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Thermal Characterization of Biofluids for Heat Transfer Fluid in Thermal Transport Technologies

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ABSTRACT

Thermal fluids modulate temperature conditions around the thermal collector systems indirectly by circulating the heat transfer fluid throughout the heat exchanger, thereby simulating cooling and heating with thermal condition. This study investigates biofluid from Moringa oleifera kernel, Date kernel, Palm kernel, Coconut kernel and Mango kernel as base fluids for heat transfer fluid application in solar thermal technology. The methodology employed in this study is experimental and the analyzed biofluids results was compared with conventional heat transfer base fluids. Thermal constant analyzer (TPS-2005S), CT-72 Transparent viscometer and Eagle eye SG-500 portable digital hydrometer were used to measure the thermophysical properties, viscosity, and density, of the biofluids respectfully. From the results, the biofluids showed comparative thermophysical properties to conventional base fluids. Moringa oleifera kernel oil and Mango kernel oil has the best quality among the biofluids with thermal conductivity, specific heat, viscosity, and density value was 0.1698Wm/k, 1984.01J/kg.K, 37.12mm^2/s, 874.23kg/m^3, and 0.2642Wm/k, 763.18J/kg.K, 45.27mm^2/s, 914.22kg/m^3, respectively. The biofluids was thermally stable after exposure to several heating cycles and heating temperature as no significant degradation was observed in there thermophysical properties. However, there are needs for further experimental studies on clogging and possibility of enhancement of biofluids with organic nanoadditives.

1. Introduction

Energy consumption in building sector is on the rise, and the chunk of the energy consumed is for domestic water and space heating. For example, in residential and commercial buildings, process heat accounts for about 40% of the primary energy supply, at low and medium operating temperatures which can be achieved using solar thermal collectors [1,2]. In addition, thermal cleanings applied in food, pharmaceutical, automobile, textile industries, hospitals, and other healthcare sectors, heating operations range (30°C to 120°C), can be achieved using flat-plate

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collectors, thus, reducing the reliance on conventional fossil fuels which is unclean and contributes to greenhouse gas emission [3,4]. Solar thermal collectors (STCs) systems are designed with buildings, as passive and active integrations, but the performance efficiency is very low and requires improvement. Several studies have proposed different enhancement techniques to STCs systems: thermal surface coating [5,6], design configurations [7,8], TES additives [9,10], heat transfer fluid, [11,12] and hybrid collector techniques, [13].

Heat transfer fluid (HTF) is major component of STCs because it's the medium of heat absorb and delivery. Water a conventional base fluid for nanofluids and hybrid nanofluids, in STCs system application, have been studied widely, [14,15] but safety issues arising from the use of inorganic chemically synthesized base fluids and nanofluids use in food, drug and health related industries, as raised health concerns. Studies on biofluids for HTFs has attracted the interest of many researchers because of the green sustainable nature and the promising thermophysical and thermoelectric properties. In recent times, investigations on utilization of different types of biofluids as HTFs in food processing equipment's, medical and health related equipment's, macro and micro channels in electronics equipment's, heat exchanger equipment's, is gaining prominence among researchers focus. Base fluids like water, propylene glycol, ethylene glycol can cause corrosion and clogging in ducts and pipes sections, low thermal properties, freezing at low climatic condition and more importantly safety concerns because of nano-additives used for enhancement. These setbacks can be addressed by using fluid extracts from plant by-products of nonedible oils which a clean, sustainable, environmentally friendly, and comparative thermal properties with conventional base fluids. Still, less emphasis has been given on studies investigating biofluids as alternative heat transfer fluids. Therefore, this study, focuses on biofluids obtained from by-products of Moringa Oleifera (Moringaceae) kernel, Date (Phoenix dactylifera) kernel, Palm (Elaeis-guineensis) kernel, Coconut (Cocos nucifera) kernels and Mango (Mangifera indica) kernels for use as HTFs applications. Characterization of the biofluid thermophysical properties and thermal analysis was carried and compared with other conventional base fluids.

