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Development of Coconut Oil Based Bio-heat Transfer Fluid for Concentrated Solar Plant

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ABSTRACT
Vegetable oils are proven to be potential heat transfer fluids (HTF) in concentrated solar power plant (CSP) and their thermophysical and rheological properties are comparable to the contemporarily used synthetic HTF. The present study aims to investigate the use of coconut oil as potential HTF and to improve some of its properties for better performance. Natural additives are used to alleviate certain limitations of coconut oil in performing as an HTF. Primarily, the oxidative stability and cold flow property are improved by adding essential oils of garlic to coconut oil at different concentrations. The optimum mixture is chosen and the thermophysical properties which include density, specific heat capacity and thermal conductivity are looked into. These properties as well as the dynamic viscosity are correlated individually to temperature using polynomial equations. Further, the biodegradability of the mixture is checked to ensure the eco-friendliness of the mixture. Thus, an attempt is made to produce a bio-heat transfer fluid (BHTF) with improved thermophysical properties, dynamic viscosity, cold flow property and oxidative stability for performing as an effective substitute for synthetic HTF.

Keywords: *Heat transfer fluids, concentrated solar plant, coconut oil, natural additives*

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INTRODUCTION

Technologies for utilizing solar energy as an eco-friendly alternative to electricity have been implemented in areas which receive sunlight abundantly. Concentrated solar plant (CSP) is one such invention which helps to store thermal energy using heat transfer fluids (HTFs). The plant consists of several concentrators which help focus sunlight on the absorber tubes so that heat from the sunlight can be utilized by the HTF flowing inside the tubes. The HTF circulates in the solar receiver and the thermal energy is transferred to a heat exchanger which is attached in the thermal power block to generate electricity in a conventional steam generator [1, 2]. One of the pertinent reasons for the success of CSPs is the involvement of HTF which helps to utilize the thermal energy even when sunlight is not available. Rapid growth within the field of solar technology is impeded by technical barriers and those should be addressed to improve the efficiency of solar systems [3].

The thermodynamic performance of the working fluid is imperative in determining the plant's efficiency and helps in improving the industrial process [4, 5]. The other important factors that determine the type of HTF are the low lower temperature limit and a high upper temperature limit at low pressures. The high temperature limit depends on the plant design and lower limit is generally taken as the ambient temperature at the region in which the plant is situated. The thermal stability and pour point are also considered as the key determining factors of temperature range. Linear Fresnel reflectors normally have a temperature range of 25°C to 250°C and present study involves the investigation of thermophysical properties and rheological properties within this range. The enhancement of onset temperature for oxidative degradation will lead to resistance to oxidation within that temperature [6]. The thermal energy storage of HFT should be improved by ameliorating properties like thermal conductivity, density and specific heat which increases heat transfer, but the dynamic viscosity has to be kept low to limit pressure drop and ensure flowability [1, 2, 4, 7, 8]. An ideal thermal fluid must also have low toxicity, flammability, explosivity, corrosiveness and must also be eco-friendly so that the storage and disposal does not become deleterious to the environment. Petroleum based oils are depleting resources and also their disposal would negatively affect the environment. The heat transfer fluids commonly used in CSP technologies include air, water, molten salts, glycol based, glycerol based and synthetic oils which can transfer heat effectively [2]. Air does not make an ideal HTF as it expands with increase in temperature which will subsequently require a large heat exchanger. Water is not widely used as it oxidizes quickly at high temperature and leads to corrosion in absorber tubes. Molten salts tend to solidify at high temperature whereas glycol based and synthetic based HTFs are corrosive and cannot function efficiently without corrosion inhibitors [2]. With the need for eco-friendliness, a better nontoxic HTF with better thermal and rheological properties is necessary in the future which possibly ameliorate the defects of synthetic HTFs.

Synthetic or mineral high temperature oils are widely used as industrial heat transfer fluids in many process applications but their environment repercussions while in use as well as during disposal are quite detrimental [2]. They can also lead to substantive corrosion in the absorber tubes and transporting pipes due to oxidation [1]. Vegetable oils are proposed to be better alternatives as they generally possess high flash point, low viscosity, higher lubricity, low evaporative losses, and good metal adherence. The main limitations of using vegetables oils are their low thermal stability and poor cold flow properties which should be improved to widen their application in this area.

Among vegetable oils, coconut oil is already proven to have immense potential as HTF. Coconut oil, being abundantly available in southern states of India, is a viable substitution to synthetic HTFs if several limitations are alleviated. The usage of chemical additives can disrupt the eco-friendly aspect of the HTF and therefore, bio-additives can be used to upgrade the thermal stability, pour point, thermophysical and rheological properties of oils for such purposes. There are natural antioxidants which can be extracted from low cost resources with more antioxidant activity and thermal stability than synthetic ones [9]. Studies have revealed that essential oils are effective in increasing the thermal stability of coconut oil, which helped to improve its shelf life also [10]. Garlic essential oil is a potential additive due to its pertinent antioxidant properties and also due to local availability. The present study focuses on enhancing the properties of coconut oil which helps in developing a better bio-HTF with stability at high temperature, low material maintenance, low freezing point, low viscosity, low cost and better compatibility [1].

