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EXPERIMENTAL INVESTIGATION AND MECHANISM ANALYSIS: EFFECT OF CONCENTRATION AND TEMPERATURE ON THE HEAT TRANSFER CHARACTERISTICS OF NOVEL MWCNT-MUSTARD OIL NANOFLUID

V. Vignesh[1*], S. Vijayan[2], G. Selvakumar[3] and D. Prince Sahaya Sudherson[4]

[1]Department of Mechanical Engineering, St. Mother Theresa Engineering College, Vagaikulam-628103, Tamil Nadu, India
[2]Department of Mechanical Engineering, Sri Sivasubramaniya Nadar College of Engineering, kalavakkam, Chennai 603110, India
[3]Department of Mechanical Engineering, Sri Sivasubramaniya Nadar College of Engineering, kalavakkam, Chennai 603110, India
[4]Department of Mechanical Engineering, Rohini College of Engineering and Technology, Paulkulam, Kanyakumari 629401, India

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ABSTRACT. The bio-oils as alternative lubricating fluid are potential solution for the automotive and industrial mechanical systems. The development of novel renewable and non-toxic bio-oils with better heat transfer distinctiveness will strengthen the economy of farmers in the agricultural based countries. The most innovative approach to improve the heat transfer characteristics of bio-oils is converting it into nanofluids by dispersing nanomaterials which has extremely high heat transfer characteristics. In this study, MWCNT-Mustard oil nanofluids were formulated through ultrasonication and their dispersion stability was estimated through Zeta-potential technique. The thermal stability of the MWCNT-Mustard oil nanofluids are estimated through thermogravimetric analysis and concentration and temperature dependent density, thermal conductivity and specific heat capacity of MWCNT-Mustard oil nanofluids are also determined and their characteristics are discussed. The heat transfer characteristics of MWCNT-Mustard oil nanofluids observed through the heat pipe test rig at different inlet temperatures, mass flow rate of nanofluids and Reynolds number. The results exhibits that the dispersion of MWCNT enhances the heat transfer characteristics of MWCNT-Mustard oil nanofluids.

KEY WORDS: Non-toxic bio-oils, Nanomaterials, Nanofluids, Thermogravimetric analysis, MWCNT, Mustard oil

INTRODUCTION

The rapid industrialization demands considerable rise in the requirement of energy for domestic and all industrial sectors. Recently, the focus of International Energy Agency (IEA) and researchers has shifted on the global energy crisis due to growing energy requirement of the world. The aggravated global population, economic growth, issues of fossil fuels reduction, industrial and transportation activities are the reasons behind worldwide energy extremity. The emergent concern to curtail the exploit of petroleum derivative mineral oil has led to the exploration for alternative eco-friendly lubricating agents as the mineral oil based lubricants have the lowest biodegradation rate, a high potential for bio-accumulation and toxicity to all organisms.

The bio-lubricants degrade faster without bio-accumulation, however, they exhibit considerably less wear rate than mineral oils which limits their industrial applications [1]. In general, the bio-oils are vegetable fat which can be produced at industrial scale and are characterized by their fatty acid composition. Among the wide range of bio-oils, the mustard oil has a distinctive pungent taste which is often used for cooking in North India, Nepal, Bangladesh and Pakistan which has the average thermal conductivity of 0.166 - 0.171 W/mK at 20 °C, 0.169 - 0.174 W/mK at 60 °C and the average dynamic viscosity of 93.9 mPa.s at 20 °C, 20.989 mPa.s

*Corresponding author. E-mail: vvigneshsmt@gmail.com

at 60 °C [2]. The characteristic issues of bio-oils are thermo-oxidative instability and poor cold flow behavior. The chemico-physical distinctiveness of the bio-oils is highly influenced by temperature and their fatty acid compositions [3]. To diminish the ecological damage caused by mineral lubrication oils, it is essential to enhance the distinctiveness of bio-oils to compete with mineral oils commercially.