2. Materials and Methods

2.1 List of Materials and Equipment

Moringa Oleifera kernel oil (MOKO), Date kernel oil (DKO), Palm kernel oi (PKO), Coconut kernel oil (CKO), Mango kernel oil (MKO), measuring cylinder, conical flask, beaker, magnetic resonance stirrer, digital hot-plate, Thermal constant analyzer (TPS-2005S), CT-72 Transparent viscometer, Eagle eye SG-500 portable digital hydrometer, cold press machine, fridge, desiccator, METTLER TOLEDO benchtop portable digital density meter, thermometer, and stopwatch.

2.2 Material Preparation

10 kg of Moringa oleifera kernel, Date kernel, Palm kernel, Coconut kernel and Mango kernels were purchased from local markets from Akure, Ondo state, Nigeria and from Ipoh, Perak, Malaysia. The seeds were sun-dried, picked to remove foreign materials, rotten and immature seeds and kept inside refrigerator until extraction.

2.3 Cold Press Extraction Method

A cold press machine model –SH-48-100, (Seng Hup Machine, Lahat Malaysia), of 100tons capacity, operated at 1350psi, Stainless steel mold head circumference of 147.1mm and thickness of

30.44mm. A 750g of biomass (MOKO, DKO, PKO, CKO and MKO) was placed inside muslin cloth and kept inside the hollow part of the mold and then subjected to pressing load of 100kg at 45°C till oil recovery. The oil obtained was filtered, the amount of oil extracted was measured gravimetrically, and then centrifuge at 3500rpm for 20mins, and kept in amber bottle, flush with Nitrogen gas and stored at 4°C till further. Figure 1 shows photo-image of the biomass seed, kernel, and the cold press machine.

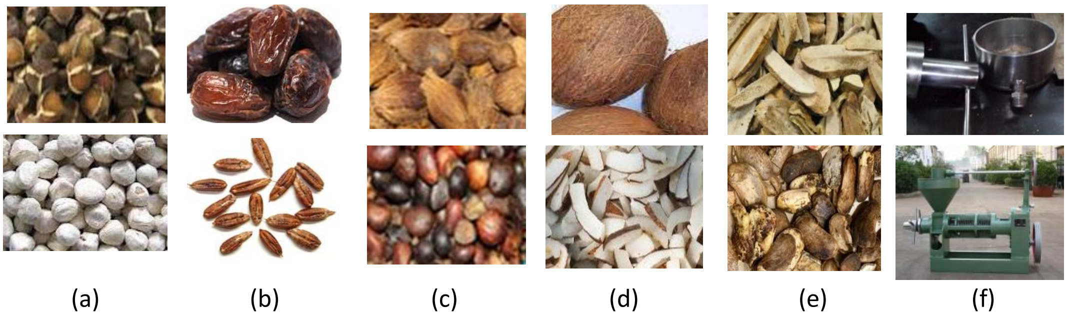

Fig. 1. (a) Moringa seed & kernel (b) Date seed and kernel (c) Palm seed and kernel (d) Coconut seed and kernel (e) Mango seed and kernel (f) Cold press machines

2.4 Characterization

Thermophysical properties of the MOKO, DKO, PKO, CKO, and MKO was carried to determine the melting and boiling point, thermal conductivity, specific heat, thermal diffusivity, density, and viscosity. This are essential fluid properties that determines suitability for heat transfer fluids. Many reports [16,17]on characterization of heat transfer fluids have been presented with fewer studies on biofluids [18]. 5ml for each of the biofluids samples was taken to the laboratory, the measurement was repeated in triplicates.

2.5 Thermal Behavior

Measurement of heating temperature and heating cycle was adopted as parameters of investigation. The heating temperature used was 120°C, while 100 and 200 heating cycles was adopted was thermal degradation analysis. For each heating cycle, the oils are heated from ambient temperature to 120°C, then allowed to cool till ambient temperature to complete one cycle. The process was repeated 100 and 200 heating cycle, with each taken 20 mins.

