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Experimental determination of thermal conductivity of CNTs-H_2O based nanofluids

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ABSTRACT

Solar thermal collectors are being widely used for water heating applications in domestic, commercial, and industrial sectors. The main drawback of these collectors is their low thermal efficiency. The thermal efficiency of these collectors can be significantly increased by enhancing the heat transfer fluid's thermal properties. This problem can be overcome by homogeneous mixing of nanoparticles in the base fluid such as water. The fluids with nanoparticles have better heat transfer efficiency and thermo-physical properties as compared to monofluid (water). In this study, the percent rise in thermal conductivity of the nanofluids is measured through experimentation by dissolving carbon nanotubes (CNTs) as nanoparticles in different concentrations (v/v %) inside the base fluid. The nanofluids are characterized by using the computer controlled thermal conductivity of liquids and gases unit, (TCLGC) by varying the CNTs sample composition from 0.01-0.05 v/v %. The results show that the inclusion of CNTs as nanoparticles significantly improves the thermal conductivity of nanofluids. Moreover, when CNTs are used at 0.05 v/v% inside a 100 ml sample solution, the highest increase in thermal conductivity is observed as 72%.

1. Introduction

Energy conservation is an essential concern of the global economy right now and will be certainly in the future [1, 2]. The most effective strategy to reduce consumption of energy is to deploy it more effectively [3]. Therefore, heat transfer and the design of heat transfer equipment remain vital to energy saving efforts [4, 5]. Due to the depletion of global energy resources and rising energy costs, energy efficiency and effective heat transfer have become critical [6, 7]. As a result, research on improving heat transfer has become more and more prevalent [8, 9]. Therefore, it is crucial to ascertain how well heat exchange devices operate in terms of both heat transmission and thermodynamic factors [10]. Therefore, scientists have been researching new-generation heat transfer fluids lately. These fluids are prepared by uniform diffusion of solid nanoparticles inside the water and are termed as nanofluids [11, 12].

Yousefi et al. investigated the effect of Al_2O_3-H_2O on thermal efficiency of a flat plate solar collector and used a concentration ratio of 0.2 % and 0.4 % with a particle size of 15 nm. Triton X-100 is employed as a active surface agent to enhance and maintain the suspension of nanoparticles. The rate of mass flow is varied from 1 to 3 L/min and double distilled water used as base fluid. Al_2O_3 with a concentration ratio of

0.2 % and 0.4 % was added along with an optimum concentration ratio of 0.021 % of Triton X-100 after sonification for 30 minutes. The stability time of Al_2O_3 with Triton X-100 was observed to be three days and is greater than the stability of the solution without surfactant [13]. Said et al. studied the thermal physical properties of alumina with water to make nanofluids. They also characterized the nanofluids based on density and viscosity by considering pumping power. The results reveal that alumina with water as nanofluids perform better against sedimentation and suspension to the glycol-based nanofluids. The concentrations of alumina that were investigated are 0.05 % and 0.1 % v/v. 60:40 by mass is used for the base fluid of ethylene glycol and distilled water while the second base fluid was simply distilled water [14].

The present study experimentally investigates the heat transfer fluids thermal properties such as thermal conductivity by using CNTs as nanoparticles by using TCLGC unit. The thermal conductivity for different percentage concentration is measured ranging 0.01-0.05 v/v %. The study provides a basis for the experimental and numerical investigation of solar thermal collectors used in industrial, commercial, and domestic levels for different applications by using the proposed concentration and thermophysical properties of nanoparticles.

2. Material and Methods

2.1 Apparatus Description

The CNTs-H_2O based nanofluids are characterized by using a "TCLGC" unit as shown in Fig. 1. This setup is used to calculate the conductivity of any type of gas or liquid. The test fluid and water are contained in an aluminum body (cylinder) with a brass jacket. The conduction heat TCLGC unit is made up of an aluminium chamber that make the core shape of the equipment that has a heating source in the cylinder (AR-1) in the centre and three tthermocouples ST-1, ST-2 and ST-3 at different radial distances from the centre of the aluminium cylinder. Outside the aluminum cylinder there is a radial clearance with a brass jacket on the outer radius. The brass jacket is provided with colder fluid. This small clearance, which is thin enough to preclude natural convection, is filled with the fluid to calculate thermal conductivity as shown in Fig. 2.

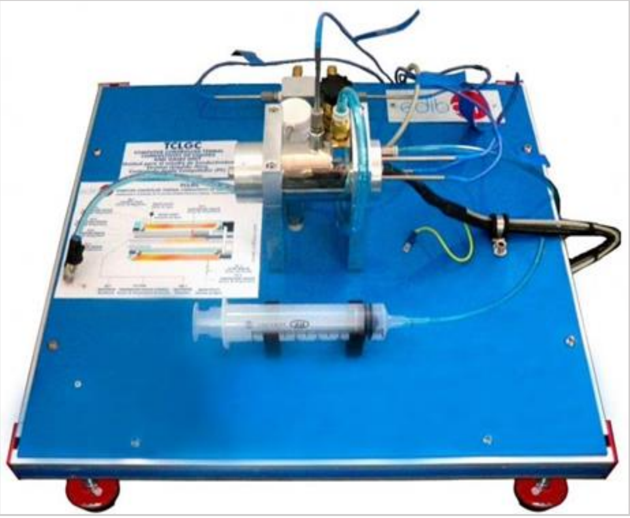


Fig. 1. TCLGC Unit for Measuring Thermal Conductivity

Power is employed to control the temperature of heating element through computer and measured with help of a sensor. For measurement of thermal-hydraulic characteristics, 6 thermocouples, "T" type (high quality) and flow rate sensors are used to obtain the data of the cooling water flow in the range from 0.25 - 6.5 l/min. In addition, the water flow is controlled by means of valves and a syringe.