The recent research evolutions have exposed a promise to conquer these infirmities through dispersing performance enhancing nano-scaled additives [4] and blending by other mineral based oils [5]. The most innovative approach to improve the heat transfer characteristics of conventional fluids is converting it into nanofluids by dispersing nanomaterials which have extremely high thermal conductivities [6]. The homogeneous dispersion of regular morphological nanomaterials into the mustard oil intensifies the inter-particle reaction and flourishes extensive aggregate structure. The exiting literature reveals that the thermo-physical possessions of the nanofluids significantly depend on the concentration, temperature as well as geometrical distinctiveness of dispersed nanomaterials. The temperature and nanomaterial concentration significantly affects the dispersion stability of nanofluids. Poonam *et al.* investigated the environmental impacts of mustard oil creation through life cycle approach and reported that the advancement in environmental concern of the agriculture stage can lead to cleaner oil production. Hence, the blending of bio-lubricants with nano-scale additives possess the leeway for formulating novel renewable and non-toxic lubricants with better lubricating distinctiveness and to compete with mineral oil based lubricants technically [7]. Huijuan *et al.* investigated the effectiveness of 35 heat transfer fluids in organic and supercritical Rankine cycles by considering their thermodynamic and physical properties. Their results indicate that the thermo-physical properties of heat transfer fluids play an imperative part in the cycle performance. Further, the heat transfer fluids with high density and latent heat exhibits relatively high turbine output [8]. Wang *et al.* investigated the thermo-physical properties of ethylene glycol based TiO_2-Al_2O_3 hybrid nanofluids and reported 40.86% of maximum thermal conductivity and 38% of dynamic viscosity enhancement than the base fluid. Further, they reported that the higher nanomaterial concentration exhibits superior thermo-physical property enhancement and also proposed empirical correlations to estimate the thermo-physical properties of nanofluids [9]. Tao *et al.* experimentally investigated the flow and heat transfer characteristics of ZnO-EG/water nanofluid and estimated the Nusselt number, friction factor and heat transfer coefficient. The results reveals that the nanofluid exhibits 10.6%, 47.3% and 0.92–1.09 of Nusselt number, friction factor and heat transfer coefficient ratio, respectively at 1.5 vol% nanofluids [10]. In this study, the effect of concentration and temperature on the heat transfer characteristics of novel MWCNT-Mustard oil nanofluid is experimentally investigated.

EXPERIMENTAL

The carbon nanotubes such as single-wall carbon nanotubes (SWCNT) and multi-wall carbon nanotubes (MWCNT) are the long straight and parallel carbon layers of cylindrically rolled bulky tubes that received a great consideration since their development due to admirable gas sensing [11], thermal [12], electrical [13], mechanical [14] and tribological [15] distinctiveness. They also widely applied as carriers in therapeutic/detective molecules [16] and energy storage [17] applications. It has honeycomb network graphitic carbon atoms (graphene) and is seamlessly rolled to form MWCNT. In general, it has low density, high specific surface area and large aspect ratio compared to other nanomaterials. The densely packed and randomly oriented MWCNT with the diameter is ranging from 80 to 140 nm with few microns length is observed from its SEM image (Figure 1). The structure of MWCNT has regular hexagonal lattice on the cylindrical plane.

The homogeneous suspension of MWCNT-Mustard oil nanofluid was acquired by ultrasonic agitation using a 700 W probe ultrasonicator. The dynamic light scattering (DLS) technique (ZS ZEN 360, Malvern Instruments Ltd) is employed to estimate the zeta potential of different weight fractions of MWCNT-Mustard oil nanofluids. In this DLS technique, the dispersed MWCNT will be in motion due to interaction between the charged nanomaterials in which the direction depends on the electric field strength which designates the extent of repulsion among the charged atoms in dispersion. The nanofluids with greatest zeta potential are categorized as stable fluids whereas nanofluids with squat zeta potentials may have the tendency to flocculate.

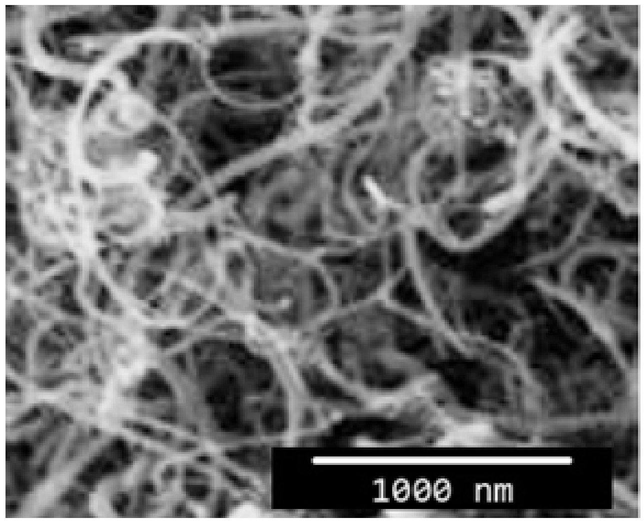

Figure 1. SEM image of MWCNT.