3. Result and Discussion

Result of biofluid characterization - The measured thermophysical properties of the biofluids is presented in Table 1. The melting and boiling temperature of the biofluids ranged from (20(40))°C and (160(310))°C, this temperature is higher than the boiling temperature of water, propylene glycol, ethylene glycol and mixture of water / propylene glycol which implies can hold more heat and can be used at higher working temperatures. The MKO have the highest melting and boiling temperature among the biofluids. The biofluids can with stand 160°C without causing chemical changes, and thermally stable.

Table 1
Thermophysical properties of biofluids oil

Biofluid Type	Melting / Boiling Point °C	Thermal Conductivity λ/ Wm-1k-1 30o C	Specific Heat J/(kg.K)	Thermal Diffusivity m2/s	Viscosity (μ) mm2 /s at 30 °C	Density (ρ) Kg/m3
MOKO	21 / 186	0.1698	1984.01	0.00061	37.12	874.23
DKO	37 / 165	0.1384	1642.53	0.00076	29.65	711.24
PKO	26 / 218	0.1421	1773.24	0.00054	32.33	928.11
CKO	25 / 260	0.1659	2401.23	0.00016	3.24	919.04
MKO	39 / 305	0.2642	2763.18	0.00023	45.27	914.22

Thermal conductivity of the HTF is an important thermophysical property which influences the Nusselt number and sensitive to temperature. Higher thermal conductivity means faster rate of heat transfer between the constituents. From the measured biofluid thermal conductivity data, the MKO had the highest values with 0.264 Wm/K, and lowest was DKO with 0.1384 Wm/K. Other values are 0.1698, 0.1659 and 0.142 Wm/K, for MOKO, CKO and PKO, respectively. This values are comparable to conventional base fluids, and suitable for HTFs in thermal applications because higher thermal conductivity implies good heat transfer mechanism within the fluid [3,11]. Synthetic thermal oil when heated above operating temperature decomposes quickly, producing hydrogen gas, degrades and reduce the life cycle and thermal efficacy. Water is utilized as the conventional HTFs in STC system because of its appreciable heat capacity of 4.185 J/Kg K. Although, from this study, the biofluids had lower specific heat values compared to water but higher than mixture of water/propylene glycol. The specific heat of MKO was the highest 2.764 J/Kg.K, while the MOKO, DKO, PKO, and CKO values are 1984.01, 1642.03, 1773.24, and 2401 J/Kg.K, respectively. Viscosity is a measure of an oil's resistance to flow, lower viscosity enhances fluid flows, reduce heat dissipation caused by friction, the measured viscosities of CKO (3.24 mm2/s) was the lowest and closer to water, [19,20]. The remaining biofluids exhibited higher viscosities with average of 35.03 mm2/s, which within range of commonly used base fluid mixtures. The biofluids viscosity reduces as the temperature increases and cause lower oil consumption and less wear during fluid flow. Overall, the oil viscosity values are suitable for heat transfer fluid in thermal applications. The transfer of momentum and heat is affected by variable density, because convective heat transfer is affected by density differential within fluid flow, [21]. The density values of the biofluids are 874.23, 711.24, 928.11, 919.04 and 914.22, (Kg/m3), for MOKO, DKO, PKO, CKO and MKO, respectively. The biofluid densities are comparatively better than water, water/propylene mixture, water/ethylene mixture and some nanofluids. This density values decrease as oil temperature increases and will become less dense in presence of heat. Thermal behavior of the biofluids is shown in Table 2.

