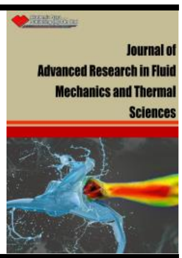
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Experimental Investigation on Evacuated Tube Solar Collector Using Biofluid as Heat Transfer Fluid

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ARTICLE INFO

Article history:
Received 27 July 2021
Received in revised form 1 September 2021
Accepted 7 September 2021
Available online 28 September 2021

Keywords:
Evacuated tube solar collector; biofluid, heat transfer fluid; solar radiation; thermophysical properties

ABSTRACT

Bio-oil extracted from waste of different plant kernel was used as heat transfer fluid in evacuated tube solar collector. Thermal performance of the biofluids to the enhancement of the evacuated tube solar collector under varying weather conditions and experimental analysis was carried-out. Thermal analysis on the storage water tank temperature, outlet and inlet heat transfer fluid temperature, and heat gains by was studied. In addition, the biofluids thermophysical properties and degradation analysis was conducted and compared with conventional base-fluids. From the results the biofluids caused enhancement of heat gain in the collector receiver by 9.5%, 6.4% and 3.2% for *moringa oleifera* kernel oil (*MOKO*), *date kernel* oil (*DKO*) and *palm kerne*l oil (*PKO*), respectively. The storage water tank temperature at night fall was 53, 49, 51 and 47°C, for the *MOKO*, *DKO*, *PKO* and water HTFs, respectively. The biofluids were thermal stable and with no degradation. The biofluids demonstrated potentials as heat transfer fluids in thermal applications but there are needs for more investigations on their enhancement with organically synthesized nano particles to preserve there no corrosive and toxicity nature, and experimental performance on heat exchangers after several heating cycles.

1. Introduction

Renewable solar energy is clean, sustainable, and globally abundant, but intermittent in nature, and has been used for thousands of years in many ways by people all over the world. This radiant energy comes from the light and heat of the sun, has been harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis. The oldest use of solar energy is drying, water and space heating. Solar thermal collectors (STC), has been employed in harnessing, storing, and converting solar energy into useful form of energy for domestic and industrial consumption. Different types of STCs designs are in existence, with the flat plate solar collector, (FPSC), and evacuated tube

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https://doi.org/10.37934/arfmts.87.3.4050

solar collector, (ETSC) considered an important type of solar collector, partly because of their simple design configuration, low maintenance and applications in low and medium temperature operations [1]. The ETSC has advantage because of less convection heat losses, high absorbance, high surface area, and high temperature difference with surrounding, low maintenance, low weight and higher efficiency value compared to FPSC.

Heat transfer fluid, (HTF) is an important component in STCs, and contribute hugely to the overall efficiency of the systems. Several studies on different types of HTFs used to improve the thermal performance and overall efficiency of ETSC are available in literatures [1-4]. Studies on conventional base fluids like propylene-glycol / water mixture, [5], ZnO ethylene glycol / water mixture, [6]; Synthetic and aromatic fluids like theminol oils [7], halide salt mixture, [8]; Nanofluids like CeO^2/water nanofluid [9], carbon nanotubes, [10], copper nanofluids, [11], Al_2O_3/distilled water nanofluid, [12]; Hybrid nanofluid like titanium dioxide nanofluid, [13], supercritical CO^2, [14], graphene nanoplatelets nanofluid, [15]. Despite the several reports and performance enhancement achieved using these base fluids, hybrid fluid and nanofluids, the HTFs enhancement in thermal collectors are still low, besides the problems of melting / boiling temperatures of base fluids, corrosion and clogging of pipe ducts and micro-channels needs to be addressed and more importantly, the issues of toxicity, arising from the chemically synthesized base fluids are source of concern for manufacturer and consumer alike. One such ways of mitigating this setback is by the use of biofluids as HTFs in a thermally driven heating and cooling systems.

Biofluids have been long studied by several researchers on their physicochemical properties [16-18], structural elucidation [18,19], medicinal and health properties [20,21], cosmetics and allied properties [22]. Whereas few studies [17,23], investigated on thermal and physical properties of oils. While fewer studied on their mechanical and thermophysical properties. Therefore, biofluids from Moringa Oleifera seed (*Moringaceae)* kernel, Date seed (*Phoenix dactylifera L)* kernel, and Palm seed (*Elaeis*) kernel are investigated in this study for heat transfer applications in solar thermal collectors.

2. Materials and Methods

2.1 List of Materials and Equipment

Biofluids of moringa oleifera kernel, date kernel and palm kernel, thermal constant analyzer, evacuated tube solar collectors (ETSC), storage water tanks (SWT), coil heat exchanger, solarimeter, centrifugal pump, connecting valves, timer, thermocouples, flowmeter, data-logger, differential scanning calorimetry (DSC), thermogravimetric (TGA).

2.2 Description of the Experiment

The outdoor examinations were carried out in Perak, Malaysia (4.5921° N, 101.0901° E), for 4 months period from 7am–7pm daily, to represent all weather conditions. The evacuated tuber STCs and storage water tanks was operated simultaneously to provide accurate thermal performance comparison between HTFs. The SWT, capacity was 70 liters, a coil heat exchanger of 1500mm long, 10mm diameter provides constant heat flux from the ETSC to the SWT in a close-loop connection. Aperture area of $1.85m^2$, gross area $1.85m^2$, width 750mm, length 1895mm, height 142mm, 8 vacuum tubes, absorbance 0.93, emission factor 0.006, net weight of 44kg, glass wool, and thickness 60mm. There was no water drawn-off during experiment, and 0.5kg/s flowrate was implemented. K-type thermocouples were equally spaced around the outer surface of the ETSC and SWTs and extended to temperature indicator. Figure 1 shows the schematic diagram of the experimental setup.