The density of fluids plays a vital role in developing nanofluid based heat transfer equipment with optimum efficiency and it is determined through Anton-Paar (DMA 45) density meter in which a temperature bath is used to maintain the temperature of base fluid and nanofluids. The TGA 550, Thermogravimetric analyzer is used for determining the thermal stability of mustard oil and MWCNT-Mustard oil nanofluids. The Tru-Mass Balance system of this TGA 550, Thermogravimetric analyzer (TA Instruments) is thermally isolated for getting high sensitivity in each measurements, delivers the highest resolution, reliable and sensitivity data. The specific heat capacities of nanofluids are estimated by differential scanning calorimetric (DSC) method which is the ratio of the heat flow and the heating rate. Further, NETZSCH LFA 457 Micro-Flash, Germany, thermal conductivity analyzer is used for determining the thermal properties of mustard oil and MWCNT-Mustard oil nanofluids. It works through laser flash technique which is a fast and non-contact technique for estimating thermal properties. The front surface of the thermal conductivity analyzer is heated by light pulse and infrared (IR) detector is used to estimate the resulting temperature excursion the thermal properties are determined. The heat transfer characteristics of MWCNT-Mustard oil nanofluids observed through the heat pipe test rig at different inlet temperatures, mass flow rate of nanofluids and Reynolds number. The influences of specific heat capacity and density on the heat transfer characteristics of MWCNT-Mustard oil nanofluids are also discussed.

RESULTS AND DISCUSSION

The homogeneous suspension of MWCNT-Mustard oil nanofluid was acquired by ultrasonic agitation using a 700 W probe ultrasonicator. The steps involved in the nanofluid formulation are given as follows: (1) The mustard oil is used as base oil for coining MWCNT-Mustard oil nanofluid by ultrasonication technique. (2) The weight of MWCNT and mustard oil was measured by a precise digital weighing balance (accuracy of 0.01 mg). (3) The stable MWCNT-Mustard oil nanofluids are acquired by magnetic stirring (120 min) followed by ultrasonication (45 min) at room temperature. (4) Similar procedure is followed for coining the 0.2, 0.4, 0.6, 0.8 and 1 wt% of MWCNT-Mustard oil nanofluids. (5) All the prepared the nanofluids are kept in a separate closed containers for stability investigation.

The dynamic light scattering (DLS) technique (ZS ZEN 360, Malvern Instruments Ltd) is employed to estimate the zeta potential of different weight fractions of MWCNT-Mustard oil nanofluids and the results of DLS measurements are presented in the Table 1. The nanofluids having 40-60 mV of potential difference are having tremendous stability [18]. The DLS estimations are conducted at 25 ºC with the tolerance of about 0.1 ºC.

Table 1. The results of DLS measurement.

Concentration of MWCNT-Mustard oil nanofluids	Zeta potential (mV)		
	After 144 hours	After 288 hours	After 432 hours
0.2 wt%	26.8	26.5	23
0.4 wt%	26.7	26.4	22.5
0.6 wt%	26.5	26.2	21.4
0.8 wt%	26.4	26	20.5
1 wt%	26.2	25.8	20.1

The Table 1 reveals that the potential difference of the all weight fractions of MWCNT-Mustard oil nanofluids significantly decreases after 288 hours of dispersion stability examination. The aggregation effect of the MWCNT on the dispersion stability of MWCNT-Mustard oil nanofluid lies in multifarious mechanism due to their inter-particle reaction. In accordance with Brownian theory, MWCNT in the mustard oil are relentlessly in the faction of collision as well as agglomeration which leads to the formation of aggregate MWCNT structure and accounts for the superior dynamic viscosity. The Brownian motion of the MWCNT in mustard oil is expressed through the Stokes–Einstein diffusion Equation (1) where D’, KB, T, η and d are the diffusion constant, Boltzmann's constant, absolute temperature, mobility and size of dispersed nanomaterials, respectively. The diffusion time (τD) of the dispersed MWCNT-Mustard nanofluid is determined through the Equation 2 which estimates the time required to travel the distance equal to the size of the dispersed MWCNT in the mustard oil.

$$D' = \frac{K_B T}{3\,\pi \eta d} \tag{1}$$

$$\tau_D = \frac{3\,\pi \eta d^3}{6\,K_B T} in\mu s \tag{2}$$

The homogeneous dispersion of regular morphological nanomaterials into the mustard oil intensifies the inter-particle reaction and flourishes extensive aggregate structure. The diffusion constant increases with increasing temperature and nanomaterial weight fractions, hence, the optimum temperature and nanomaterial weight fractions must be estimated to utilize the MWCNT-Mustard oil nanofluid in the suitable industrial heat transfer applications.