In the present study, extract from garlic is considered as additives in base stock, i.e., coconut oil, to develop a potential bio-HTF. Bio-sustainability analysis based on bacterial growth is conducted to establish the mixture as a bio-HTF. The modified oil is expected to exhibit improved thermal stability, thermophysical properties (density, thermal conductivity and specific heat capacity) and rheological property (dynamic viscosity) for performing as a bio-HTF and replacing existing synthetic HTF in solar power plants.

MATERIALS AND METHODS

Materials

Refined coconut oil is purchased from local market. Essential oil based out of garlic is chosen as the natural antioxidant additive for the present study due to less corrosive nature and good storage stability. Three samples of modified coconut oil are prepared by adding garlic extract up to 5%, so as not to decrease viscosity of coconut oil to considerable level. The rheological and thermophysical properties of the constituent oils at ambient conditions are given in Table 1.

Table 1. *Rheological and thermophysical properties of constituent oils at ambient conditions.*

Properties	Coconut oil [4]	Garlic oil [11–13, 18]
Viscosity (cP)	35.41	64.20
Density (kg/m^3)	912	1083
Thermal Conductivity (W/mK)	0.16	0.18
Specific heat (kJ/kgK)	2.3	1.52

Tests Conducted

Tests are conducted on prepared samples of modified coconut oil for thermal stability, pour point, bacterial growth and dynamic viscosity and the equipment used for these tests are illustrated in Table 2.

Table 2. *Equipment used for testing.*

Test	Equipment
Pour point	Ice bath apparatus
Thermal stability	Perkin Elmer STA8000
Viscosity	Ametek Brookfield Rheometer
Bacterial growth	Digital colony meter

Thermogravimetric analysis is done using Perkin Elmer STA8000 apparatus. During the test, the temperature is increased at a rate of 10°C/min and the corresponding temperatures and weight percentage of the sample are noted. Onset of thermal degradation is estimated from the TGA thermal curve based on ASTM method.

Cold flow property or pour point test is conducted based on ASTM D97 method using a specifically prepared ice bath setup. For every drop of 3°C in temperature, surface movement of the sample liquid is observed by tilting the vessel by about 15°. Pour point is estimated as 3°C above the temperature at which the fluid surface did not move while tilting.

Bacterial growth tests conducted in a Laminar Air flow chamber. The oil samples are vortexed. 10µl from each are dropped to respective petri-plates and are swabbed on to Nutrient agar plates. The plates are incubated at 37°C for 24 hours in a microbiological incubator. After incubation the plates are observed for colony forming units (CFUs). The CFUs are counted using a Digital Colony counter and are expressed in CFUs/ml.

Viscosity test is done using Ametek Brookfield Rheometer. The dynamic viscosity is measured for different temperatures 35°C up to 65°C.

Estimation of Properties

Based on data available from viscosity tests, dynamic viscosities of modified coconut oil for the entire working temperature range of HTF, i.e., from 25°C to 250°C is estimated using regression techniques. The variation of density, thermal conductivity and specific heat within this temperature range are also estimated and corresponding polynomial equations are developed. For this, the relations depicted in Table 3 were used from literature.

Table 3. *Relations for rheological and thermophysical properties.*

Properties	Garlic oil [4, 5, 11–13]
Viscosity (cP)	Log(μ(T)) = 3.957 -1.632(Log(T))
Density (kg/m^3)	ρ (T) = c × T + d#
Thermal Conductivity (W/mK)	k = y × T + x*
Specific heat (kJ/kgK)	c_p = 0.0041T + 2.3476 (17% moisture)

#As the density-temperature co-efficient ‘c’ lies between -7.2 × 10–^{4} and -8.4 × 10–^{4} g/cc/°C, it is assumed to be -8 × 10–^{44} g/cc/°C.

*The co-efficient for specific heat variation is estimated as 0.0045 for 0% moisture. The co-efficient for conductivity (y) is assumed be 0.00045, as numerical value of conductivity is one tenth that of specific heat capacity for the range of temperature considered.

RESULTS AND DISCUSSIONS

Pour point, onset of thermal degradation and dynamic viscosity are measured for samples prepared by thoroughly mixing essential oil of garlic in different concentrations to coconut oil forming three additional samples apart from pure coconut oil. Sample oils are prepared with 2%, 3% and 5% essential oil mixed in coconut oil for variational study. Results of thermogravimetric analysis (TGA) and pour point tests conducted for different samples are given in Table 4.