Table 2
Melting and crystallization behavior of bio-oil

	Melting Temperature (°C)			Crystallization Temperature (°C)			
	Onset	Peak	End	Onset	Peak 1	Peak 2	End
MKO	-15.86	-3.82	3.21	5.92	4.60	-39.87	2.67
DKO	-13.83	-4.92	0.55	7.32	5.91	-43.75	3.17
PKO	-14.34	-3.19	2.02	5.87	3.93	-41.06	1.25
CKO	-13.12	-4.90	0.55	7.32	5.91	-43.75	3.17
MKO	-14.34	-3.19	2.02	5.87	3.93	-41.06	1.25

The resulting DSC data was analyzed with respect to their melting temperature (Tm), crystallization temperature (Tc), endset temperature (Test) and enthalpy. Melting temperature was considered as the temperature at which a material change from solid to liquid [22], while the end temperature is the complete melting temperature of triglyceride. The melting behavior reveal onset point started from -13.12 and -15.86°C for all the biofluids. The oils exhibited close peak temperature during melting with the highest peak reached at -4.92°C for DKO and -4.90°C for CKO. During crystallization, the average onset and endset temperature was 4.05 and 2.25°C, respectively. The MOKO shows a broadening peak, and tends towards higher temperature, compared to DKO, PKO, CKO and MKO. This result indicate that melting behavior depends on the physicochemical and thermal properties of the oils. Samaram, Mirhosseini [23], reported similar findings that melting behavior of oil depends on their extraction process parameters. The amount of heat released or absorbed during a chemical reaction carried out at constant pressure is the enthalpy, [24]. Table 3 shows the internal energy of the biofluids. From the result, the MKO and MOKO had the highest enthalpies at 64.23±0.2 and 59.46±0.5, which implies their suitability for heat transfer fluid compared to some conventional base fluids. However, the MOKO had larger transition period (-3.82±0.1 to -39.87±0.3), from melting to crystallization compared to the rest of the biofluids. The biofluid enthalpy is increased as the fluid temperature increases, thus improve convective heat transfer between the fluid and heat exchanger systems.

Table 3
Enthalpy of biofluids oils

Extraction Method	Enthalpy ΔH(Kj/Kg)	Glass Transition T_G (ºC)	Melting Temperature T_m (ºC)	Crystallization Temperature T_c (ºC)
MOKO	59.46±0.5	43.79±0.1	-3.82±0.1	-39.87±0.3
DKO	48.30±0.4	40.63±0.3	-4.92±0.2	-43.75±0.2
PKO	52.14±0.3	39.08±0.2	-3.19±0.1	-41.06±0.5
CKO	41.26±0.1	37.15±0.2	-3.44±0.3	-38.19±0.2
MKO	64.23±0.2	46.37±0.3	-5.28±0.1	-45.42±0.3

Thermal analysis was carried out on the biofluid oils to determine thermal reliability after several heating temperature and heating cycles. Table 4 shows the thermal reliability parameters for the oils. Each of the oil was subjected to 100 and 200 heating cycles at constant heating temperature (120°C). From the result, the thermal conductivity values of the biofluids reduced by 7.2%:14.3% (MOKO), 6.6%:13.6% (DKO), 1.9%:4.9% (PKO), 1.9%:2.9% (CKO), 2.7%:3.1% (MKO) for 100 and 200 heating cycles, respectively.

It is observed that the heating cycle impacted the oil thermophysical properties because of gradual degradation in the oil physicochemical properties. The impact was higher on the 200-heating cycle for all the biofluids thermal conductivity, with MOKO and DKO having the highest degradation with 14.3% and 13.6%, respectively. Whereas the heating cycle impacted less on the PKO (1.9%) and CKO (2.7%), thermal conductivity after 200-heating cycles. Thermal conductivity are temperature dependents and oils are temperature sensitive, most reports agreed that heating degrades thermal properties, [19].