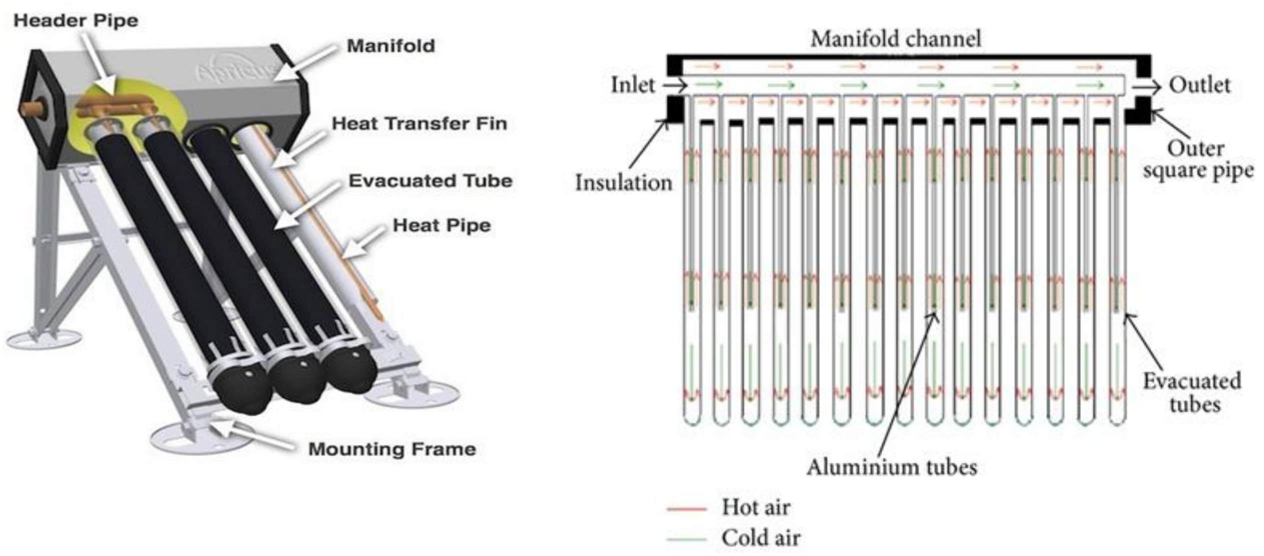


Fig. 1. Schematic of evacuated tube solar thermal collector

ASHRAE standard 93-2003, was employed in examination of the collector performance, which highlighted the outdoor test variation was 610 w/m^2 and 785w/m^2 for average monthly solar radiation during cloudy and sunny weather conditions, with maximum variation period was ±23 and ±34 W/m^2. In addition, the maximum variation of ambient temperature during data period was ±1.5°C, for test period of 15 mins.

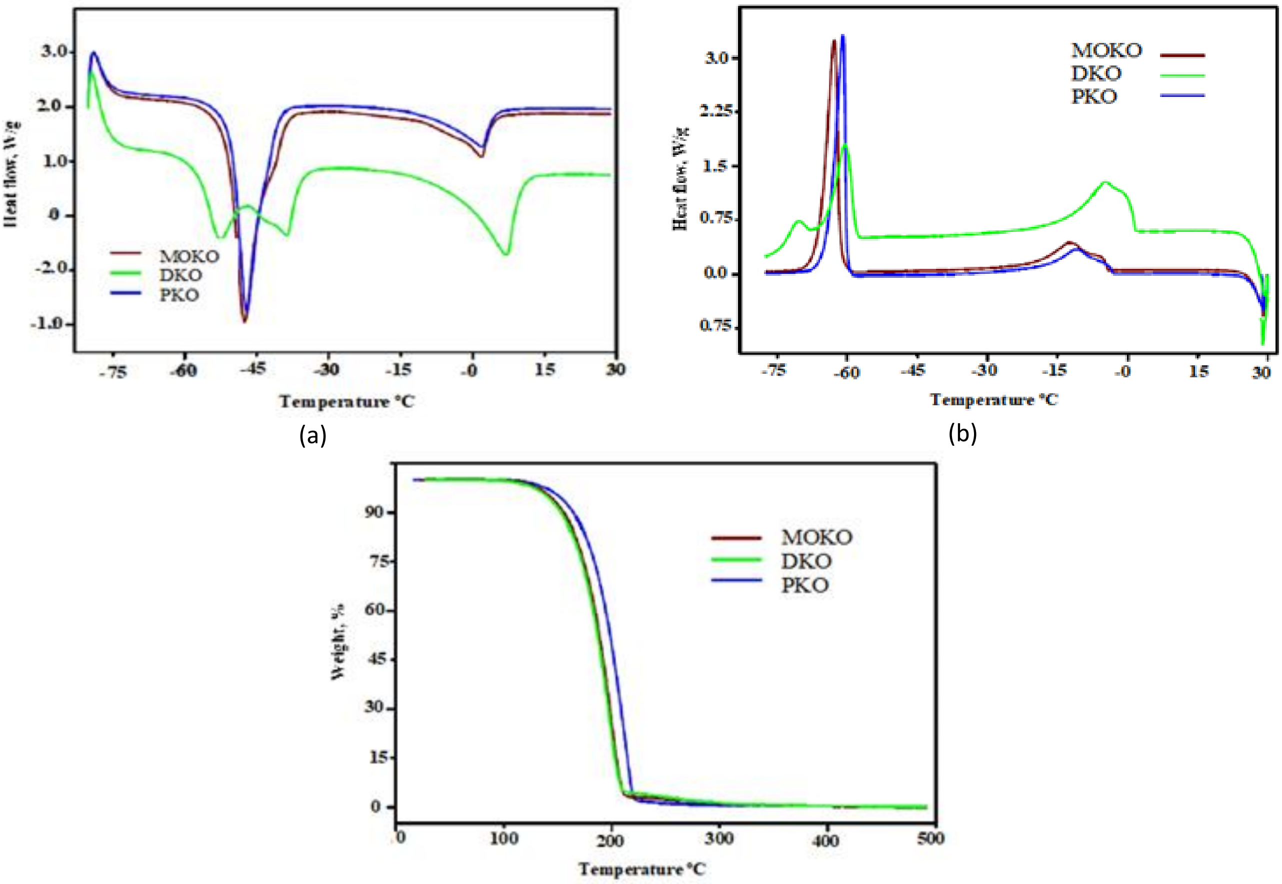
2.3 Laboratory Measurement Thermal Analysis

Table 1 shows the thermophysical properties of the biofluids HTFs and compared with conventional base fluid - water. The thermal conductivity values of the biofluids are less than water, with *MOKO* have the highest thermal conductivity, specific heat, and enthalpy values of 0.1698 W/m.K, 1984.01 MJ/m^{3}K and 59.46 J/g, respectively. The average enthalpy values of the biofluid are 53 kJ/kg, which is less than the enthalpy value of water 123.23 kJ/kg, but the biofluids have higher melting and boiling temperature compared to the water. Higher melting point indicates greater intermolecular forces and therefore less vapor pressure [24,25]. This implies the biofluids can be used for high temperature operating HTFs in heat transfer applications, with average melting and boiling temperature at 26^{o}C and 201^{o}C. Besides, the setback of freezing and clog formation which can block pipes and tubing ducts connections, the issues of corrosion, toxicity [26,27], from the chemically synthesized conventional base fluids and base fluid mixtures, and health issues are raising serious concerns among manufacturing and consumers.