Table 4. *Thermal stability and pour points of pure and modified coconut oil.*

Oil	% additive	Onset temperature for thermal degradation, °C	Pour point, °C
Pure coconut oil	-	241	23
Coconut oil with garlic	2	305	10.5
	3	312	9
	5	316	8.5

A comparative illustration of onset temperature for all oil samples is shown in Figure 1. It becomes evident that coconut oil showed drastic improvement in thermal stability on addition of essential oils. For garlic essential oil, steady increase in oxidation temperature was observed. Generally, it can be concluded that thermal stability is maximum for essential oil additions up to 3%. This may be due to least addition in free fatty acids and peroxide values at high temperatures, as essential oils are good antioxidants. The antioxidants prevent oxidation of oils and fats by giving their hydrogen to free radicals formed in the initiation ad propagation stages of oxidation.

The TGA plot for coconut oil added with 3% garlic essential oil is shown in Figure 2. For all samples, the onset temperature for oxidative degradation due to oxidation is found out by the ASTM method of extrapolation.

An additional benefit derived out of essential oil addition was the remarkable reduction in the pour point of oil. As can be seen in Figure 3, all samples added with essential oils recorded a steep drop in pour point compared to pure coconut oil. The continuing trend of pour point reduction

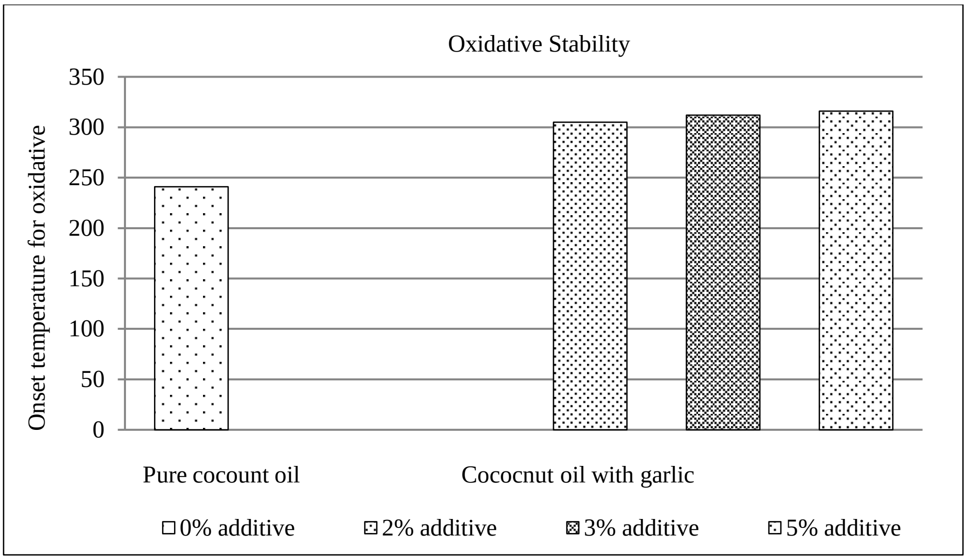

Fig. 1. *Oxidative stability of pure and modified coconut oil.*

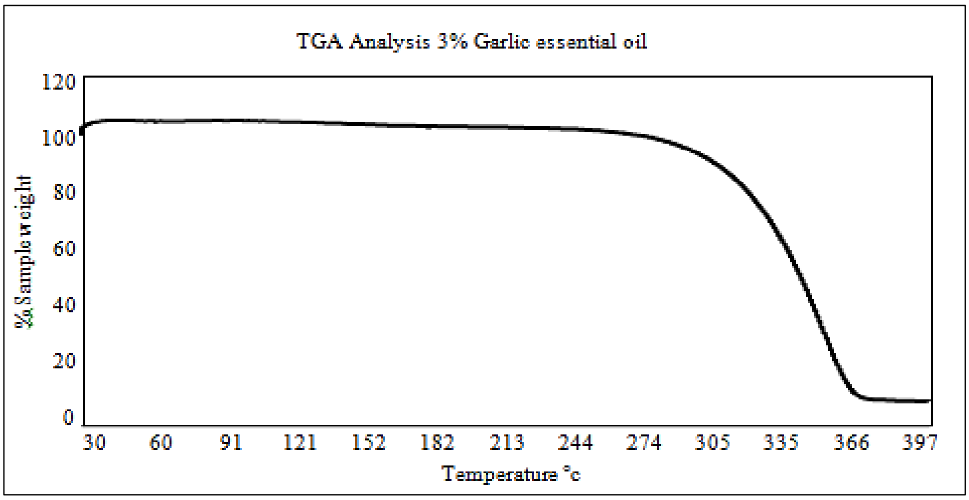

Fig. 2. *Thermogravimetric analysis plot of coconut oil with 3% garlic essential oil.*