The density of MWCNT-Mustard oil nanofluids plays a vital role in developing nanofluid based heat transfer equipment with optimum efficiency and it is determined through Anton-Paar (DMA 45) density meter in which a temperature bath is used to maintain the temperature of base fluid and nanofluids. The test fluid is filled in an oscillating U-tube manometer without any air bubbles which has frequency counter and display. In this density meter, the oscillation period is estimated by a built-in clock for each 2 seconds and it is transmitted to the built-in processor for estimating the density through Equation 3. Further, the theoretical density of MWCNT-Mustard oil nanofluids are estimated through the following correlation (Equation 4) reported by Pak and Cho [9].

Density ofMWCNT-Mustard oil nanofluids, $\rho_{nf} = \frac{T^2 - C_2}{C_1}$ (3)

Density ofnanofluids, $\rho_{nf} = \O_{np} + (1-\O)\ \rho_{bf}$ (4)

where, ρ_{nf}, T, C, $\O_{np}$ and ρ_{bf} are density of MWCNT-Mustard oil nanofluids, oscillation period, Anton-Paar constant, weight fraction of MWCNT and density of mustard oil, respectively. The average density of base fluid and 0.2, 0.4, 0.6, 0.8 and 1 wt% of MWCNT-Mustard oil nanofluids for the temperature ranging from 40-100 °C estimated through digital density meter is depicted in the Figure 2.

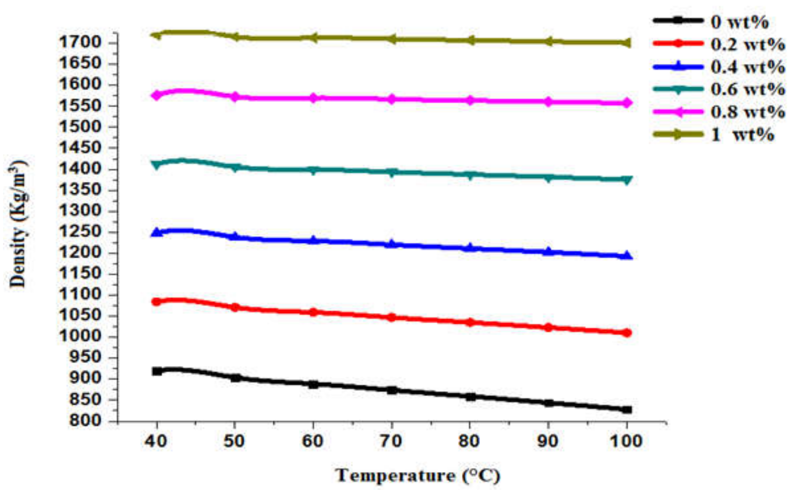

Figure 2. Density of MWCNT-Mustard oil nanofluids.

Initially, the density of mustard oil at different temperatures were determined experimentally and the results were compared with the theoretical density obtained through the density correlation (Equation 2) reported by Pak and Cho [19]. The experimental results were good argument with the theoretical correlation with less than 4.5% of deviation. The experimental results exhibit that the density of MWCNT-Mustard oil nanofluids decreases by temperature augmentation and increased by the MWCNT concentration augmentation for all tested conditions. The dispersion of MWCNT into the Mustard oil is reason for the density enhancement whereas the rapid breaking of Mustard oil and MWCNT-Mustard oil nanofluids bonds is the reason for the density decrement with the corresponding temperature augmentation.

Table 2. Parameters used in the thermal stability measurement.

Parameter	Specification
Temperature range	Ambient to 500 °C
Heating rate	20 °C/min
Sample weight	100 mg
Weighing precision	±0.01 %
Pan material	Platinum
Atmosphere	Helium
Software	TRIOS software

The thermal stability is estimated through thermogravimetric analysis (TGA) in which the mass of a sample base oil or nanofluid is recorded over time as the temperature increases. The thermal stability of Mustard oil and 0.2, 0.6 and 1 wt% of MWCNT-Mustard oil nanofluids estimated with the following parameters (Table 2).

The following procedure was employed for recording the TGA thermograms of base oil and MWCNT-Mustard oil nanofluids. (i) An empty crucible was placed on the sample holder platform. (ii) The sample (base oil/nanofluid) was kept on the sample holder. (iii) The initial weight reading was set to 100%. (iv) The gas environment and its mass flow rate was selected. (v) The temperature range and heating rate was selected. (vi) The thermogram of percent weight loss versus temperature was plotted.

