservoir (mm), and R_b is the radius of the rotor (mm).

Table 3
Thermophysical properties of Bio-Nanofluid based on virgin coconut oil-graphene at temperature 25°C

Bio-nanofluid	Density (kg/m^3)	Specific Heat (J/kg.K)	Thermal Conductivity (W/m.K)
Virgin coconut oil (base fluid)	836.00	4100.000	0.153
VCO-GNP-No Surfactant	836.67	4008.387	0.155
VCO-GNP- PVP Surfactant	837.78	4003.071	0.158
VCO-GNP- SDS Surfactant	838.89	3997.769	0.156
VCO-GNP- CTAB Surfactant	840.00	3992.481	0.157

2.5 Measurement of Efficiency

Efficiency represents the performance of an energy conversion instrument. The efficiency of PVT being measured in this study included thermal, electrical, and overall efficiencies.

2.5.1 Thermal efficiency (η_{th})

The thermal efficiency was assessed using Eq. (2) to identify the heat transfer within the bio-nanofluid.

$$\eta_{th} = \frac{\dot{m}.C_p.(T_{nf,out}-T_{nf,in})}{I.A_c} \tag{2}$$

The thermal efficiency relies on the mass flow rate (ṁ), specific heat (C_p), light intensity (I), area of PVT (A_c), bio-nanofluid inlet temperature ($T_{nf,\,in}$), and bio-nanofluid outlet temperature ($T_{nf,\,out}$) within the heat absorbing tube within the PVT [33].

2.5.2 Electrical efficiency (η_e)

The electric efficiency was measured using Eq. (3) and Eq. (4).

$$P_{max} = V_{oc}.I_{sc}.FF = V_{max}.I_{max} \tag{3}$$

$$\eta_e = \frac{P_{max}}{I.A_c} \tag{4}$$

In which P_{max} is the maximum electrical power, I is the light intensity, and A_c represents the PVT area, while V_{oc} shows the open circuit voltage, I_{sc} is the short circuit current, and FF is the filling factor. A Watt Meter was used to measure the electric efficiency, showing the maximum voltage (V_{max}), maximum current (I_{max}), and maximum electrical power (P_{max}).

2.5.3 Overall efficiency (η_o)

A number of studies have used Eq. (5) to measure the overall efficiency in evaluating the PVT system [34]. In simple terms, overall efficiency (η_o) is the sum of electrical and thermal efficiency.

$$\eta_o = \eta_{th} + \eta_e \tag{5}$$

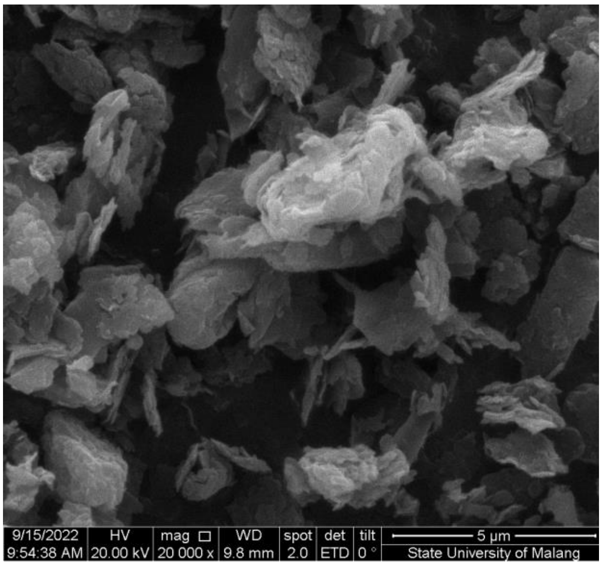
3. Results

3.1 Nanoparticle Characteristic

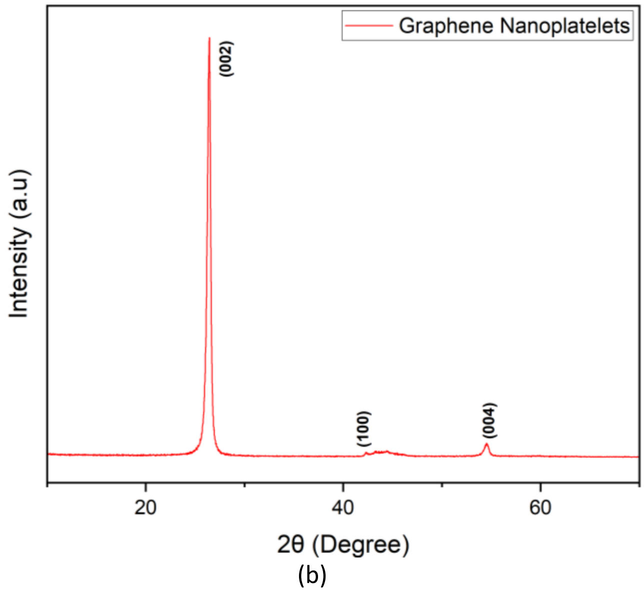
The morphology of graphene's nanoparticle is shown in Figure 3(a). The thermophysical property of bio-nanofluid is highly impacted by its particle morphology [35,36]. The graphene has a planar shape [37,38], with a stacking structure similar to the nanoplatelets due to the nanomaterial's high surface energy and surface ratio toward its great volume. The nanoplatelets tend to pull one another to lower the surface energy, producing stable thermodynamics [31], which further enhances the thermal conductivity within the bio-nanofluid. Sadri *et al.,* [39] added that the platelets structure in graphene improves its thermal conductivity from 8.9 to 35.7%. Meanwhile, Timofeeva *et al.,* [40] reported platelets structure present lower thermal conductivity than cylinder and bricks structure since platelets structure ≈ blades < bricks < cylinder.

In addition, the X-ray diffraction pattern was recorded at 2θ = 20° – 80°, and the results are presented in Figure 3(b). The graphene nanoplatelets secure the highest intensity peak at 2θ = 26.426°. Each of those peaks is in accordance with the peak of graphite carbon (002) and (100), in which peak (002) represents high carbon crystallinity trait [41]. The layered structure of the graphene nanoplatelets with d-spacing 3,37 Å was also confirmed through the sharp diffraction peaks (hkl) being indexed at 2θ = 26.46°. The highest peak with the Miller index (002) has also been also observed from the XRD pattern, following the layered structure on the graphene sheet [42].

The results of FTIR illustrated in Figure 4 and Table 4 show that the graphene nanoplatelets are classified as a single bond group. A single bond is formed when a pair of electrons is divided into two atoms. This bond is relatively frail with smaller electron density than the double and triple bonds, but it has the most excellent stability due to its lower reactivity which results in more minimum electron loss. Besides, the platelet morphology in the graphene also reflects its stability toward electron beam radiation [43].