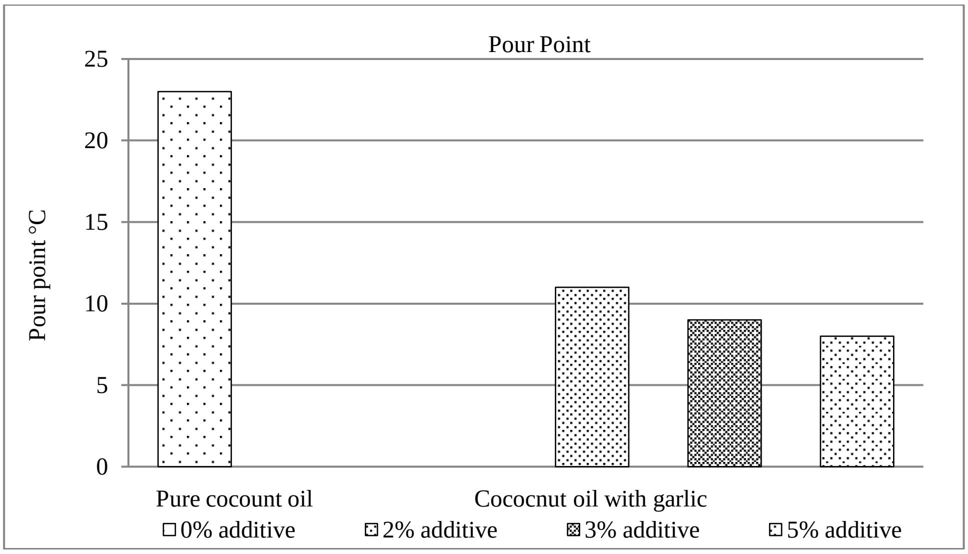

Fig. 3. *Pour point temperature of pure and modified coconut oil.*

on further addition of essential oil is an encouraging revelation. Coconut oils have lauric acid as their major fatty acid constituent. The fatty acid chains are mostly parallel to one another. This enables the close packing of molecules during cooling leading to a gel like structure which traps the low melting constituents**.** Thus, self-stacking occurs which leads to the reduction of kinetic energy of individual molecules [14].

The branched hydrocarbon molecules get attached to the free radical thereby altering the structure of fatty acids in such a way that it increases the gap between the fatty acid chains. The structure thus formed prevent close packing of molecules during cooling and reduces the pour point. Progressive decrease in pour point is observed on further increase in concentration of garlic in coconut oil as shown in Figure 3 [15].

Eco-friendliness is a pertinent aspect of the study and in order to establish this, all the samples are subjected to bacterial growth study. The colony forming units per ml for all the samples are obtained and on investigation, as given in Table 5, it is found that all samples of modified coconut oil exhibited healthy bacterial growth indicating bio-sustainability of the samples [16].

The bacterial growth was found to decline as the concentration of garlic added increases, possibly due to its antimicrobial properties. Therefore, further studies were conducted based on samples with essential oil garlic additives limited to 3%. Table 6 gives the values of dynamic viscosity of pure and modified coconut oil with 3% garlic at different temperatures.

Table 5. *Bacterial growth study for samples.*

Oil	% additive	Bacterial growth, CFUs/ml
Coconut oil with garlic	2	78×10^2
	3	32×10^2
	5	20×10^2

Table 6. *Dynamic viscosity in cP for different temperatures.*

Temperature (°C)	35	45	55	65
Pure coconut oil	30.8	20.03	14.38	10.8
Coconut oil with 3% garlic	27.05	18.51	13.13	9.87

Viscosity measurements could reveal slight reduction in dynamic viscosity of modified coconut oil when compared with pure coconut oil as seen in Figure 4. The difference in viscosity between the two oils is seen to reduce with the increase in temperature.

Using regression technique, polynomial equation is developed for viscosity using values obtained from experiments shown in Table 6. The density, specific heat capacity and thermal conductivity of modified coconut oil is determined for the entire operating range of CSP, i.e., 25°C to 250°C; applying rule of mixtures using relations depicted in Table 3. The polynomial equations developed for the modified coconut oil (MCO) are shown in Table 7. These relations are used to further plot the properties of MCO for the operating temperature range of CSP.

Table 7. *Relations for rheological and thermophysical properties of MCO.*

Properties	**Modified Coconut oil (MCO)**
Viscosity (cP)	$\mu = -15.46 \ln(\Delta T) + 80.544$ ($r^2 = 0.535$)
Density (kg/m^3) × 10^3	$\rho = 1.083-(8 \times 1\ 0^{-4})\ \Delta T$ ($r^2 = 0.999$)
Thermal Conductivity (W/mK)	$K = 0.18 + 0.00045\ \Delta T$ ($r^2 = 0.994$)
Specific heat (kJ/kgK)	$C_p = 1.52 + 0.0045\ \Delta T$ ($r^2 = 0.870$)