Table 1
Thermophysical properties of biofluids oil

Heat Transfer Fluids	Thermal Conductivity λ/ Wm^{-1}k^{-1} 30^{o}C	Specific Heat J/(kg.K)	Viscosity (µ) at 30°C	Density Kg/m^3 at 30°C	Enthalpy (kJ/kg)	Melting /Boiling Temp (ºC)
Water	0.6072	4180.12	1.0034	997.53	123.24	0 / 100
MOKO	0.2098	2384.01	35.3625	0.8742	59.46	23 / 186
DKO	0.1384	1597.42	29.6511	0.7123	42.30	28 / 205
PKO	0.1421	1813.51	32.3342	0.9281	52.14	27 /213

Thermal analysis of the biofluids showed no degradation as shown in the DSC and TGA in Figure 2. During melting and crystallization, two peak values was observed, the primary and secondary peak values was (-51: 5) °C and (-48: -3) °C, for the *MOKO* and *PKO*, respectively. Although, the *DKO* biofluids showed identical heat transition pattern but with triple peaks. The primary and secondary peak values during melting and crystallization was (-58: -4) °C, respectively. The sharp difference in the biofluids glass transition temperature can be traced to the enthalpy difference, the *DKO* was 7.2% less off the enthalpies of the *MOKO* and *PKO*. The TGA curve of the biofluids are consistent, there was no weight loss observed, after degradation temperature measurement. Biofluids unlike mineral oil and synthetic aromatic-based HTFs do not produce sludge that blocks pipe plugging, seal wear and fouling of heat exchange surfaces in heat transfer systems, [26,28].



(a) (b)

(c)

Fig. 2. Thermal analysis of MOKO, DKO and PKO (a) DSC - Melting (b) DSC - Crystallization and (c) TGA

2.4 Uncertainty Analysis

In any experimental or measurement design, uncertainty analysis is an important aspect of the program. The system performance is determined from the systematic and random uncertainties which comprises the combined experimental uncertainty considered. The errors from measuring instruments, data recording or calibration errors are referred to as the systematic uncertainties. While errors caused by scattering or fluctuations in measured data are referred to as systematic uncertainties. Herein, the results of the calculated uncertainty analysis for the experimentation of the heat gain and evacuated tube solar collector efficiency are presented.

$$Q_{gain} = \dot{m}\, C_p\, (T_{out} - T_{in}) \quad (1)$$

$$Q_{gain} = f\,(T_{in}, T_{out}, \dot{m}, C_p) \quad (2)$$

$$\eta_{ETSC} = \frac{\dot{m}\, C_p\, (T_{out} - T_{in})}{I_{inc-pow}} \quad (3)$$

Therefore, the systematic uncertainty of the system efficiency can be written as

$$\Delta Q_{gain} = \sqrt{(\Delta T_{in} \frac{\partial Q_{gain}}{\partial T_{in}} + \Delta T_{out} \frac{\partial Q_{gain}}{\partial T_{out}} + \Delta \dot{m} \frac{\partial Q_{gain}}{\partial \dot{m}} + \Delta C_P \frac{\partial Q_{gain}}{\partial C_P})^2} \quad (4)$$

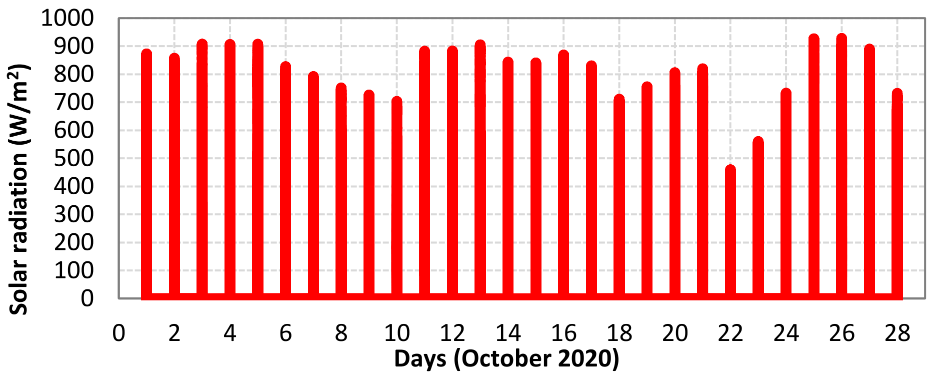
The random uncertainty can be written as

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \quad (5)$$

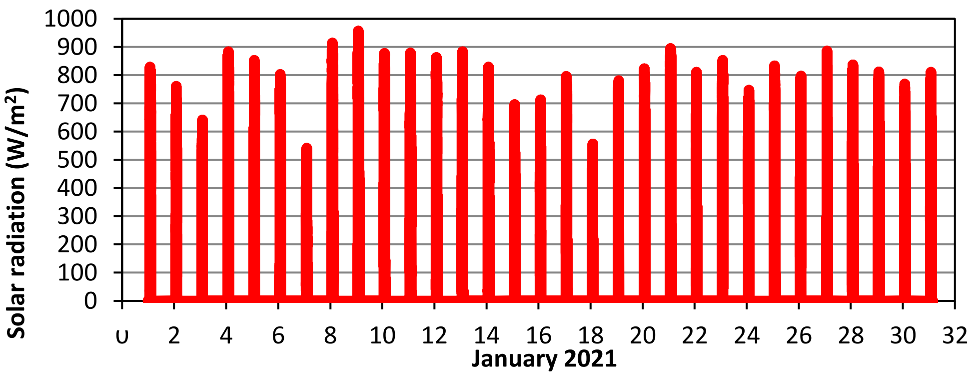
3. Result and Discussion

3.1 Experimental Measurement Heat Transfer

Figure 3(a) and (b) shows the variation in daily average solar radiation for October 2020 and January 2021. Four days was selected among the test period to represent both sunny and cloudy weathers.