The TGA thermograms of Mustard oil and 0.2, 0.6 and 1 wt% of MWCNT-Mustard oil nanofluids estimated through the thermogravimetric analyzer is depicted in Figure 3.

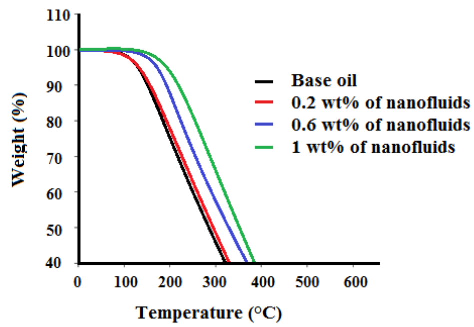

Figure 3. TGA thermograms of base fluid and MWCNT-Mustard oil nanofluids.

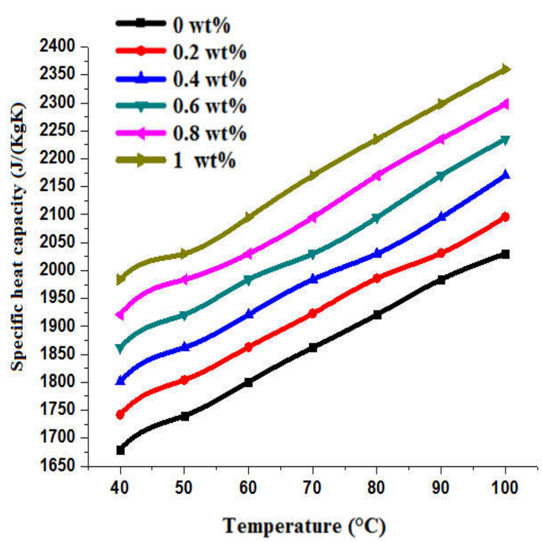

Figure 4. Specific heat capacity of MWCNT-Mustard oil nanofluids.

The thermogram of additive free mustard oil exhibits that the evaporation of moisture content begins from 92 °C. The oil content and triglyceride fatty acid compounds of the mustard oil decompose from 128 °C. A slight improvement in the resistance to decomposing of mustard oil compounds observed for the 0.2wt% of MWCNT-Mustard oil nanofluids. Further, the 0.6wt% and 1 wt% of MWCNT-Mustard oil nanofluids begins to decompose from about 174 °C and 193.5 °C, respectively. The homogeneous dispersion of the MWCNT into the mustard oil is the reason for this thermal stability enhancement and the results clearly indicates that the thermal stability increases with increase in MWCNT concentration.

The specific heat capacities of nanofluids are estimated by differential scanning calorimetric (DSC) method which is the ratio of the heat flow and the heating rate. It represents the ability of MWCNT-Mustard oil nanofluids to store thermal energy. In DSC, temperature difference is induced through the heat flow with appropriate calibration and the specific heat is estimated from the ratio of the heat flow and the heating rate. The average specific heat capacity of base fluid and 0.2, 0.4, 0.6, 0.8 and 1 wt% of MWCNT-Mustard oil nanofluids for the temperature ranging from 40-100 °C estimated through DSC is depicted in the Figure 4.

The thermal energy is applied in a controlled environment to the heating agents which heats the nanofluid and the change of mass of each sample was recorded carefully from the mass balance. The theoretical specific heat capacity of MWCNT-Mustard oil nanofluids are calculated from Equation 5:

$$\text{Specific heat capacity, } C_{Pnf} = \frac{Q\Delta T - m_c C_{Pc}\Delta T_C - m_{co}C_{pco}\Delta T_{co} - m_{in}C_{pin}\Delta T_{in} - q_L\Delta t}{m_{nf}\Delta T_{nf}} \quad (5)$$

where, C_{Pnf}, Q, Δt, ΔT, m, q_L, m_c, C_{pc}, ΔT_c, m_{co}, C_{pco}, ΔT_{co}, m_{in}, C_{pin} and ΔT_{in} Specific heat capacity of MWCNT-Mustard oil nanofluids, heat supplied, time delay, change in temperature, mass, heat loss of apparatus, mass of container, Specific heat capacity of container, temperature rise in the container, mass of heating coil, Specific heat capacity of heating coil, temperature rise in the heating coil, mass of insulation, specific heat capacity of insulation and temperature change in the insulation, respectively.