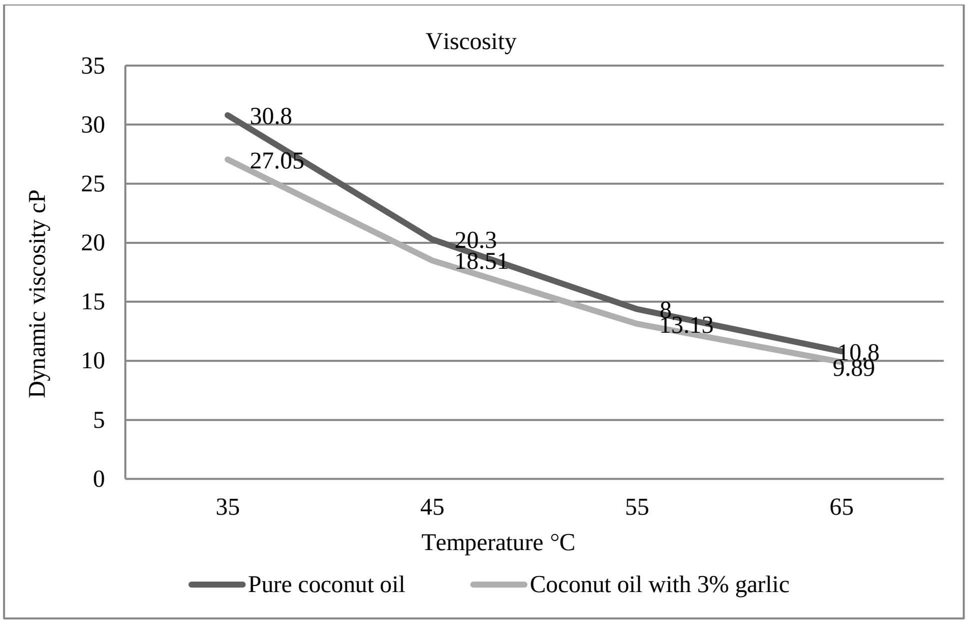

Fig. 4. *Variation of dynamic viscosity with temperature.*

The density variation of pure and modified coconut oils within the operating temperature range of 25°C to 250°C is shown in Figure 5. The density is seen to decrease linearly for both samples with increasing temperature due to thermal expansion. However, the density of MCO is seen to be consistently higher than pure oil at all temperatures. The modified oil therefore can have higher conductive heat transfer than pure coconut oil due to better molecular proximity. Also, the increase in density due to thermal expansion reduces the void spaces in the sample. This leads to less air retention in the bulk material. Decrease in the quantity of air, which is a bad thermal conductor, leads to increased thermal conductivity [17].

Figure 6 shows the variation of specific heat capacity with respect to temperature. Generally, an increasing trend in values of specific heat capacity can be observed with rising temperature. However, MCO exhibits lesser specific heat capacity than coconut oil at all values of temperature considered. So, MCO would have slightly lesser tendency to absorb energy and thus would conduct heat quickly through the fluid body [18].

Thermal conductivity of pure and modified coconut oils is compared in Figure 7 for the operating range of temperature considered, where a positive trend is observed for both the oils. The breaking hydrogen bonds contribute to thermal conductivity at high temperatures. At low temperatures, the hydrogen bonds are stable and thus do not contribute significantly to thermal conductivity. As the temperatures increases, more activation energy is required to break the hydrogen bonds, which available in the form of heat, which in turn increases the thermal conductivity [19]. In comparison, MCO is exhibiting a higher thermal conductivity than pure oil throughout the range. Also, it can be seen that at higher temperatures, the difference in values becomes more. So, MCO stands out as a better thermal conductor at high temperature [20].