(a)



(b)

Fig. 3. (a) Direct normal irradiance variation during October 2020 (b) Direct normal irradiance variation during January 2021

The maximum and minimum direct irradiation recorded in October 2020 was 918 W/m2 and 444 W/m^2, respectively. Whereas the maximum and minimum daily direct radiation recorded in January 2021 was 938 W/m^2 and 556 W/m^2, respectively. Both days were selected for the experimental measurement because it represented cloudy and sunny weather conditions. On overall, the average monthly direct radiation was 623 and 725 W/m^2, respectively.

Figure 4(a) and (b) shows the variation of direct irradiation during the outdoor measurement. The measured data on October 8 and 21, 2020, and January 4 and 25, 2021, between 9am to 7pm was selected. Solar influx contributes to performance of solar thermal collector, during sunny weathers, thermal collectors absorbs high amount of radiation, and converts to heat and electricity for domestic consumption [2,29]. Thermal performance of the ETSC in terms of heat flux, HTFs temperature and SWT temperature is presented and discussed.

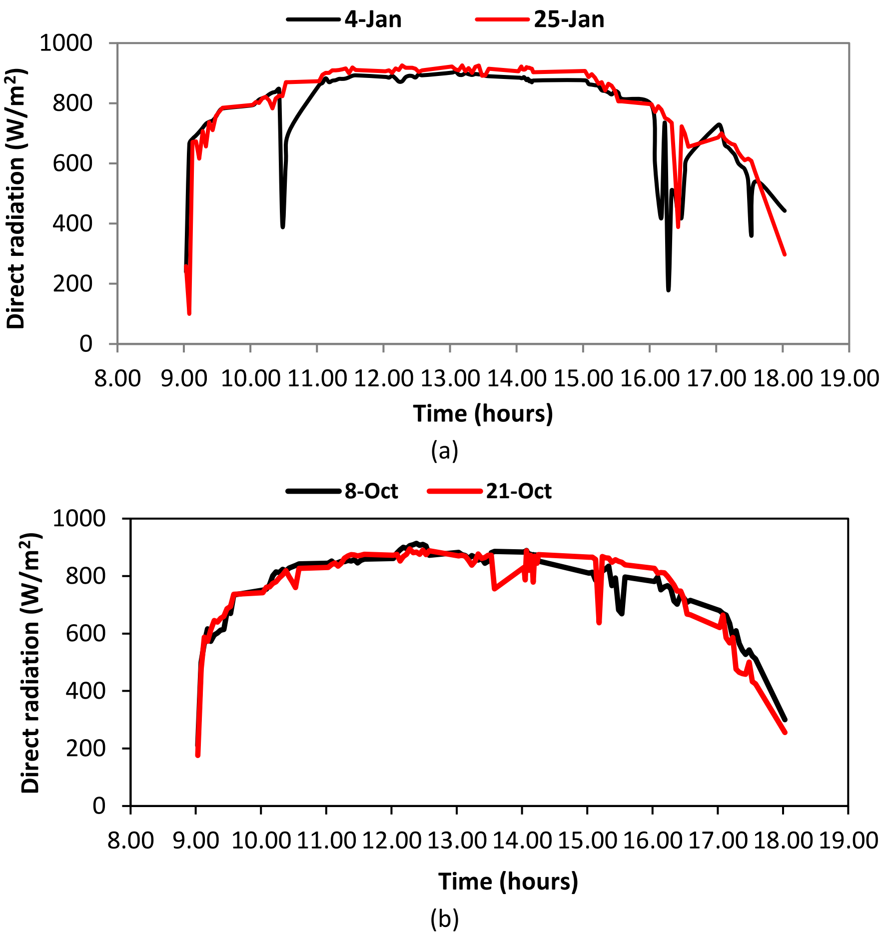


Fig. 4. (a) Direct normal irradiance variation during experimental test of the evacuated receiver January 2020 (b) Direct normal irradiance variation during experimental test of the evacuated receiver October 2020

3.2 Heat Gain Analysis

The changes in heat gain in the evacuated tube receiver (ETR) measurement is captured in Table 2 for the biofluids and water base fluid. The highest heat gain record was achieved during peak radiation period (afternoon), during both cloudy and sunny weathers. Heat gain increases as the HTF temperatures, which is caused by increase heat flux and solar radiation, [30,31]. The average heat gain for ETR was 8025W for water HTF. When the biofluid was used as HTF, the average heat gain increased by 9.5%, 6.4%, and 3.2% for *MOKO*, *DKO* and *PKO* HTFs, respectively.

Table 2
Measured ETSC heat gain enhancement for biofluid HTFs and water

Time	Radiation	HTFs heat gain enhances percentage (%)			
Hourly	W/m^2	Water	MOKO	DKO	PKO
10:00	341	7983	8713	8342	8569
12:00	889	9019	1122	9816	1001
14:00	1040	8901	9915	9814	9436
16:00	712	6073	6935	6672	6598

Between the biofluids, the *MOKO* HTFs was optimal, and the reason was because of the higher melting and boiling temperature compare to others. Besides, the *MOKO* enthalpy was 18.5% higher than the rest biofluids, though with higher viscosity values which requires more pumping power. Also, the condensation characteristics of HTFs in heat exchangers is reduced with less volatility, thus increasing the rate of heat transfer, [32]. The behavior of the HTFs temperature at the outlet of the ETSC receiver is shown in Figure 5. The temperature at the outlet of the ETSC depends on factors such as the design configuration, surface area, HTF type, heat flux etc. [33-35]. In this study, it was observed that the average HTF temperature was enhanced at the peak irradiation for the three biofluids.