(a)



(b)

Fig. 3. Results of (a) SEM (b) and XRD on graphene nanoplatelets nanoparticle

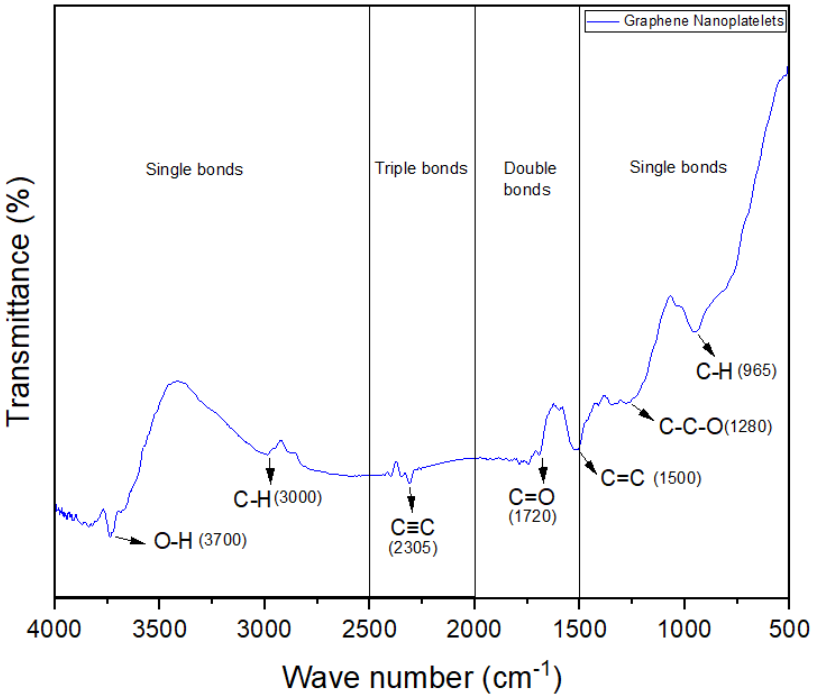


Fig. 4. FTIR results of graphene nanoplatelets nanoparticle

Table 4
Functional group of graphene nanoplatelets nanoparticle

Band	Main Peak	Wave Number	Typical Band Assignment	Reference
1	3700	3700-3584	O-H stretching alcohol	Bello *et al.,* [44]
2	3000	3000-2800	C-H stretching alkene	Pang *et al.,* [45]
3	2305	2325-2290	C≡C disubstituted alkynes	Pang *et al.,* [45]
4	1720	1720	C=O carboxyl stretching	Kartick *et al.*, [43]
5	1500	1500-1450	C=C aromatic rings	Tran *et al.*, [46]
6	1280	1310-1250	C-C-O aromatic esters	Kartick *et al.*, [43]
7	965	965	C-H vinyl trans-disubstituted alkenes	Bello *et al.* [44]

3.2 Stability of Bio-Nanofluid

Stability is the central component for improving the heat transfer power of bio-nanofluid [47]. Nanofluid is considered stable if it does not agglomerate and present slow particle deposition. Che Sidik *et al.,* [48] described that nanofluid has a great tendency for agglomeration, which may reduce its efficient heat transfer power significantly. Meanwhile, Ghadimi *et al.,* [49] contend that the particle deposition is induced by the robust Van der Waals force between the nanoparticle and basic fluid, the primary challenge for the homogeneous fluid.

The bio-nanofluid's stability test results shown in Table 5 suggest that VCO-GNP-PVP surfactant bio-nanofluid offers the best stability, even after 30 days, compared to other bio-nanofluids. The PVP surfactant has been reported to have the highest stability, with minimum deposition reaching 25 days [50]. This surfactant also has the highest absorbing power, followed by the SDS and CTAB surfactants, after the basic fluid preparation using virgin coconut oil. CTAB surfactant has the worst stability in virgin coconut oil-graphene bio-nanofluid due to differences in ionic bonding. Graphene is a non-polar compound that is hydrophobic [31], indicating its incompatibility being combined with SDS anionic surfactant (used on the detergent [51]) and CTAB cationic (used as solvents for heavy wastewater metal [52]). In contrast, the non-polar graphene is suitable for combination with similar compounds, such as the PVP surfactant, including the non-polar or non-ion compounds and the insoluble compound within the water. The nanofluid stability can be enhanced through robust refusal force between particles which can be increased through pH modification [53]. The sediments on nanofluid are induced by various factors, such as the nanofluid's pH, zeta potential between nanoparticles, shape, and size of nanoparticles, nanoparticles' concentration within the base fluid, and the forces between the particles, including the gravitational, Van der Waals, buoyant and electrostatic forces [30]. The agglomeration of the particles lowers their overall effective thermal conductivity and causes blockage in the micro lines [54].

Table 5
Sedimentation photograph of Virgin Coconut Oil-GNP Bio-Nanofluid with various surfactant

Duration	Description
1 day	
7 days	
14 days	
21 days	
30 days	

3.3 Thermophysical Properties of Bio-Nanofluid
3.3.1 Density

On nanofluid, density serves as an essential parameter for the thermal transfer measurement [36]. In this study, the density was analyzed using calculation on the nanoparticle mass and 0.1 (wt %) surfactant. Figure 5(a) illustrates the density of the four samples, with the VCO-GNP-no surfactant obtaining 836.67 kg/m^3 density, while the VCO-GNP-PVP, VCO-GNP-SDS, and VCO-GNP-CTAB attained 837.78 kg/m^3, 838.89 kg/m^3, and 840.00 kg/m^3, respectively. The bio-nanofluid density is affected by the molecular weight of the different surfactants added. Meanwhile, the density further impact the heat transfer, with a lower density having worse heat transfer [55], while a higher density shows excellent heat transfer [56]. However, greater density also generates more friction factors on the pipe wall, which later enhances the pumping power of the nanofluid [31].

3.3.2 Specific heat

Figure 5(b) shows the specific heat of the four samples, with VCO-GNP-no surfactant attaining 4008.387 J/kg.K, while the VCO-GNP-PVP, VCO-GNP-SDS, and VCO-GNP-CTAB obtained 4003.071 J/kg.K, 3997.769 J/kg.K, and 3992.481 J/kg.K specific heat. The level of specific heat can be beneficial or disastrous, depending on its application [35]. In this study, the PVT system requires a rapid transformation of temperature, so the fluid with low density is beneficial for the system. Previous studies suggested that bio-nanofluid from virgin coconut oil, graphene nanoparticle, and CTAB surfactant present the best specific heat. The addition of nanoparticle-surfactant into the basic fluid may lower the specific heat. He *et al.,* [57] described two crucial influencing factors for the specific heat of nanofluid, namely the transformation of free energy at the solid-liquid interface when the nanoparticle is added into the basic fluid and the specific heat between the nanoparticle with the basic fluid. Further, the nanoparticle-surfactant presents lower specific heat than the basic fluid, lowering the specific heat of the fluid during the suspension. On the other hand, the specific heat of nanofluid increases if it uses nanoparticles with higher density.