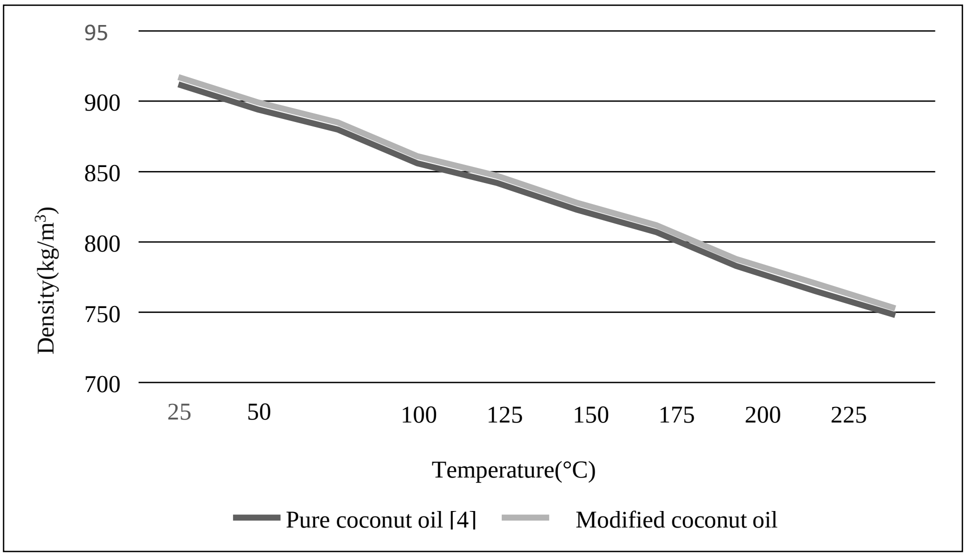

Fig. 5. *Density variation with temperature.*

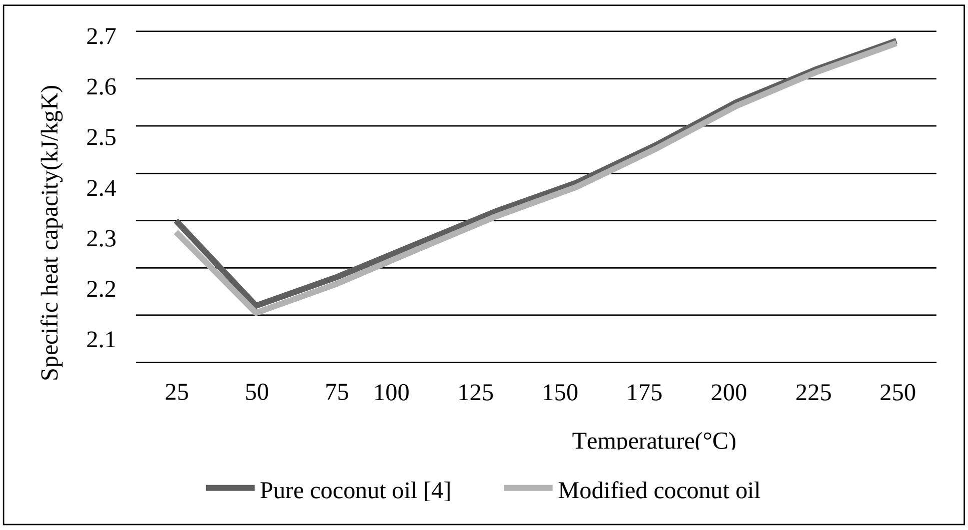

Fig. 6. *Variation of specific heat capacity with temperature.*

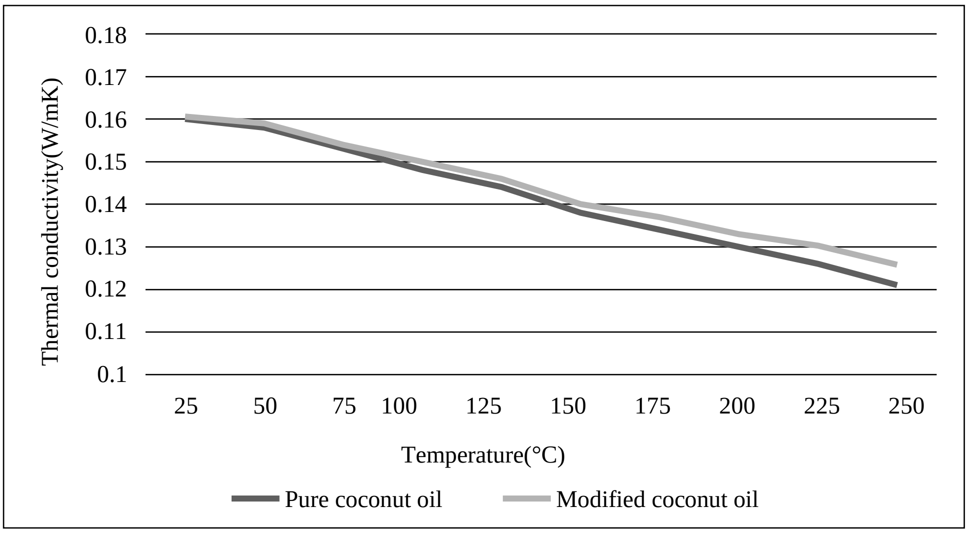

Fig. 7. *Variation of thermal conductivity with temperature.*

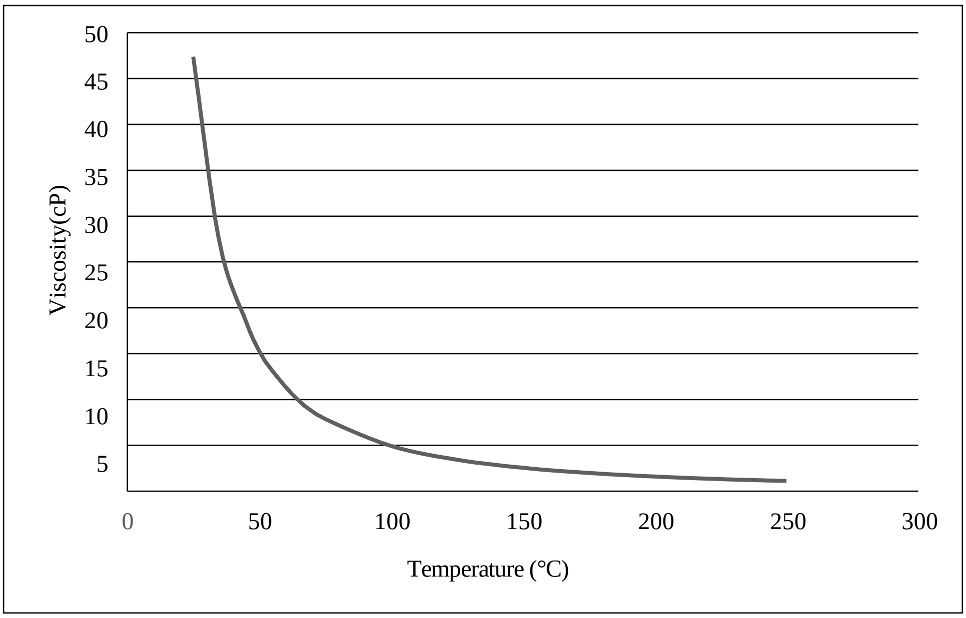

Fig. 8. *Variation of viscosity with temperature.*

Dynamic viscosity of MCO extrapolated from experimental data in Table 6 for the entire operating range of CSP and its comparison with pure coconut oil is shown in Figures 8. MCO is having lesser viscosity at all values of temperature considered, leading to increased wettability all along the inner surface of the pipe. This will result in formation of a thicker fluid film ensuring better conductivity of heat from pipe surface to fluid body. The reduction in dynamic viscosity also attributes to the better flowability of the fluid which enhances the process of heat transfer [21].

There is an increase in thermal diffusivity and decrease in momentum diffusivity due to the corresponding increase in thermal conductivity and decrease in specific heat capacity. The reduction in momentum diffusivity will in turn cause a slight reduction in Prandtl number. However, the Reynolds number increases as the viscosity decreases and also due to the fact that density is found to be greater than pure coconut oil at corresponding temperatures So the Nusselt number will have a slight increase in laminar flow as the decrease in Prandtl number and increase in Reynolds number counterbalances each other's effects, leading to an increase in the heat transfer [22].

Studies on vegetable oils as HTFs are rarely available in literature. In order to assess the utility of the present study, the MCO is compared with Synthetic oil Therminol VP1®, considered as the reference solar oil. Table 8 compares several criteria regarding synthetic oil and MCO [23].

The properties like pour point, thermal conductivity, volumetric heat capacity and density of MCO are found to be much better than that of commercially used Therminol VP1®. Also considering the eco-friendliness of MCO, it can be termed as bio-HTF which has potential to replace synthetic HTFs. Better availability and possible cost effectiveness on mass scale production can make MCO a better alternative to synthetic HTF. Also, the increase in oxidative stability and enhanced pour point helps in the widening of the temperature range of CSP, which eventually buttresses the HFT in application. Development of ~~a~~ bio-HTF in mass scale can be explored in future if the limitations are ameliorated [24–25].

Table 8. *Comparison of properties of Therminol VP1® and MCO.*

Property	**Unit**	**Therminol VP1 [1,17]**	**MCO**
Pour point	°C	12	9