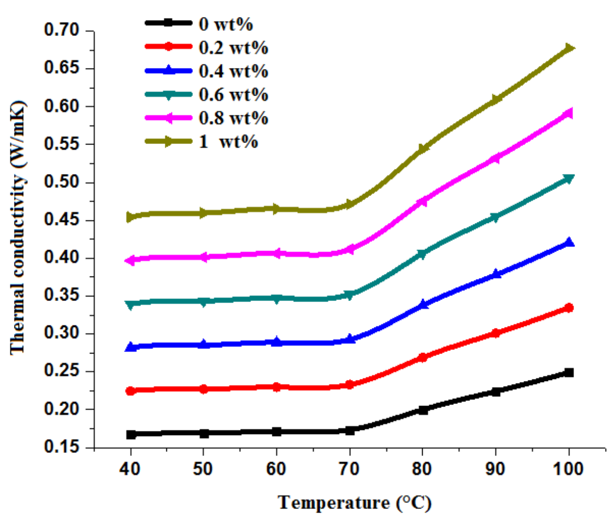

Figure 5. Thermal conductivity of base fluid and MWCNT-Mustard oil nanofluids.

The specific heat capacity of Mustard oil at different temperatures was determined experimentally and the results were compared with the theoretical density obtained through the density correlation (Equation 5). The experimental results were good argument with the theoretical correlation with less than 6% of deviation. The experimental results exhibit that the specific heat capacity of MWCNT-Mustard oil nanofluids increases by temperature and MWCNT concentration augmentation for all tested conditions. The dispersion of MWCNT into the mustard oil is reason for the specific heat capacity enhancement. The results also indicates that the when the temperature increases, both MWCNT-Mustard oil nanofluid and mustard oil molecular structure varies and the increase in the kinetic energy of the molecules leads to the enhancement of specific heat capacities.

The average thermal conductivity of base fluid and 0.2, 0.4, 0.6, 0.8 and 1 wt% of MWCNT-Mustard oil nanofluids for the temperature ranging from 40-100 °C estimated through laser flash technique is depicted in Figure 5.

The MWCNT weight fraction has a notable effect on the thermal conductivity during the measured temperature ranging from 40-100°C. It can be pinpointed through the Figure 5 that the dynamic viscosity of MWCNT-Mustard oil nanofluid as well as pure mustard oil for the all temperature increases non-linearly at constant MWCNT weight fraction. The experimental results indicated that when the temperature increases, both MWCNT-Mustard oil nanofluid and mustard oil molecular structure varies and the random motion of oil molecules structure leads to the enhancement of thermal conductivity. The raise of MWCNT weight fraction from 0 to 1 wt% the average thermal conductivity of the nanofluid raises from 0.166 to 0.45 W/mK at 40 °C whereas it raises from 0.168 to 0.458 W/mK, 0.171 to 0.47 W/mK, 0.177 to 0.48 W/mK, 0.22 to 0.54 W/mK, 0.221 to 0.62 W/mK and 0.234 to 0.681 W/mK at the temperatures of 50, 60, 70, 80, 90 and 100 °C, respectively. It clearly designates that with the raise in temperature the thermal conductivity of nanofluid increases considerably. The thermal conductivity enhancement primarily occurs due to the dispersion of MWCNT into the mustard oil and the possible thermal conductivity enhancement mechanisms are given as follow: (i) In accordance with Brownian theory, MWCNT in the mustard oil are relentlessly in the faction of collision as well as minute agglomeration which leads to the superior thermal conductivity. (ii) When the temperature increases the interactions between the dispersed MWCNT increases which significantly augment the thermal conductivity of MWCNT-Mustard oil nanofluids at higher temperatures. (iii) The nano-scale localized convection-like effects due to the Brownian motion of MWCNT.

The test rig used to investigate the heat transfer characteristics of MWCNT-Mustard oil nanofluids are depicted in the Figure 6has concentric water as well as the nanofluid flow circuits. It has water and nanofluid loops with separate flow meter (Coriolis type) and temperature control. The test tube is 3m long and it is thermally insulated. The pressure change is recorded through a differential pressure transducer. Thermocouples are used to monitor the temperature change of the test section. The centrifugal pump and electric heater are used to pump and heat the fluids. The heat transfer test is conducted at different mass flow rate, MWCNT concentrations, inlet temperature and Reynolds number. The heat transfer characteristics of MWCNT-Mustard oil nanofluids observed through the heat pipe test rig at different inlet temperatures (40-100 °C), mass flow rate of nanofluids and Reynolds number (2000-8000).