3.3.3 Thermal conductivity

Figure 5(c) shows the thermal conductivity of the research samples. The results suggested that the VCO-GNP-no surfactant, VCO-GNP-PVP, VCO-GNP-SDS, and VCO-GNP-CTAB bio-nanofluid gained 0.155 W/m.K, 0.158 W/m.K, 0.156 W/m.K, and 0,157 W/m.K thermal conductivity. These results indicate that virgin coconut oil bio-nanofluid added with graphene nanoparticles and PVP surfactant has a higher thermal conductivity than the other samples. It occurs due to the surface coating around the nanoparticle built by the molecules from the basic fluid, and this surface nano-coating presents higher thermal conductivity than the basic fluid [39].

Mingzheng *et al.,* [20] have examined SDS and PVP surfactants added into the water, reporting that the addition of surfactant has significant effects on the viscosity and thermal conductivity. Our data also suggested that the additive effects of surfactants on the single basic fluid's thermal conductivity are in the negligible range. The thermal conductivity is affected by the nanoparticle's concentration, size, shape, and type, as well as the temperature and type of basic fluid [53]. Further, the greater nanofluid concentration also increases the collision between molecules and thermal conductivity, then enhances the heat transfer performance [58]. The higher thermal conductivity can also improve the heat transfer coefficient and thermal penetration and increases the heat distribution [59]. Further, the increase in thermal conductivity lowers the operational fee, improves thermal efficiency, and increases performance [60].

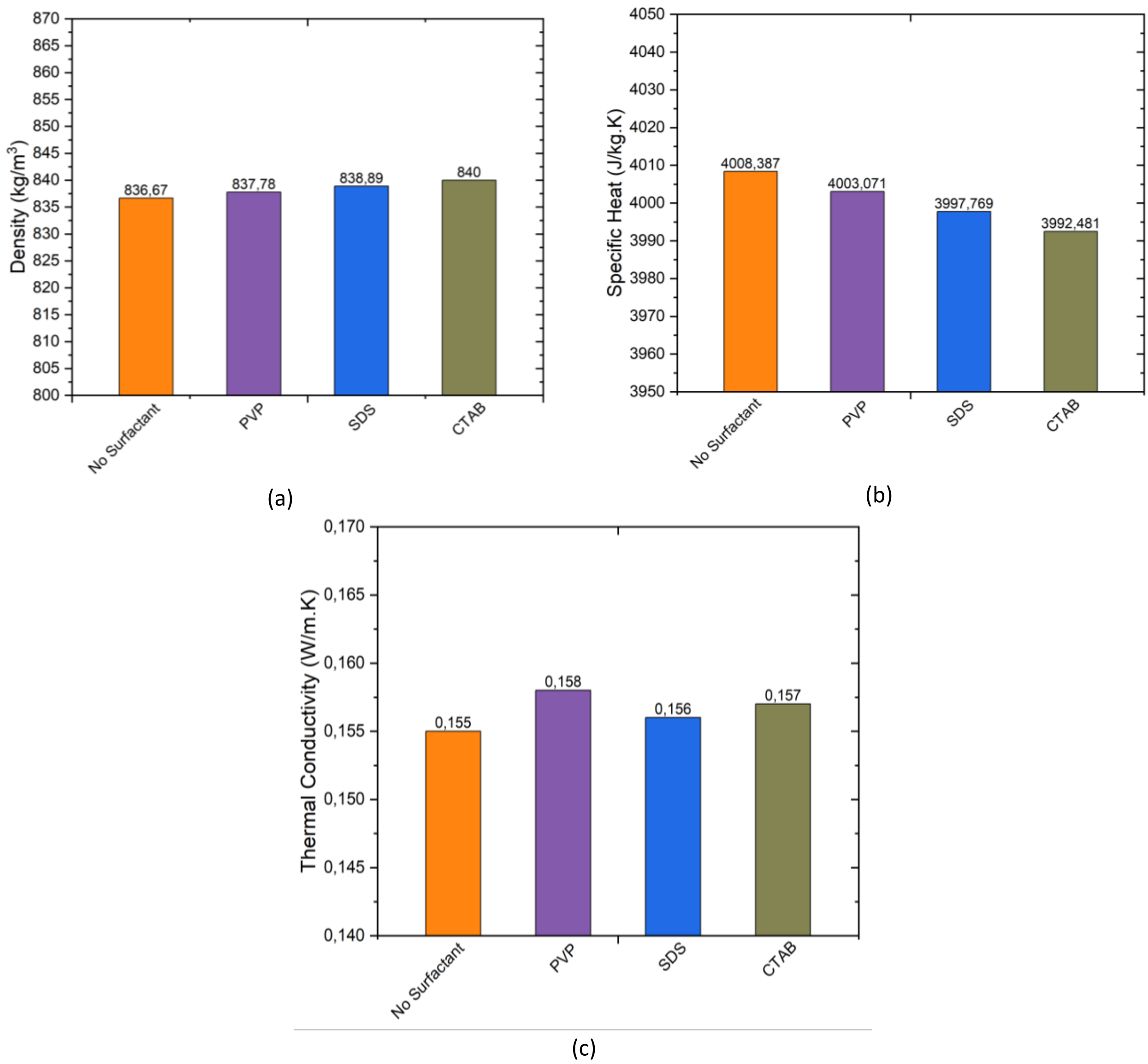


Fig. 5. Graphics of (a) Density, (b) Specific heat, and (c) Thermal conductivity of VCO-GNP Bio-Nanofluid

3.3.4 Dynamic viscosity

Viscosity of VCO-GNP-no surfactant, VCO-GNP-PVP, VCO-GNP-SDS, and VCO-GNP-CTAB bio-nanofluid were adjusted, with different shear rate ranges at 25°C. As presented in Figure 6, samples with PVP surfactants offer a lower viscosity compared to other samples at 25°C. Thus, this shows that PVP has lower agglomeration compared to other samples. On the other hand, more significant agglomeration leads to an expansion of the molecular particle size, increasing the viscosity, which further increases the fluid motion and coefficient of friction [59]. In general, the increase in the viscosity of nanofluids is affected by the surfactant concentration. Lower surfactant concentrations have been reported to have less effect on increasing viscosity [31]. In contrast, the addition of higher concentrations of surfactant also promotes an increase in the viscosity of the nanofluid, whereas super-saturation of the surfactant decreases the heat transfer performance through the construction of a heat-resistant layer on the nanoparticles [61].