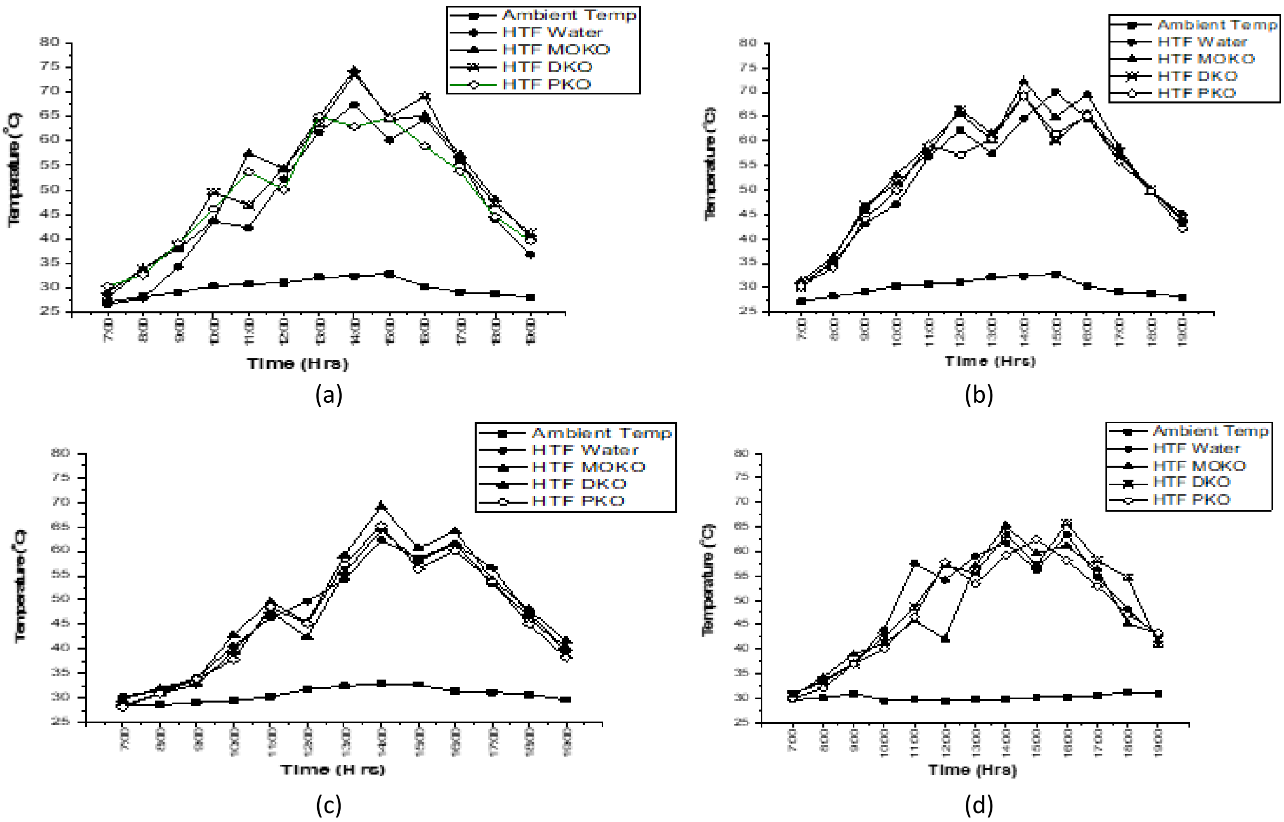


Fig. 5. Evacuated tube outlet HTF temperature for biofluids (a) Sunny weather case 1 (b) Sunny weather case 2 (c) Cloudy weather case 1 and (d) Cloudy weather case 2

The HTF temperatures was 77, 64 and 69℃ for *MOKO*, *DKO* and *PKO*, respectively, at case 1 measurement. During case 2 measurement, 65, 61 and 59℃, was obtained for *MOKO*, *DKO* and *PKO*, respectively. The average HTFs temperature of the ETR is 73, 70 and 68°C for *MOKO*, *DKO* and *PKO*, respectively, during case 1. Whereas during case 2, the average HTF temperature is 65, 62 and 59°C for *MOKO*, *DKO* and *PKO*, respectively. However, the PKO had optimal performance during case 2 because of accumulated heat flux and strongly due to higher solar irradiance received. The biofluids HTFs thermal performance was better than the water HTFs.

The relationship between the HTFs temperature and storage water temperature is presented in Figure 6. A decrease in temperature causes an increase in humidity, [36-38]. From the result, the daily maximum SWT temperature and average daily SWT temperature for water-HTF was 60.26 °C and 45°C, respectively. Similarly, daily maximum SWT and daily average HTF temperature for MOKO, DKO and PKO was (64.62; 48.80) °C, (61.16; 46.45) °C, and (58.44; 44.88) °C, respectively. The HTFs temperature of the MOKO at the outlet of the ETSC receiver and the inlet of the storage water tank was same because no heat loss is recorded. However, the gradient between the storage water tank inlet and outlet temperature was 4°C. The storage water temperature increased as the HTFs temperature gradient increased with the highest gradient at 7°C. The increment can be traced to the increase in solar radiation. Overall, the biofluids impacted the storage tank water temperature better than the water. The average storage water tank temperature was 56, 52, 48 and 50°C, for the MOKO, DKO, PKO and water HTFs, respectively, for case 1. And for case 2, the storage water tank temperature was 51, 47, 43 and 45°C, for the MOKO, DKO, PKO and water HTFs, respectively.