Temperature limit for use	°C	400	312
Thermal conductivity			
100°C	W/mK	0.128	0.150
200°C		0.114	0.133
Density			
100°C	kg/m^3	999	861.03
200°C		913	787.80
Dynamic viscosity			
100°C	cP	0.985	4.931
200°C		0.395	1.591
Volumetric heat capacity			
100°C	MJ m^{-3} K^{-1}	1.77	1.92
200°C		1.87	2.001
Availability	-	Low	High
Environmental Hazard	-	High	Low

CONCLUSIONS

Coconut oil is considered as a potential HTF for use in concentrated solar plant (CSP) due to its favorable properties like high thermal conductivity, high flash point, low toxicity etc. It's low thermal stability and high pour point can be improved by using chemical additives, but this can lead to detrimental environmental effects during disposal. Eco-friendliness will be a key factor while considering HTF, in near future. Natural additives are better alternatives to chemical additives for improving the properties of coconut oil. Garlic oil is chosen as the additive in this study for modifying coconut oil, based on its many superior qualities such as less corrosive tendency, antioxidant property, superior thermal properties etc. The addition of garlic oil is found to be efficacious as it resulted in substantial improvement in thermal stability and reduction in pour point. This further enhances the working temperature range of the oil making it more competitive to synthetic HTFs available in market. The prospects of enhanced heat transfer using modified oil as HTF are also revealed in the study, due to possibly better thermophysical properties which are comparable to commercial synthetic HTFs. The study has thus revealed possibilities of using locally available natural additives to formulate bio-HTF (BHTF) that is not hazardous to nature during use as well as during disposal.

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REFERENCES

[1] Rai, DK., Shukla, M., Khan, AA. and Singh, AK., Heat transfer Fluids in Concentrated Solar Power Plants (CSP). *International Journal of Electrical and Electronics Engineers* 2015: 7(2) : 407–410.

[2] Kumar, V P. and Sharma, M., Analysis of Heat Transfer Fluids in Concentrated Solar Power (CSP). *International Journal of Engineering Research & Technology*. 2014 : 3(12): 239–240.

[3] Rajendran, D R., Sundaram, E G., and Jawahar, P., Review on

influencing parameters in the performance of concentrated solar power collector based on materials, heat transfer fluids and design. *Journal of Thermal Analysis and Calorimetry* 2019 : 140 : 33–51.

[4] Hoffmann, JF., Vaitilingom G., Henry, JF, Chirtoc, M., Olives, R. and Goetz, V., Temperature dependence of thermophysical and rheological properties of seven vegetable oils in view of their use as heat transfer fluids in concentrated solar plants. *Solar Energy Materials and Solar Cells* 2018 : 178 : 129–138.