In general, the study of nanofluids focuses on increasing the conductivity and thermal stability with lower viscosities [62]. Low viscosity facilitates the reduction of energy dissipation by reducing pumping power and increasing convective heat transfer. The test results shown in Figure 6 show that all nanofluid samples have non-Newtonian behavior. Meanwhile, an increase in the shear rate increases the viscosity which is commonly referred to as shear thickening. This is possibly due to the rotational motion of the nanoparticles and surfactants in the bio-nanofluid with different molecular sizes. Larger fluid rotation tends to produce shear thickening, in contrast to shear thinning [30].

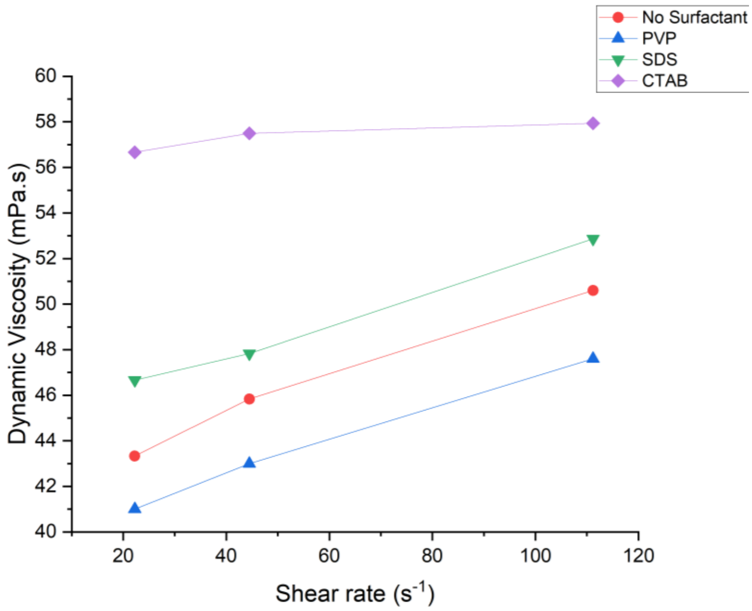


Fig. 6. Dynamic viscosity of Bio-Nanofluid with variations of shear rate

3.4 Efficiency of PVT

The results of PVT efficiency using virgin coconut oil added with graphene nanoparticles as a cooling system with variations of surfactants and flow rate are shown in Figure 7(a), (b), and (c). The results showed that the virgin coconut oil bio-nanofluid added with graphene nanoparticle and PVP surfactant had the best efficiency in general since the PVP surfactant addition enhances the thermal conductivity of bio-nanofluid, allowing greater absorption of thermal energy. In this study, the bio-nanofluid added with PVP surfactant showed the greatest thermal conductivity (0.158 W/m.K), followed by bio-nanofluid with CTAB (0.157 W/m.K), bio-nanofluid with SDS (0.156 W/m.K), and without surfactant (0.155 W/m.K). According to Gibbs absorption effects, the molecules in PVP surfactant can be absorbed by the liquid-solid interface, decreasing the interface energy of the fluid and nanoparticle, which lowers agglomeration and improves thermal conductivity [50]. Contrastingly, ionic surfactant (SDS and CTAB) has greater aggregation size than the virgin coconut oil basic fluid, which signifies a poor absorption rate, producing a lower thermal conductivity than the PVP surfactant. The PVT efficiency from the bio-nanofluid with SDS surfactant is even lower than the bio-nanofluid with no surfactant addition because the viscosity of the bio-nanofluid with SDS surfactant is higher than the bio-nanofluid with no surfactant. Meanwhile, heat transfer is directly affected by the nanofluid’s viscosity, with the low viscosity reducing the friction coefficient between the serpentine tube and the working fluid for the most optimum heat transfer. AT 100°C PVT temperature, the Brown movement from nanofluid induces more ferocious particle collision, which facilitates higher heat transfer, expanding the general thermal conductivity [63]. The higher heat transfer also indicates maximum thermal efficiency [64].