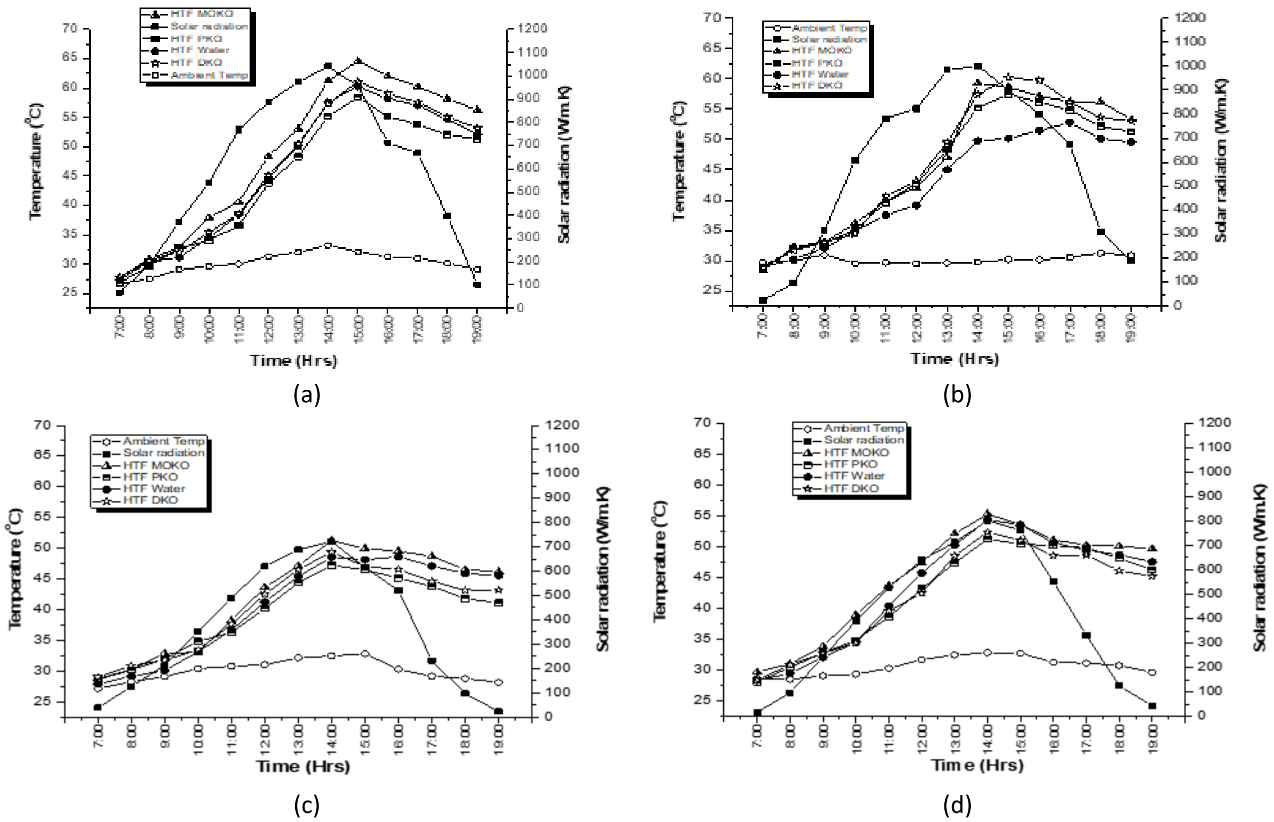


Fig. 6. Storage water tank temperature using biofluids HTF (a) sunny weather case 1 (b) sunny weather case 2 (c) cloudy weather case 1 (d) cloudy weather case 2

3.3 Uncertainty Analysis of the Experiment of the Heat Gain

The margin of error for the heat gain is acceptable, where the maximum error is ±3.1%. The mean percentage of error is ±2.86%. The maximum percentages of error in the three cases are ±2.6%, ±2.9% and ±3.1% for data cases of 152℃, 158℃, and 170℃, respectively.

3.4 Uncertainty of the Evacuated Tube Solar Collector

Efficiency - Accordingly, the predicted uncertainty of the receiver efficiency for the cases was within the range of ± 2%. It is low due to high accuracy of the instruments used in the experiments.

4. Conclusion

The intrinsic nature of biofluid resources because of their thermophysical and chemical characteristics from biomass waste and by-produce conversion into useful energy carriers because of the biofluid limitations. Needs to evaluate the advances of biofluids production processes, identify their potential applications, appropriate feedstocks, suitable power generation systems, technoeconomic values and environmental impacts. The integration of biofluids with power generation systems, in thermal and electrical can contribute new economic dynamics by creation of new feedstock demand and supply, thereby impacting the economic positively, without undermining food impacts. It has been observed that the biofluids can be used as heat transfer fluid in many thermal applications because of the enhancement in heat transfers. The biofluids (*MOKO*, *DKO* and *PKO*), studied were thermally stable, as no degradation or weight lost is recorded. There thermophysical properties was comparable to conventional water base HTFs, also the non-corrosive and non-toxic property is an advantage over synthetic chemical and aromatic oils. By using biofluids, in heat exchanging devices like solar thermal collectors, micro and macro heat channels, heat engines and thermal electronics cooling applications may be made more energy efficient and compact. Biofluids has a promising future in industry applications, there are opportunities to interact biofluids into power generation systems, though the need for evaluation on suitability with current and future technology is essential.

Conflict of Interest
The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Acknowledgements
The corresponding author acknowledge the Research Management Centre, (RMC), Universiti Tun Hussein Onn Malaysia for the financial support under the RMC TIER-1 (H829) and RMC Research Fund (E15501).

References
[1] Muhammad, Mahmud Jamil, Isa Adamu Muhammad, Nor Azwadi Che Sidik, and Muhammad Noor Afiq Witri Muhammad Yazid. "Thermal performance enhancement of flat-plate and evacuated tube solar collectors using nanofluid: a review." *International Communications in Heat and Mass Transfer* 76 (2016): 6-15. https://doi.org/10.1016/j.icheatmasstransfer.2016.05.009

[2] Afolabi, Lukmon Owolabi, Hussain Hamoud Al-Kayiem, and Tesfamichael Baheta Aklilu. "Performance analysis of integrated collector system with immersed coil heat exchanger." In *Applied Mechanics and Materials*, vol. 660, pp. 740-744. Trans Tech Publications Ltd, 2014. https://doi.org/10.4028/www.scientific.net/AMM.660.740