In the test rig is an insulated counter flow heat exchanger in which MWCNT-Mustard oil nanofluid flows through the central tube and water flows through the annular space. The inside and outside diameter of the central tube are 4.4 mm and 10.7 mm, respectively. Thermocouples are placed longitudinally on the outer surface of the tube for measuring the temperature distributions. The MWCNT-Mustard oil nanofluid is heated inside a tank through a 1 kW electric heater and it is circulated by centrifugal pump. Similarly, the water circuit cooled by 0.5 TR chilling unit and a stirrer is used for ensuring the homogeneous temperature distribution. The adiabatic sections are completely insulated with glass wool to diminish the heat losses between the test section and the atmosphere. The following experimental conditions are used for estimating the heat transfer characteristics MWCNT-Mustard oil nanofluids. Table 3 shows the test conditions followed in the heat transfer test rig. During each test, the average value of inlet temperature of water and exit temperatures of water, inlet temperature of nanofluids, exit temperatures of nanofluids, temperatures of the tube wall, mass flow rate of nanofluid and mass flow rate of the water and nanofluid are recorded.

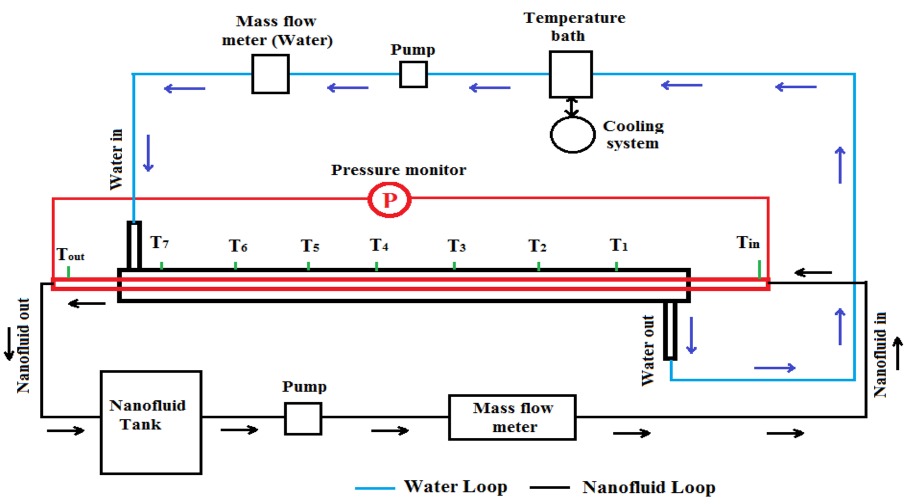

Figure 6. Test rig for estimating the heat transfer characteristics of MWCNT-Mustard oil nanofluid.

Table 3. Test conditions followed in the heat transfer test rig.

Central tube diameter	4.4 m
Reynolds number (Re)	2000-8000
Temperature of nanofluids (T_{nano})	40-100 °C
Temperature of water (T_{nano})	25 °C
Mass flow rate of water	0.015 kg/s
Estimated uncertainty	4.5%

The heat transfer rate of the MWCNT-Mustard oil nanofluid was estimated through the Equations 6-8.

The heat transfer rate of nanofluid, $Q_{nf} = m_{nf}\, CP_{nf}\, (T_{in(nf)} - T_{out(nf)})$ (6)

Nusselt number of nanofluid, $Nu_{nf} = \frac{h_{nf}\, D}{k_{nf}}$ (7)

where, m_{nf}, CP_{nf}, $T_{in(nf)}$, $T_{out(nf)}$, Nu_{nf}, h_{nf}, D and k_{nf} are mass flow rate of MWCNT-Mustard oil nanofluid, specific heat of MWCNT-Mustard oil nanofluid, inlet temperature of MWCNT-Mustard oil nanofluid, exit temperature of MWCNT-Mustard oil nanofluid, Nusselt number, heat transfer co-efficient, diameter of central tube and thermal conductivity of MWCNT-Mustard oil nanofluid, respectively. The heat transfer coefficient (h_{nf}), Nusselt number (Nu_{nf}) of the MWCNT-Mustard oil nanofluid significantly depends on Reynolds number (Re), Prandtl number (Pr) thermal conductivity of Mustard oil (k_{bf}), thermal conductivity of MWCNT-Mustard oil nanofluid (k_{nf}), specific heat capacity of Mustard oil (C_{pbf}), specific heat capacity of MWCNT (C_p), dynamic viscosity of the nanofluid (μ_{nf}), concentration of MWCNT (Ø), and size factor of MWCNT are correlated as follows:

$$\text{Nusselt number, } (Nu_{nf}) = f\left\{Re, Pr, \frac{k_{nf}}{k_{bf}}, \frac{(\rho C_p)_{nf}}{(\rho C_p)_{bf}}, size\ and\ shape\ factor\right\} \quad (8)$$

The average Nusselt number and the heat transfer coefficient of the MWCNT-Mustard oil nanofluids against Reynolds number are depicted in the Figure 7 and 8, respectively.