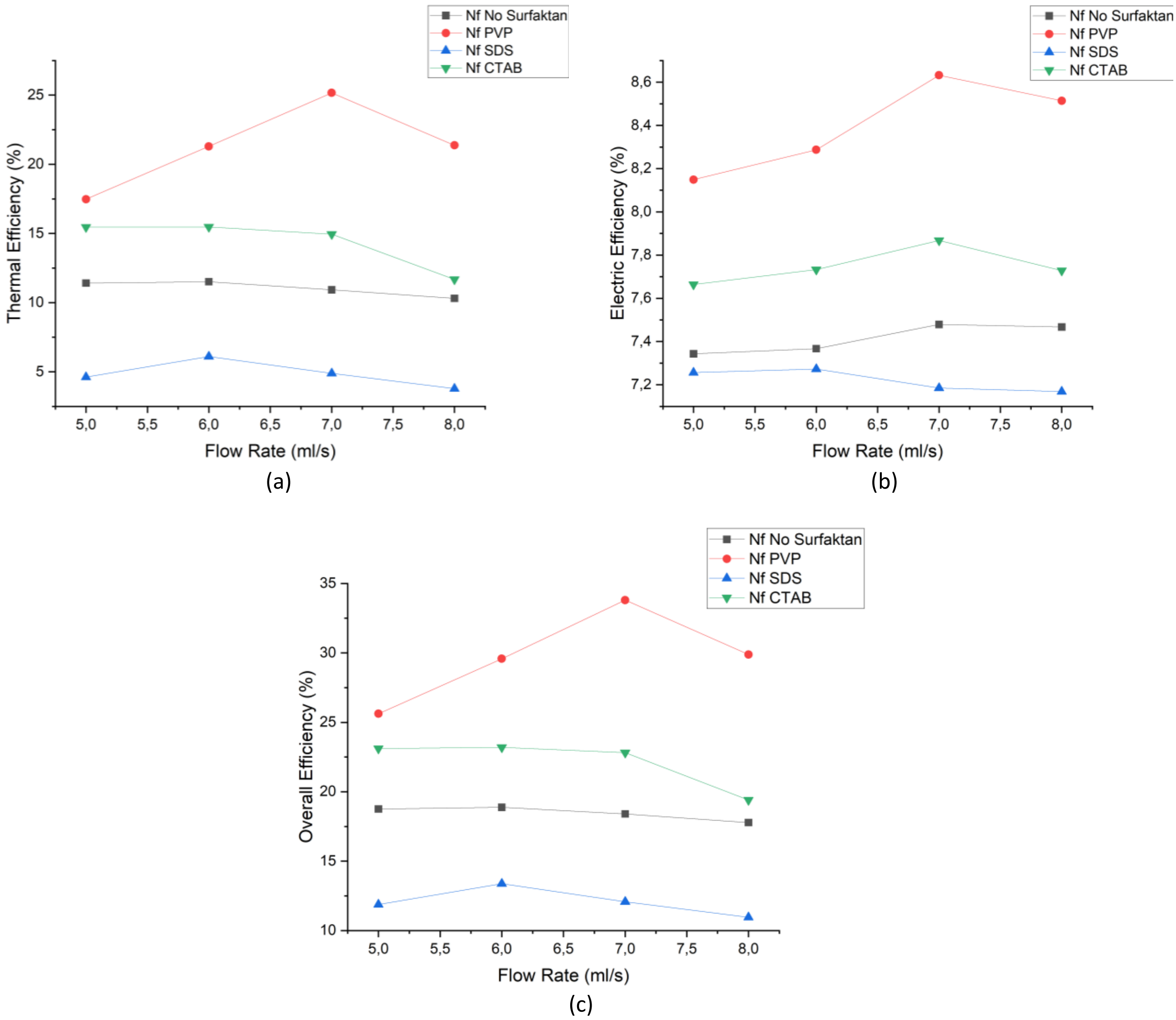


Fig. 7. PVT efficiency using VCO-GNP bio-nanofluid with various surfactant and flow rate, (a) thermal efficiency, (b) electrical efficiency, (c) overall efficiency

As illustrated in Figure 7(a), the virgin coconut oil bio-nanofluid with graphene nanoparticle and PVP surfactant present the best thermal efficiency, followed by the bio-nanofluid with CTAB surfactant, no surfactant, and SDS surfactant. The optimum thermal efficiency on bio-nanofluid with PVP surfactant is 25.169% at 7 mL/s. Thermal efficiency is impacted by the nanofluid's specific heat, inlet, and outlet cooling agent temperatures [65], as well as light intensity and mass flow rate [33]. The thermal efficiency tends to increase, but once it passes the optimum flow rate, the thermal efficiency decreases. In a lower flow rate, the working fluid requires a longer time to absorb the heat from the PVT panel, resulting in a lower convection rate from the PVT panel into the serpentine tube. Further, a low mass flow rate enhances the outlet temperature while reducing thermal efficiency [13]. The increase in mass flow rate improves the convection coefficient between the serpentine tube and working fluid which declines the PVT panel's temperature and increases the thermal efficiency [66].

Figure 7(b) shows that the electrical efficiency tends to increase following the greater flow rate. The best electric efficiency was observed from the bio-nanofluid added with PVP surfactant by 8.632% at 7 mL/s. The escalation of the mass flow rate up to its optimum level increases thermal efficiency and overall efficiency. However, if the optimum value has been passed, the thermal efficiency decreases, while the electrical efficiency can be enhanced to attain a constant value.

Lastly, the overall efficiency results presented in Figure 7(c) indicate that at 7 mL/s flowrate, the total energy efficiency of bio-nanofluid samples with no surfactant, PVP surfactant, SDS surfactant, and CTAB surfactant is 18.406%, 33.801%, 12.077%, and 22.817%, respectfully. That results are the best efficiency compared to the efficiency at different flowrate. Therefore, the most optimum flow rate for the PVT system with virgin coconut oil based bio-nanofluid added by graphene and various surfactant has been observed at 7 mL/s. Besides, the results of PVT efficiency analysis on variations of surfactant within virgin coconut oil basic fluid suggest that the addition of graphene nanoparticle results in high heat transfer as observed from the high working fluid density, high thermal conductivity, low fluid's specific heat, low fluid's viscosity, and excellent stability of nanofluid.

4. Conclusions and Suggestion

4.1 Conclusions

This study analyses the PVT efficiency based on variations of surfactant and flowrate, using virgin coconut oil-graphene as the working fluid. From our analysis, we drew a number of conclusions discussed in the following

i. The results of thermal and electrical efficiency showed that the VCO-GNP bio-nanofluid with PVP surfactant attained the maximum results, with the highest conductivity of 0.158 W/m.K, resulting in more thermal absorption compared to other bio-nanofluids.
ii. Efficiency analysis results suggested that the most optimum thermal and electrical efficiency was observed at 7 mL/s flow rate from virgin coconut oil-graphene-PVP, with a thermal and electrical efficiency of 25.169% and 8.632%. The efficiency tends to increase as the flow rate improves, but it lowers when the optimum flow rate has been exceeded. The low mass flow rate expands the outlet temperature but reduces the overall system efficiency. In contrast, the increasing mass flow rate improves the convection coefficient between the serpentine tube and working fluid, lowering the PVT panel's temperature and enhancing the overall efficiency.
iii. The higher efficiency of PVT is marked by higher heat transfer in the system, which is affected by the thermophysical properties of the working fluid, including high density, high thermal conductivity, low specific heat, low viscosity, and excellent stability of the bio-nanofluid. Further, maintaining viscosity, stability, and density for reaching the optimum heat transfer is the greatest challenge in the study of nanofluids.

4.2 Suggestion

Following the results of our study, we suggest a number of improvements for future relevant research, as described in the following

i. The nanofluid preparation requires a sterile condition to avoid contaminants that may affect the test results.

ii. The nanofluid preparation should be carried out using the same treatments before the laboratory testing and thermal efficiency data collection.
iii. A further study on green nanofluid for the thermal system is required since it presents minimum environmental effects.
iv. The environmental temperature should be measured for every sample collection since it highly affects the thermal efficiency of the PVT.