[3] Ozsoy, Ahmet, and Vahit Corumlu. "Thermal performance of a thermosyphon heat pipe evacuated tube solar collector using silver-water nanofluid for commercial applications." *Renewable Energy* 122 (2018): 26-34. https://doi.org/10.1016/j.renene.2018.01.031
[4] Kim, Hyeongmin, Jinhyun Kim, and Honghyun Cho. "Review of thermal performance and efficiency in evacuated tube solar collector with various nanofluids." *International Journal of Air-Conditioning and Refrigeration* 25, no. 02 (2017): 1730001. https://doi.org/10.1142/S2010132517300014
[5] Manikandan, S., and K. S. Rajan. "New hybrid nanofluid containing encapsulated paraffin wax and sand nanoparticles in propylene glycol-water mixture: Potential heat transfer fluid for energy management." *Energy Conversion and Management* 137 (2017): 74-85. https://doi.org/10.1016/j.enconman.2017.01.033
[6] Kaya, Hüseyin, Kamil Arslan, and Nurettin Eltugral. "Experimental investigation of thermal performance of an evacuated U-Tube solar collector with ZnO/Etylene glycol-pure water nanofluids." *Renewable energy* 122 (2018): 329-338. https://doi.org/10.1016/j.renene.2018.01.115
[7] Bindu, M. V., and GM Joseline Herbert. "Applications of Parabolic Trough Concentrating Technology: A Review." *Advances in Automation, Signal Processing, Instrumentation, and Control: Select Proceedings of I-CASIC 2020* 700 (2021): 361. https://doi.org/10.1007/978-981-15-8221-9_34
[8] Mwesigye, Aggrey, and İbrahim Halil Yılmaz. "Thermal and thermodynamic benchmarking of liquid heat transfer fluids in a high concentration ratio parabolic trough solar collector system." *Journal of Molecular Liquids* 319 (2020): 114151. https://doi.org/10.1016/j.molliq.2020.114151
[9] Sharafeldin, M. A., and Gyula Grof. "Evacuated tube solar collector performance using CeO2/water nanofluid." *Journal of Cleaner Production* 185 (2018): 347-356. https://doi.org/10.1016/j.jclepro.2018.03.054
[10] Mahbubul, I. M., Mohammed Mumtaz A. Khan, Nasiru I. Ibrahim, Hafiz Muhammad Ali, Fahad A. Al-Sulaiman, and R. J. R. E. Saidur. "Carbon nanotube nanofluid in enhancing the efficiency of evacuated tube solar collector." *Renewable energy* 121 (2018): 36-44. https://doi.org/10.1016/j.renene.2018.01.006
[11] Sharafeldin, M. A., Gyula Gróf, Eiyad Abu-Nada, and Omid Mahian. "Evacuated tube solar collector performance using copper nanofluid: Energy and environmental analysis." *Applied Thermal Engineering* 162 (2019): 114205. https://doi.org/10.1016/j.applthermaleng.2019.114205
[12] Ghaderian, Javad, and Nor Azwadi Che Sidik. "An experimental investigation on the effect of Al2O3/distilled water nanofluid on the energy efficiency of evacuated tube solar collector." *International Journal of Heat and Mass Transfer* 108 (2017): 972-987. https://doi.org/10.1016/j.ijheatmasstransfer.2016.12.101
[13] Gan, Yong Yang, Hwai Chyuan Ong, Tau Chuan Ling, Nurin Wahidah Mohd Zulkifli, Chin-Tsan Wang, and Yung-Chin Yang. "Thermal conductivity optimization and entropy generation analysis of titanium dioxide nanofluid in evacuated tube solar collector." *Applied Thermal Engineering* 145 (2018): 155-164. https://doi.org/10.1016/j.applthermaleng.2018.09.012
[14] Qiu, Yu, Ming-Jia Li, Ya-Ling He, and Wen-Quan Tao. "Thermal performance analysis of a parabolic trough solar collector using supercritical CO2 as heat transfer fluid under non-uniform solar flux." *Applied Thermal Engineering* 115 (2017): 1255-1265. https://doi.org/10.1016/j.applthermaleng.2016.09.044
[15] Iranmanesh, Soudeh, Hwai Chyuan Ong, Bee Chin Ang, Emad Sadeghinezhad, Alireza Esmaeilzadeh, and Mohammad Mehrali. "Thermal performance enhancement of an evacuated tube solar collector using graphene nanoplatelets nanofluid." *Journal of cleaner production* 162 (2017): 121-129. https://doi.org/10.1016/j.jclepro.2017.05.175
[16] Oluwafunke Toyin, Afolabi-Owolabi. "Extraction And Characterization Of Moringa Oleifera Kernel Oil And Encapsulation By Coaxial Electrospinning." PhD diss., Universiti Sains Malaysia, 2019.
[17] Afolabi-Owolabi, Oluwafunke T., Syahariza Z. Abidin, and Fazila Ariffin. "Electrospun polymer nanofiber from moringa oleifera kernel oil with coaxial electrospinning method." *Current Nutrition & Food Science* 16, no. 1 (2020): 90-97. https://doi.org/10.2174/1573401315666181120113219
[18] Iram, Wajiha, Tehmina Anjum, Mazhar Iqbal, Abdul Ghaffar, and Mateen Abbas. "Structural elucidation and toxicity assessment of degraded products of aflatoxin B1 and B2 by aqueous extracts of Trachyspermum ammi." *Frontiers in microbiology* 7 (2016): 346. https://doi.org/10.3389/fmicb.2016.00346
[19] Sawada, Kazue, Takuya Nakagami, Halida Rahmania, Midori Matsuki, Junya Ito, Tomoyo Mohri, Yusuke Ogura, Shigefumi Kuwahara, Hiroyuki Hashimoto, and Kiyotaka Nakagawa. "Isolation and structural elucidation of unique γ-oryzanol species in rice bran oil." *Food Chemistry* 337 (2021): 127956. https://doi.org/10.1016/j.foodchem.2020.127956
[20] Arasu, Mariadhas Valan, Ponnuswamy Viayaraghavan, Soundarrajan Ilavenil, Naif Abdullah Al-Dhabi, and Ki Choon Choi. "Essential oil of four medicinal plants and protective properties in plum fruits against the spoilage bacteria and fungi." *Industrial Crops and Products* 133 (2019): 54-62. https://doi.org/10.1016/j.indcrop.2019.03.018