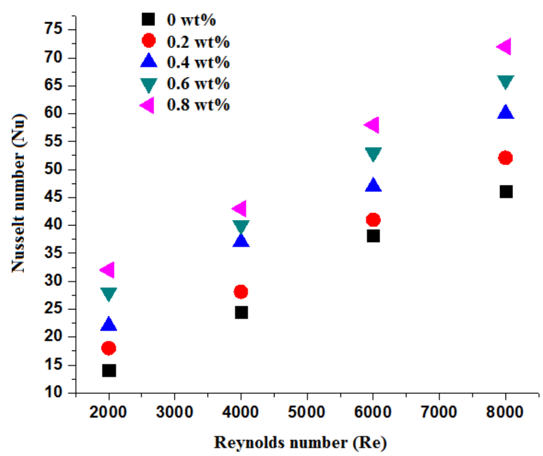

Figure 7. The Nusselt Number (Nu) of the MWCNT-Mustard oil nanofluids against Reynolds number.

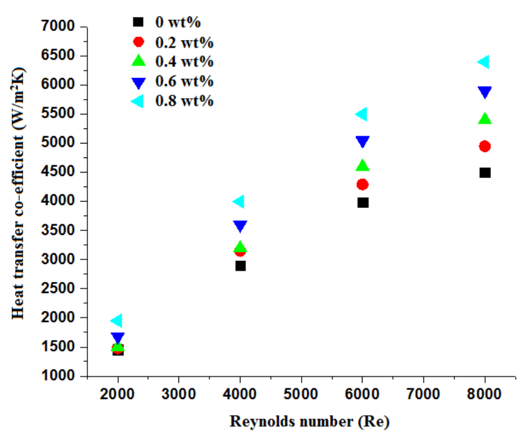

Figure 8. The heat transfer coefficient of the MWCNT-Mustard oil nanofluids against Reynolds number.

The experiments in the test rig were conducted according to the conditions mentioned in Table 3. The surface temperature of the test section is slightly higher than the evaporator section as it has the direct contact with the electric heater and the thermal resistance of the test section is significantly high at the low loading conditions. However, the thermal resistance diminishes when the MWCNT dispersed in the Mustard oil due to the high surface tension between the MWCNT and Mustard oil interfaces [20]. The results exhibits that the Nusselt number, heat transfer coefficient and heat transfer rate are significantly enhanced due to the dispersion of MWCNT into the Mustard oil. Obviously, the influence on thermal conductivity of MWCNT-Mustard oil nanofluids plays a foremost part in heat transfer augmentation. The heat transfer augmentation highly depends on the working temperature and the concentration of the MWCNT available in the mustard oil. In the nonexistence of turbulent eddies, Brownian diffusion is the potential heat transfer coefficient enhancement mechanism.

CONCLUSIONS

The thermo-physical properties of heat transfer fluids play a vital role in the categorization of heat transfer equipment in industrial applications. The inferences from the experimental results are summarized as (1) The concentration and temperature dependent thermal conductivity of MWCNT-Mustard oil nanofluids were determined through transient hot wire method and the results revealed that the when the temperature increases, both MWCNT-Mustard oil nanofluid and mustard oil molecular structure varies and the random motion of oil molecules structure leads to the enhancement of thermal conductivity. (2) The dispersion of MWCNT into the Mustard oil is reason for the density enhancement whereas the rapid breaking of Mustard oil and MWCNT-Mustard oil nanofluids bonds is the reason for the density decrement with the corresponding temperature augmentation. (3) The specific heat capacities of nanofluids are estimated by differential scanning calorimetric (DSC) technique reveals that the increase in the kinetic energy of the molecules leads to the enhancement of specific heat capacities. (4) The heat transfer characteristics augmentation of the MWCNT-Mustard oil nanofluids are highly depends on the working temperature and the concentration of the MWCNT available in the mustard oil.

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