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References
[1] Al-Musawi, Ahmed Issa Abbood, Amin Taheri, Amin Farzanehnia, Mohammad Sardarabadi, and Mohammad Passandideh-Fard. "Numerical study of the effects of nanofluids and phase-change materials in photovoltaic thermal (PVT) systems." *Journal of Thermal Analysis and Calorimetry* 137 (2019): 623-636. https://doi.org/10.1007/s10973-018-7972-6
[2] Rosli, Mohd Afzanizam Mohd, Danial Shafiq Mohd Zaki, Fatiha Abdul Rahman, Suhaila Sepeai, Nurfaizey Abdul Hamid, and Muhammad Zaid Nawam. "F-chart method for design domestic hot water heating system in Ayer Keroh Melaka." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 56, no. 1 (2019): 59-67.
[3] Gangadevi, R., and B. K. Vinayagam. "Experimental determination of thermal conductivity and viscosity of different nanofluids and its effect on a hybrid solar collector." *Journal of Thermal Analysis and Calorimetry* 136 (2019): 199-209. https://doi.org/10.1007/s10973-018-7840-4
[4] Erfiansyah, Rizky, and Taufik Adriansyah. "Penggunaan Pipa Kalor Pipih sebagai Pendingin Sel Surya."
[5] Esfe, Mohammad Hemmat, Mohammad Hassan Kamyab, and Majid Valadkhani. "Application of nanofluids and fluids in photovoltaic thermal system: An updated review." *Solar Energy* 199 (2020): 796-818. https://doi.org/10.1016/j.solener.2020.01.015
[6] Rosli, Mohd Afzanizam Mohd, Yew Wai Loon, Muhammad Zaid Nawam, Suhaimi Misha, Aiman Roslizar, Faridah Hussain, Nurfaizey Abdul Hamid, Zainal Arifin, and Safarudin Gazali Herawan. "Validation Study of Photovoltaic Thermal Nanofluid Based Coolant Using Computational Fluid Dynamics Approach." *CFD Letters* 13, no. 3 (2021): 58-71. https://doi.org/10.37934/cfdl.13.3.5871
[7] Lee, Joo Hee, Seong Geon Hwang, and Gwi Hyun Lee. "Efficiency improvement of a photovoltaic thermal (PVT) system using nanofluids." *Energies* 12, no. 16 (2019): 3063. https://doi.org/10.3390/en12163063
[8] Bin Mohd Rosli, Mohamad Afzanizam, Sohif Mat, Kamaruzzaman Sopian, Mohd Yusof Sulaiman, Elias Ilias Salleh, and Mohd Khairul Anuar Sharif. "Thermal performance on unglazed photovoltaic thermal polymer collector." *Advanced materials research* 911 (2014): 238-242. https://doi.org/10.4028/www.scientific.net/AMR.911.238
[9] Sachit, F. A., Noreffendy Tamaldin, M. A. M. Rosli, S. Misha, and A. L. Abdullah. "Current progress on flat-plate water collector design in photovoltaic thermal (PV/T) systems: A Review." *Journal of Advanced Research in Dynamical and Control Systems* 10, no. 4 (2018): 680-89.
[10] Diwania, Sourav, Rajeev Kumar, Sudhir Kumar Singh, Gagandeep Singh Dua, and Pavan Khetrapal. "Performance assessment of a serpentine tube PVT system using Cu and TiO2 nanofluids: an experimental study." *Journal of the Brazilian Society of Mechanical Sciences and Engineering* 44, no. 2 (2022): 71. https://doi.org/10.1007/s40430-022-03366-5
[11] Permanasari, Avita Ayu, Brilian Shakti Kuncara, Poppy Puspitasari, Sukarni Sukarni, Turnad Lenggo Ginta, and Windra Irdianto. "Convective heat transfer characteristics of TiO2-EG nanofluid as coolant fluid in heat exchanger." In *AIP Conference Proceedings*, vol. 2120, no. 1. AIP Publishing, 2019. https://doi.org/10.1063/1.5115691
[12] Priyanka, Sunil Kumar, and Anil Kumar. "Effect of mono/hybrid nanofluids and passive techniques on thermal performance of parabolic trough solar collector: A review." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 45, no. 1 (2023): 1686-1709. https://doi.org/10.1080/15567036.2023.2178551
[13] Brekke, Nick, John Dale, Drew DeJarnette, Parameswar Hari, Matthew Orosz, Kenneth Roberts, Ebrima Tunkara, and Todd Otanicar. "Detailed performance model of a hybrid photovoltaic/thermal system utilizing selective spectral nanofluid absorption." *Renewable Energy* 123 (2018): 683-693.

https://doi.org/10.1016/j.renene.2018.01.025

[14] Tang, Li Qing, and Qun Zhi Zhu. "Performance study of flowing-over PV/T system with different working fluid." *Applied Mechanics and Materials* 488 (2014): 1173-1176. https://doi.org/10.4028/www.scientific.net/AMM.488-489.1173

[15] Xu, Zelin, and Clement Kleinstreuer. "Concentration photovoltaic–thermal energy co-generation system using nanofluids for cooling and heating." *Energy conversion and management* 87 (2014): 504-512. https://doi.org/10.1016/j.enconman.2014.07.047

[16] Al-Shamani, Ali Najah, K. Sopian, Sohif Mat, Husam Abdulrasool Hasan, Azher M. Abed, and M. H. Ruslan. "Experimental studies of rectangular tube absorber photovoltaic thermal collector with various types of nanofluids under the tropical climate conditions." *Energy Conversion and Management* 124 (2016): 528-542. https://doi.org/10.1016/j.enconman.2016.07.052

[17] Khanjari, Y., F. Pourfayaz, and A. B. Kasaeian. "Numerical investigation on using of nanofluid in a water-cooled photovoltaic thermal system." *Energy Conversion and Management* 122 (2016): 263-278. https://doi.org/10.1016/j.enconman.2016.05.083

[18] Kumar, Anil, Priyanka, Sunil Kumar, and Susheel Kalia. "Optimization and correlations development for heat transfer and fluid flow characteristics of ZnO/H2O-ethylene glycol-based nanofluid flow through an inclined ribbed square duct." *Numerical Heat Transfer, Part A: Applications* (2023): 1-16. https://doi.org/10.1080/10407782.2023.2175747

[19] Mahmood Alsalame, Haedr Abdalha, Joo Hee Lee, and Gwi Hyun Lee. "Performance Evaluation of a Photovoltaic Thermal (PVT) system using nanofluids." *Energies* 14, no. 2 (2021): 301. https://doi.org/10.3390/en14020301

[20] Mingzheng, Zhou, Xia Guodong, Li Jian, Chai Lei, and Zhou Lijun. "Analysis of factors influencing thermal conductivity and viscosity in different kinds of surfactant solutions." *Experimental Thermal and Fluid Science* 36 (2012): 22-29. https://doi.org/10.1016/j.expthermflusci.2011.07.014

[21] Bambrook, S. M., and A. B. Sproul. "Maximising the energy output of a PVT air system." *Solar Energy* 86, no. 6 (2012): 1857-1871. https://doi.org/10.1016/j.solener.2012.02.038

[22] Liang, Kai, Kaili Xue, Heng Zhang, Haiping Chen, and Jianxiong Ni. "Design and performance analysis of an annular fresnel solar concentrator." *Energy* 210 (2020): 118594. https://doi.org/10.1016/j.energy.2020.118594

[23] Rosli, M. A. M., S. Misha, K. Sopian, S. Mat, M. Yusof Sulaiman, and E. Salleh. "Parametric analysis on heat removal factor for a flat plate solar collector of serpentine tube." *World Applied Sciences Journal* 29, no. 2 (2014): 184-187.