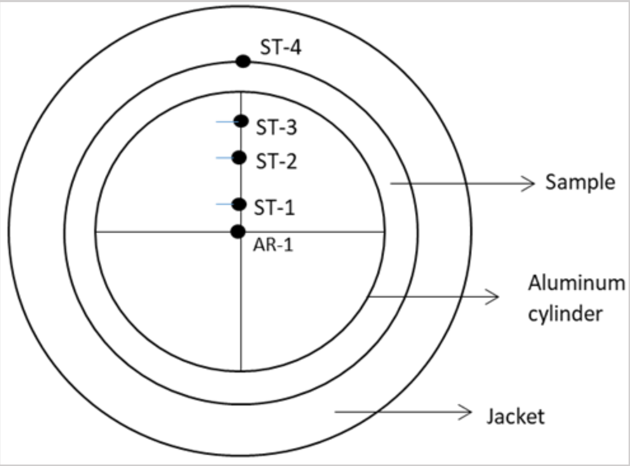


Fig. 2. Cross-Sectional Side View Labelling

The specifications of this apparatus are given below:

- Nominal radial clearance between plug (Aluminium) and jacket = 3 mm.
- r_i, Inner radius of the heated surface = 19.7 mm
- r_e, Inner radius of jacket = r_i+ 3mm
- Length of contact surface, L = 94 mm.
- Thermal conductivity of Aluminum, k = 198 W/m-K.
- Contact surface of the aluminum plug with the radial space, $A_a = 0.116\ m^2$
- Contact surface of the brass jacket with the fluid/radial space, $A_c = 0.118\ m^2$

2.2 Governing Equation

Fig. 3 shows the front view schematic of TCLGC unit that shows the two fluids circulating paths. The fluid sample circulates through the inner path while chilled water flows in outer path. The heat supplied from the heated element is transferred to the that fluid to get the conductivity value of the chilled water. Therefore, the energy balance of the unit is given as follows [4]:

$$\dot{Q}_{conducted} = \dot{Q}_{generated} - \dot{Q}_{lost} \qquad (1)$$

Where, $\dot{Q}_{conducted}$ is the heat conducted through the film in the radial space (W),

$\dot{Q}_{generated}$ is the heat generated by the heating element (W), and

$\dot{Q}_{lost}$is the incidental heat loss (W) as per calibration.

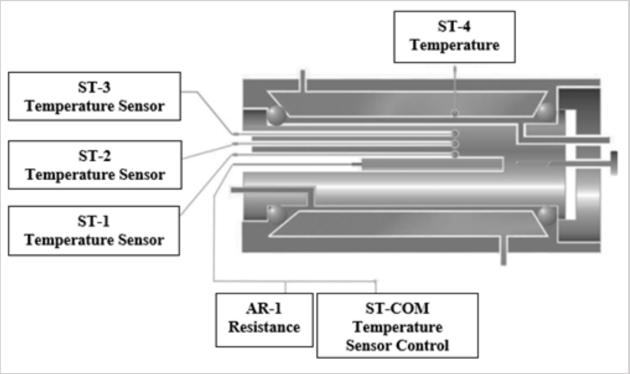


Fig. 3. TCLGC Unit Cross-Sectional Front View

The heat transferred $\dot{\mathrm{Q}}_{\mathrm{conducted}}$ to fluid can be determined as [4]:

$$\dot{Q}_{conducted} = k2\pi L \frac{T_i - T_e}{ln\frac{r_e}{r_i}} \qquad (2)$$

Where, $\mathrm{T_i}$ and $\mathrm{T_e}$ are the fluid inlet and exit temperature (^{o}C), k denoted the thermal conductivity of aluminum (W/mK), and

L represent the length of the contact surface.

After calculating the conduction heat transfer, the value of k of the desired fluid can be calculated using the following relation [15]:

$$k = \frac{\dot{Q}_{conducted}}{2\pi L\,(T_i - T_e)} ln\frac{r_e}{r_i} \qquad (3)$$

2.3 Characterization Of Nanofluids

For the characterization of nanofluids, samples are prepared by uniform mixing of carbon nanotube nanoparticles (CNTs) inside the distilled water. These nanoparticles behave as dispersed phase inside the base fluid water. Therefore, five different solutions of 100 ml are prepared for CNTs-H_2O base nanofluids having different concentrations of nanoparticles on volume basis as shown in Table 1.