The specific heat degradation effects on heating cycle and temperature of the biofluids showed degradation of 3.1%:8.5% (MOKO), 7.9%:11.7% (DKO), 8.2%:10.1% (PKO), 0.7%:1.8% (CKO), 1.9%:2.1% (MKO) for 100 and 200 heating cycles, respectively. The CKO (1.8%), and MKO (2.1%), had less degradation changes compared with the MOKO (8.5%), DKO (11.7%) and PKO (10.1%). The viscosity degradation effects on heating cycle and temperature of the biofluids showed degradation of 3.9%:12.7% (MOKO), 3.3%:17.2% (DKO), 13.8%:23.8% (PKO), 1.9%:43.2% (CKO), 6.2%:8.5% (MKO) for 100 and 200 heating cycles, respectively. The PKO (23.8%), and CKO (43.2%), had higher degradation effects compared with the MOKO (12.7%), DKO (17.2%) and MKO (6.5%). Thus, as heating cycle increases, the viscosity degrades especially for the PKO which will impact the biofluid flow in thermal applications. The density degradation effects on heating cycle and temperature of the biofluids showed degradation of 3.7%:10.6% (MOKO), 4.1%:4.2% (DKO), 3.1%:6.2% (PKO), 0.9%:2.1% (CKO), 0.8%:1.2% (MKO) for 100 and 200 heating cycles, respectively. The MOKO (10.6%), and PKO (6.2%), had higher degradation density effects compared with the DKO (4.2%), CKO (1.2%) and MKO (1.2%). As the heating cycle increases, the density values degrade especially for the MOKO which made it denser compared to the initial values [25,26]. Summarily, the biofluids properties are thermally stable, low viscosity, high enthalpy, large glass transition, and low operating temperature. This property makes this biofluids suitable for thermal transports in heat transfer application.

Table 4
Thermal analysis of biofluids and conventional fluids

Heat Transfer Fluids										
Biofluid Types	MOKO		DKO		PKO		CKO		MKO	
Thermal Parameters	100 heating cycle at heating temp 120°C	200 heating cycle at heating temp 120°C	100 heating cycle at heating temp 120°C	200 heating cycle at heating temp 120°C	100 heating cycle at heating temp 120°C	200 heating cycle at heating temp 120°C	100 heating cycle at heating temp 120°C	200 heating cycle at heating temp 120°C	100 heating cycle at heating temp 120°C	200 heating cycle at heating temp 120°C
Thermophysical Reliability										
Thermal Conductivity λ/ Wm^{-1}k^{-1}	0.1522	0.1472	0.1213	0.1042	0.1367	0.1289	0.1598	0.1567	0.2503	0.2489
Specific Heat J/(kg.K)	1864.03	1672.28	1401.34	1274.14	1504.28	1448.62	2364.04	2316.13	2661.27	2652.41
Thermal Diffusivity [x10^{-6} m^2/s]	0.00053	0.00042	0.00068	0.00062	0.00042	0.00038	0.00016	0.00016	0.00023	0.00023
Viscosity *(μ)* mm^2 /s	35.0072	30.4532	28.3201	25.0015	28.2254	25.4232	3.18	5.03	48.13	49.32
Density *(ρ)* Kg/m^3	842.43	786.24	683.21	640.14	900.16	872.33	927.22	938.04	921.22	925.32
Melting / Boiling Temp (°C)	19.4 / 179	18.2 / 178	35.5 / 163	34.7 / 162	25.3 / 222	24.2 / 220	26.4 / 263	27.2 / 264	40.2 / 301	41.4 / 299

4. Conclusion

Summarily, it is estimated that about 35% of the process heat demand could be covered with low to medium temperature solar collector systems. One key component of STC enhancement is the HTFs. Conventional base fluids like water and mixture of water/propylene glycol have been enhanced using nano additives. However, the setbacks of corrosion, clogging, freezing, and toxicity persist. The use of biofluid as alternative base fluid can address some of the setbacks in conventional base fluid and base fluid mixtures. In this study, the characterized biofluids demonstrated quality properties suitable for HTF application and comparable to conventional base fluids used in various thermal technologies. Among the biofluids, the MKO and MOKO showed optimal quality compare to the other fluids. No significant degradation was observed in the quality properties of the biofluids after undergoing several heating temperature and heating cycle. However, further investigation is recommended on thermal stability of the oils after extended cycles. In addition, synthesizing the biofluids with organic nano additives can improve the oil thermophysical properties. Experimental investigation utilizing biofluids as HTFs in various solar thermal technology, micro and macro channel heat exchangers is recommended to confirm the thermal enhancement and system performance.

Declaration of Competing Interest

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

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