[24] Singhy, Arvind, Robin Thakur, and Raj Kumar. "Experimental analysis for co-generation of heat and power with convex lens as SOE and linear Fresnel Lens as POE using active water stream." *Renewable Energy* 163 (2021): 740-754. https://doi.org/10.1016/j.renene.2020.08.132

[25] Singhy, Arvind, Robin Thakur, Raj Kumar, Sushil Kumar, Sanjeev Kumar, and Sashank Thapa. "Influence of active water stream, irradiance, ambient temperature and wind speed on the efficiency of Fresnel lens based two stage PVT system." *Thermal Science* 26, no. 2 Part A (2022): 1139-1150. https://doi.org/10.2298/TSCI200801193S

[26] Zheng, Nianben, Long Wang, and Zhiqiang Sun. "The effects of ultrasonication power and time on the dispersion stability of few-layer graphene nanofluids under the constant ultrasonic energy consumption condition." *Ultrasonics Sonochemistry* 80 (2021): 105816. https://doi.org/10.1016/j.ultsonch.2021.105816

[27] Javadpour, Reza, Saeed Zeinali Heris, and Josua P. Meyer. "Experimental study of the effect of filled bed type on the performance of a cross-flow cooling tower with the approach of using nanofluids." *Energy Reports* 8 (2022): 8346-8360. https://doi.org/10.1016/j.egyr.2022.06.027

[28] Pawley, James, and Heide Schatten, eds. *Biological low-voltage scanning electron microscopy*. Springer Science & Business Media, 2007.

[29] Titus, D., and James Jebaseelan Samuel. "E. & Roopan, SM Nanoparticle characterization techniques. Green Synthesis, Characterization and Applications of Nanoparticles." (2019). https://doi.org/10.1016/B978-0-08-102579-6.00012-5

[30] Al-Janabi, Aws S., M. Hussin, and M. Z. Abdullah. "Stability, thermal conductivity and rheological properties of graphene and MWCNT in nanolubricant using additive surfactants." *Case Studies in Thermal Engineering* 28 (2021): 101607. https://doi.org/10.1016/j.csite.2021.101607

[31] Ebrahim, Shikha A., Emil Pradeep, Sayantan Mukherjee, and Naser Ali. "Rheological behavior of dilute graphene-water nanofluids using various surfactants: An experimental evaluation." *Journal of Molecular Liquids* 370 (2023): 120987. https://doi.org/10.1016/j.molliq.2022.120987

[32] Harchaoui, Ahmed, Ridha Mazouzi, and Abdelkader Karas. "The Rheology of Nanolubricants Based on Fe2O3, Al2O3, and ZnO Oxide Nanoparticles: A Comparative Study." *Physical Chemistry Research* 11, no. 2 (2023): 181-189.

[33] Yazdanifard, Farideh, Mehran Ameri, and Ehsan Ebrahimnia-Bajestan. "Performance of nanofluid-based photovoltaic/thermal systems: a review." *Renewable and Sustainable Energy Reviews* 76 (2017): 323-352. https://doi.org/10.1016/j.rser.2017.03.025

[34] He, Wei, Yang Zhang, and Jie Ji. "Comparative experiment study on photovoltaic and thermal solar system under natural circulation of water." *Applied Thermal Engineering* 31, no. 16 (2011): 3369-3376. https://doi.org/10.1016/j.applthermaleng.2011.06.021
[35] Zainon, S. N. M., and W. H. Azmi. "Recent progress on stability and thermo-physical properties of mono and hybrid towards green nanofluids." *Micromachines* 12, no. 2 (2021): 176. https://doi.org/10.3390/mi12020176
[36] Mahamude, Abu Shadate Faisal, Wan Sharuzi Wan Harun, Kumaran Kadirgama, Kaniz Farhana, D. Ramasamy, L. Samylingam, and Navid Aslfattahi. "Thermal performance of nanomaterial in solar collector: State-of-play for graphene." *Journal of Energy Storage* 42 (2021): 103022. https://doi.org/10.1016/j.est.2021.103022
[37] Taufantri, Yudha, Irdhawati Irdhawati, and I. A. R. A. Asih. "Sintesis dan Karakterisasi Grafena dengan Metode Reduksi Grafit Oksida Menggunakan Pereduksi Zn." *Jurnal Kimia VALENSI* 2, no. 1 (2016): 17-23. https://doi.org/10.15408/jkv.v2i1.2233
[38] Jiménez-Suárez, A., and S. G. Prolongo. "Graphene nanoplatelets." *Applied Sciences* 10, no. 5 (2020): 1753. https://doi.org/10.3390/app10051753
[39] Sadri, Rad, Khosro Zangeneh Kamali, M. Hosseini, Nashrul Zubir, S. N. Kazi, Goodarz Ahmadi, Mahidzal Dahari, Nay Ming Huang, and A. M. Golsheikh. "Experimental study on thermo-physical and rheological properties of stable and green reduced graphene oxide nanofluids: Hydrothermal assisted technique." *Journal of dispersion science and technology* 38, no. 9 (2017): 1302-1310. https://doi.org/10.1080/01932691.2016.1234387
[40] Timofeeva, Elena V., Jules L. Routbort, and Dileep Singh. "Particle shape effects on thermophysical properties of alumina nanofluids." *Journal of applied physics* 106, no. 1 (2009). https://doi.org/10.1063/1.3155999
[41] Choudhury, Bhaskar J., and Vijayanand S. Moholkar. "Ultrasound-assisted facile one-pot synthesis of ternary MWCNT/MnO2/rGO nanocomposite for high performance supercapacitors with commercial-level mass loadings." *Ultrasonics Sonochemistry* 82 (2022): 105896. https://doi.org/10.1016/j.ultsonch.2021.105896
[42] Khani, Hassan, and Omid Moradi. "Influence of surface oxidation on the morphological and crystallographic structure of multi-walled carbon nanotubes via different oxidants." *Journal of Nanostructure in Chemistry* 3 (2013): 1-8. https://doi.org/10.1186/2193-8865-3-73
[43] Kartick, B., and S. K. Srivastava. "Green synthesis of graphene." *Journal of nanoscience and nanotechnology* 13, no. 6 (2013): 4320-4324. https://doi.org/10.1166/jnn.2013.7461
[44] Bello, Roger H., Luiz AF Coelho, and Daniela Becker. "Role of chemical funcionalization of carbon nanoparticles in epoxy matrices." *Journal of Composite Materials* 52, no. 4 (2018): 449-464. https://doi.org/10.1177/0021998317709082
[45] Pang, Ai Ling, Muhamad Rasyidi Husin, Agus Arsad, and Mohsen Ahmadipour. "Effect of graphene nanoplatelets on structural, morphological, thermal, and electrical properties of recycled polypropylene/polyaniline nanocomposites." *Journal of Materials Science: Materials in Electronics* 32 (2021): 9574-9583. https://doi.org/10.1007/s10854-021-05620-3
[46] Tran, Vinh Q., Hai T. Doan, Nhiem T. Nguyen, and Cuong V. Do. "Preparation of graphene nanoplatelets by thermal shock combined with ball milling methods for fabricating flame-retardant polymers." *Journal of Chemistry* 2019 (2019). https://doi.org/10.1155/2019/5284160
[47] Iacobazzi, Fabrizio, Marco Milanese, Gianpiero Colangelo, and Arturo de Risi. "A critical analysis of clustering phenomenon in Al 2 O 3 nanofluids." *Journal of Thermal Analysis and Calorimetry* 135 (2019): 371-377. https://doi.org/10.1007/s10973-018-7099-9
[48] Sidik, Nor Azwadi Che, Muhammad Mahmud Jamil, Wan Mohd Arif Aziz Japar, and Isa Muhammad Adamu. "A review on preparation methods, stability and applications of hybrid nanofluids." *Renewable and Sustainable Energy Reviews* 80 (2017): 1112-1122. https://doi.org/10.1016/j.rser.2017.05.221
[49] Ghadimi, A., Rahman Saidur, and H. S. C. Metselaar. "A review of nanofluid stability properties and characterization in stationary conditions." *International journal of heat and mass transfer* 54, no. 17-18 (2011): 4051-4068. https://doi.org/10.1016/j.ijheatmasstransfer.2011.04.014
[50] Ma, Mingyan, Yuling Zhai, Peitao Yao, Yanhua Li, and Hua Wang. "Effect of surfactant on the rheological behavior and thermophysical properties of hybrid nanofluids." *Powder Technology* 379 (2021): 373-383. https://doi.org/10.1016/j.powtec.2020.10.089
[51] Das, Debadutta, Swetashree Pattanaik, Pankaj Kumar Parhi, Ranjan Kumar Mohapatra, Rajesh Kumar Jyothi, Jin-Young Lee, and Hong In Kim. "Stabilization and Rheological Behavior of Fly Ash–Water Slurry Using a Natural Dispersant in Pipeline Transportation." *ACS omega* 4, no. 25 (2019): 21604-21611. https://doi.org/10.1021/acsomega.9b03477
[52] Elfeky, Souad A., Shymaa Ebrahim Mahmoud, and Ahmed Fahmy Youssef. "Applications of CTAB modified magnetic nanoparticles for removal of chromium (VI) from contaminated water." *Journal of advanced research* 8, no. 4 (2017): 435-443. https://doi.org/10.1016/j.jare.2017.06.002
[53] Sajid, Muhammad Usman, and Hafiz Muhammad Ali. "Thermal conductivity of hybrid nanofluids: a critical