[21] Mohammadhosseini, Majid. "The ethnobotanical, phytochemical and pharmacological properties and medicinal applications of essential oils and extracts of different Ziziphora species." *Industrial crops and products* 105 (2017): 164-192. https://doi.org/10.1016/j.indcrop.2017.05.009
[22] González-Minero, Francisco José, Luis Bravo-Díaz, and Antonio Ayala-Gómez. "Rosmarinus officinalis L.(Rosemary): An Ancient Plant with Uses in Personal Healthcare and Cosmetics." *Cosmetics* 7, no. 4 (2020): 77. https://doi.org/10.3390/cosmetics7040077
[23] Teixeira, Gerson Lopes, Suelen Avila, Joana Léa Meira Silveira, Marcelo Ribani, and Rosemary Hoffmann Ribani. "Chemical, thermal and rheological properties and stability of sapucaia (Lecythis pisonis) nut oils." *Journal of Thermal Analysis and Calorimetry* 131, no. 3 (2018): 2105-2121. https://doi.org/10.1007/s10973-017-6742-1
[24] Krishna, Yathin, M. Faizal, R. Saidur, K. C. Ng, and Navid Aslfattahi. "State-of-the-art heat transfer fluids for parabolic trough collector." *International Journal of Heat and Mass Transfer* 152 (2020): 119541. https://doi.org/10.1016/j.ijheatmasstransfer.2020.119541
[25] Cadiou, S., M. Courtois, M. Carin, W. Berckmans, and P. Le Masson. "Heat transfer, fluid flow and electromagnetic model of droplets generation and melt pool behaviour for wire arc additive manufacturing." *International Journal of Heat and Mass Transfer* 148 (2020): 119102. https://doi.org/10.1016/j.ijheatmasstransfer.2019.119102
[26] Touaba, Oussama, Mohamed Salah Ait Cheikh, Mohamed El-Amine Slimani, Ahmed Bouraiou, Abderrezzaq Ziane, Ammar Necaibia, and Arezki Harmim. "Experimental investigation of solar water heater equipped with a solar collector using waste oil as absorber and working fluid." *Solar Energy* 199 (2020): 630-644. https://doi.org/10.1016/j.solener.2020.02.064
[27] Foulkes, Thomas, Soumyadip Sett, Peter Sokalski, Junho Oh, and Nenad Miljkovic. "Fundamental limits of jumping droplet heat transfer." *Applied Physics Letters* 116, no. 9 (2020): 093701. https://doi.org/10.1063/1.5141744
[28] Zeeshan, A., U. Masud, T. Saeed, and A. Hobiny. "On the effects of chemical reaction on controlled heat and mass transfer in magnetized non-Newtonian biofluid through a long rectangular tunnel." *Journal of Thermal Analysis and Calorimetry* 143, no. 3 (2021): 2637-2646. https://doi.org/10.1007/s10973-020-10426-2
[29] Bhattrai, Shailes, Uma Karki, Sanjok Poudel, Bidur Paneru, and Nevershi Ellis. "Maintenance of Non-Timber Plants at Low Heights Increased the Solar Radiation Influx and Understory Vegetation Biomass in Woodlands." *Global Journal of Agricultural and Allied Sciences* 2, no. 1 (2020): 18-24.
[30] Park, Hotaek, Eiji Watanabe, Youngwook Kim, Igor Polyakov, Kazuhiro Oshima, Xiangdong Zhang, John S. Kimball, and Daqing Yang. "Increasing riverine heat influx triggers Arctic sea ice decline and oceanic and atmospheric warming." *Science advances* 6, no. 45 (2020): eabc4699. https://doi.org/10.1126/sciadv.abc4699
[31] Owolabi, Afolabi L., Hussain H. Al-Kayiem, and Aklilu T. Baheta. "Performance investigation on a thermal energy storage integrated solar collector system using nanofluid." *International Journal of Energy Research* 41, no. 5 (2017): 650-657. https://doi.org/10.1002/er.3657
[32] Park, Hoon Chae, Hang Seok Choi, and Ji Eun Lee. "Heat transfer of bio-oil in a direct contact heat exchanger during condensation." *Korean Journal of Chemical Engineering* 33, no. 4 (2016): 1159-1169. https://doi.org/10.1007/s11814-015-0256-y
[33] Yurddaş, Ali. "Optimization and thermal performance of evacuated tube solar collector with various nanofluids." *International Journal of Heat and Mass Transfer* 152 (2020): 119496. https://doi.org/10.1016/j.ijheatmasstransfer.2020.119496
[34] Idris, Muhammad Syafiq, Irnie Azlin Zakaria, and Wan Azmi Wan Hamzah. "Heat Transfer and Pressure Drop of Water Based Hybrid Al2O3: SiO2 Nanofluids in Cooling Plate of PEMFC." *Journal of Advanced Research in Numerical Heat Transfer* 4, no. 1 (2021): 1-13.
[35] Usman, Auwalu Hamisu, Sadiya Ali Rano, Usa Wannasingha Humphries, and Poom Kumam. "Activity of Viscoelastic Nanofluid Film Sprayed on a Stretching Cylinder with Arrhenius Activation Energy and Entropy Generation." *Journal of Advanced Research in Micro and Nano Engineering* 3, no. 1 (2021): 12-24.
[36] Phu, Nguyen Minh, and Pham Ba Thao. "Thermohydraulic Performance of a Fin and Inclined Flat Tube Heat Exchanger: A Numerical Analysis." *CFD Letters* 13, no. 7 (2021): 1-12. https://doi.org/10.37934/cfdl.13.7.112
[37] Sultana Jahan, M. Ferdows, MD Shamshuddin, and Khairy Zaimi. "Effects of Solar Radiation and Viscous Dissipation on Mixed Convective Non-Isothermal Hybrid Nanofluid over Moving Thin Needle." *Journal of Advanced Research in Micro and Nano Engineering* 3, no. 1 (2021): 1-11.
[38] Putra, Nandy, Evi Sofia, and B. Ali Gunawan. "Evaluation of Indirect Evaporative Cooling Performance Integrated with Finned Heat Pipe and Luffa Cylindrica Fiber as Cooling/Wet Media." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 3, no. 1 (2021): 16-25.