[5] Lopez JAB., Alvarado TM., G´alvez Coyt G, Diosdado, AM., Reyes, JD., Thermal characterization of vegetable oils by means of photoacoustic techniques. *Revista Mexicana de F´ısica* 2013: S 59 (1) 168–172.

[6] Jayadas NH., and Nair KP., Coconut oil as base oil for industrial lubricants—evaluation and modification of thermal, oxidative and low temperature properties. *Tribology International* 2006: 39: 873–878.

[7] Sinha, AA., Shukla, A., and Prasad, RB., A review on CSP technologies with heat transfer fluids used in Indian power plants, *21st Century Energy Needs: Materials, Systems and Applications (ICTFCEN)* 2016: 1–6.

[8] Hoffmann, J F., and Chirtoc, M., Temperature dependence of thermal conductivity of vegetable oils for use in concentrated solar power plants, measured by 3 omega hot wire method. *International Journal of Thermal Sciences* 2016 : 107 : 105–110.

[9] Taghvaei M and Jafari SM. Application and stability of natural antioxidants in edible oils in order to substitute synthetic additives. *Journal of Food Science and Technology* 2015; 52(3): 1272–1282.

[10] Chandran J, Nayana N and Roshini N. Oxidative stability, thermal stability and acceptability of coconut oil with essential oils from black pepper and ginger. *Journal of Food Science and Technology* 2017; 54(1): 144–152.

[11] Porter, NG., and Lammerink JP., Effect of Temperature on the Relative Densities of Essential Oils and Water. *Journal of Essential Oil Research* 1994: 6(3) : 269–277.

[12] Madamba, P S., Driscoll, R H., and Buckle, K A., Models for the Specific Heat and Thermal Conductivity of Garlic. *Drying Technology: An International Journal* 2007: 13(1–2), 295–317.

[13] Kramkowski, R., Kamiński, E., and Serowik, M., Effect of Moisture and Temperature of Garlic on its Specific Heat. *Electronic Journal of Polish Agricultural Universities* 2001: 4(2).

[14] El-Baroty G S., Farag R S., and Saleh M A., Characterization of antioxidant and antimicrobial compounds of cinnamon and ginger essential oils. *African Journal of Biochemistry Research* 2010: 4(6): 167–174.

[15] Romero JT., Gabas AL., Polizelli MA., and Telis, VRN., Temperature and water content influence on thermophysical properties of coffee extract. *International Journal of Food Properties*. 2009: 3(3) : 375–384.

[16] Brian P. Baker and Jennifer A. Grant. Garlic and Garlic Oil Profile Active Ingredient Eligible for Minimum Risk Pesticide Use. *New Publications (NYS Integrated Pest Management Program)* 2018 : http://hdl.handle.net/1813/56126.

[17] Meghwal, M., and Goswami T K., Thermal properties of black pepper and its volatile oil. *International*

Journal of Advanced Biotechnology and Research 2013: 2 (3) : 334–344.

[18] Govender O., Rareyand, J., and Ramjugernath, D., Estimation of Pure Component Properties, Part 5: Estimation of the Thermal Conductivity of Nonelectrolyte Organic Liquids via Group Contributions. *Journal of chemical and Engineering data* 2020; *65* (3), 1300–1312.

[19] Rafe, A., and Nadjafi, MS., Physicochemical characteristics of garlic (Allium sativum L.) oil: Effect of extraction procedure. *International Journal of Nutrition and Food Sciences* 2014; 3(6–1): 1–5.

[20] Kobasko, NI., de Souza, EC., de Compos, L., Canale, F., and Totten, GE. Vegetable Oil Quenchants: Calculation and Comparison of The Cooling Properties of a Series of Vegetable Oils. *Strojniškivestnik: Journal of Mechanical Engineering* 2010: 56(2) :131–142.

[21] Barnwal, P., Singh, K., Choudhary, A.K., and Zachariah, J. Biochemical, antioxidant and thermal properties of cryogenic and ambient ground turmeric powder. *International Agricultural Engineering Journal* 2014 : 23(1) : 39–46.

[22] Gasni, D., Chandra, D., Putra, A., and Fajri, R. Effect of garlic oil as lubricant additive into coconut and palm oils on the physical and tribological properties. *IOP Conf. Series: Materials Science and Engineering* 602 : 2019.

[23] Ghodki, BM., and Goswami TK., Thermal and Mechanical Properties of Black Pepper at Different Temperatures. *Journal of Food Process Engineering* 2017 : 40(1).

[24] Rite, RW., and Rezkallah, KS., The Influence of Liquid Viscosity on Heat Transfer Coefficients in Gas-Liquid Flows under Microgravity Conditions. *AIP Conference Proceedings 301* 1994 : 1129–1136.

[25] Fasina, OO., and Colley Z., Viscosity and Specific Heat of Vegetable Oils as a Function of Temperature: 35°C to 180°C. *International Journal of Food Properties.* 2008: 11: 738–746.

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