review." *International Journal of Heat and Mass Transfer* 126 (2018): 211-234. https://doi.org/10.1016/j.ijheatmasstransfer.2018.05.021

[54] Li, Yanjiao, Simon Tung, Eric Schneider, and Shengqi Xi. "A review on development of nanofluid preparation and characterization." *Powder technology* 196, no. 2 (2009): 89-101. https://doi.org/10.1016/j.powtec.2009.07.025

[55] Solanki, S. C., Swapnil Dubey, and Arvind Tiwari. "Indoor simulation and testing of photovoltaic thermal (PV/T) air collectors." *Applied energy* 86, no. 11 (2009): 2421-2428. https://doi.org/10.1016/j.apenergy.2009.03.013

[56] Al-Waeli, Ali HA, Miqdam T. Chaichan, Hussein A. Kazem, K. Sopian, Adnan Ibrahim, Sohif Mat, and Mohd Hafidz Ruslan. "Comparison study of indoor/outdoor experiments of a photovoltaic thermal PV/T system containing SiC nanofluid as a coolant." *Energy* 151 (2018): 33-44. https://doi.org/10.1016/j.energy.2018.03.040

[57] He, Qinbo, Shuangfeng Wang, Mingwei Tong, and Yudong Liu. "Experimental study on thermophysical properties of nanofluids as phase-change material (PCM) in low temperature cool storage." *Energy conversion and management* 64 (2012): 199-205. https://doi.org/10.1016/j.enconman.2012.04.010

[58] Sandhya, Madderla, D. Ramasamy, K. Sudhakar, K. Kadirgama, and W. S. W. Harun. "Ultrasonication an intensifying tool for preparation of stable nanofluids and study the time influence on distinct properties of graphene nanofluids–A systematic overview." *Ultrasonics sonochemistry* 73 (2021): 105479. https://doi.org/10.1016/j.ultsonch.2021.105479

[59] Nabi, Hossein, Mohsen Pourfallah, Mosayeb Gholinia, and Omid Jahanian. "Increasing heat transfer in flat plate solar collectors using various forms of turbulence-inducing elements and CNTs-CuO hybrid nanofluids." *Case Studies in Thermal Engineering* 33 (2022): 101909. https://doi.org/10.1016/j.csite.2022.101909

[60] Aly, Wael IA. "Numerical Study of Fluid Dynamic and Heat Transfer Performance of Nanofluid in Coiled Tube-in-Tube Heat Exchangers." *Energy Convers. Manage* 79 (2014): 304-316. https://doi.org/10.1016/j.enconman.2013.12.031

[61] Ilhan, Beybin, Melike Kurt, and Hakan Ertürk. "Experimental investigation of heat transfer enhancement and viscosity change of hBN nanofluids." *Experimental Thermal and Fluid Science* 77 (2016): 272-283. https://doi.org/10.1016/j.expthermflusci.2016.04.024

[62] Mahbubul, I. M., E. B. Elcioglu, M. A. Amalina, and R. J. P. T. Saidur. "Stability, thermophysical properties and performance assessment of alumina–water nanofluid with emphasis on ultrasonication and storage period." *Powder Technology* 345 (2019): 668-675. https://doi.org/10.1016/j.powtec.2019.01.041

[63] Mukherjee, Sayantan, Purna Ch Mishra, S. K. S. Parashar, and Paritosh Chaudhuri. "Role of temperature on thermal conductivity of nanofluids: a brief literature review." *Heat and Mass Transfer* 52 (2016): 2575-2585. https://doi.org/10.1007/s00231-016-1753-1

[64] Farooq, M., M. Farhan, Gulzar Ahmad, M. Usman, M. Sultan, M. Saad Hanif, M. Imran, Saqib Anwar, Ahmed M. El-Sherbeeny, and M. Ali Shakir. "Thermal performance enhancement of nanofluids based parabolic trough solar collector (NPTSC) for sustainable environment." *Alexandria Engineering Journal* 61, no. 11 (2022): 8943-8953. https://doi.org/10.1016/j.aej.2022.02.029

[65] Khalili, Z., and M. Sheikholeslami. "Investigation of innovative cooling system for photovoltaic solar unit in existence of thermoelectric layer utilizing hybrid nanomaterial and Y-shaped fins." *Sustainable Cities and Society* 93 (2023): 104543. https://doi.org/10.1016/j.scs.2023.104543

[66] Abdullah, Amira Lateef, S. Misha, N. Tamaldin, M. A. M. Rosli, and F. A. Sachit. "Theoretical study and indoor experimental validation of performance of the new photovoltaic thermal solar collector (PVT) based water system." *Case Studies in Thermal Engineering* 18 (2020): 100595. https://doi.org/10.1016/j.csite.2020.100595