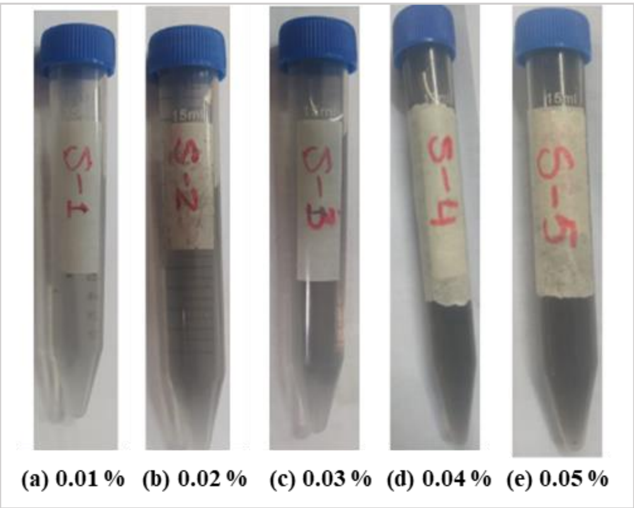
To determine the nanofluids thermal properties such as thermal conductivity, the TCLGC heat conduction unit is used. The required fluid volume of this unit is injected, by using a syringe, with these five samples of nanofluids. The experiments are performed for these samples individually by varying the heating element power through a computer. The average thermal conductivity of the sample solutions is measured by taking the average of all the values.

Table 1

Required concentration of different samples

Sr.#	Sample concentration of CNTs (v/v %)	Quantity of CNTs required for 100 ml of sample solution (mg)	The total quantity of solution required (ml)
1	0.01	0.68	100
2	0.02	1.36	100
3	0.03	2.04	100
4	0.04	2.82	100
5	0.05	3.50	100

Fig. 4 shows the nanofluids samples prepared at different concentrations of CNTs. The carbon nanotubes (Mecrk) were well dispersed in water by probe sonicator (Sonics USA) using a 1/2" probe of Ti-6Al-4V at 30% amplitude and 30 minutes sonication time. The color of the solution becomes darker when the concentration of the nanoparticles increases.



(a) 0.01 % (b) 0.02 % (c) 0.03 % (d) 0.04 % (e) 0.05 %

Fig. 4. Effect of CNTs Composition On The Color Of Samples

3. Results and Discussion

3.1 The Influence Of CNTs Composition On The Thermal Conductivity Of Nanofluid

Fig.5 shows the result of dispersed phase concentration inside the basic fluid on the average value of thermal conductivity of the nanofluids. The average thermal conductivity of the nanofluid (when nanoparticles are not dissolved inside the water) is 0.69 W/m-K. As the composition of nanoparticles increases inside the water, the value of thermal conductivity of the nanofluids increases. The maximum thermal conductivity of the CNTs-H_2O nanofluids is 1.0 W/m-K when there is a maximum concentration of nanoparticles inside the water, 0.05 v/v %. It is because the conductive heat transfer between the particles is more at their higher concentrations inside the solution. Also, there is small increase in the thermal conductivity of sample solution is observed by varying the concentration of CNTs from 0.02-0.05 v/v %. So, it is more feasible to use nanoparticles in the concentration close to 0.02 v/v % because further increasing its concentration increases the sedimentation of nanoparticles inside the flow domain. Also, there will be more pressure losses inside the flow domain.

The same thing can also be investigated by calculating the percent increase in the average thermal conductivity of the nanofluids as shown in Fig. 6. The thermal conductivity is increased by 45 % when the concentration of nanoparticles increases from 0.02-0.03 v/v %. But there is only a 8 % increment in thermal conductivity when the concentration is further increased from 0.02-0.05 v/v %.

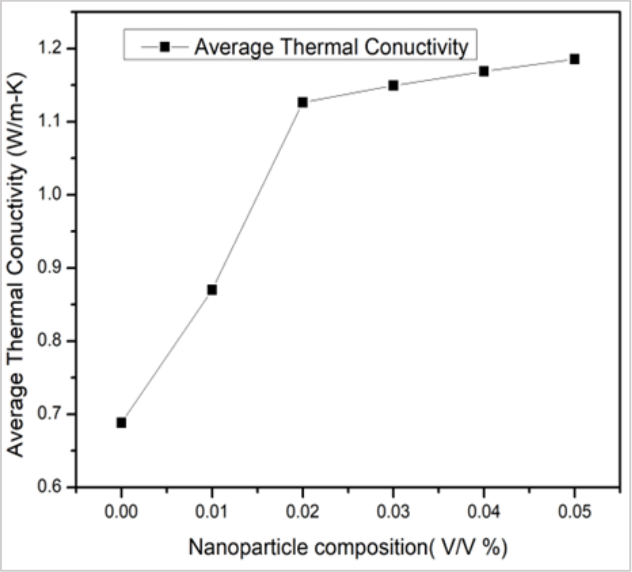


Fig. 5. The Influence of CNTs Composition On The Thermal Conductivity Of Nanofluids (CNTs-H_2O)

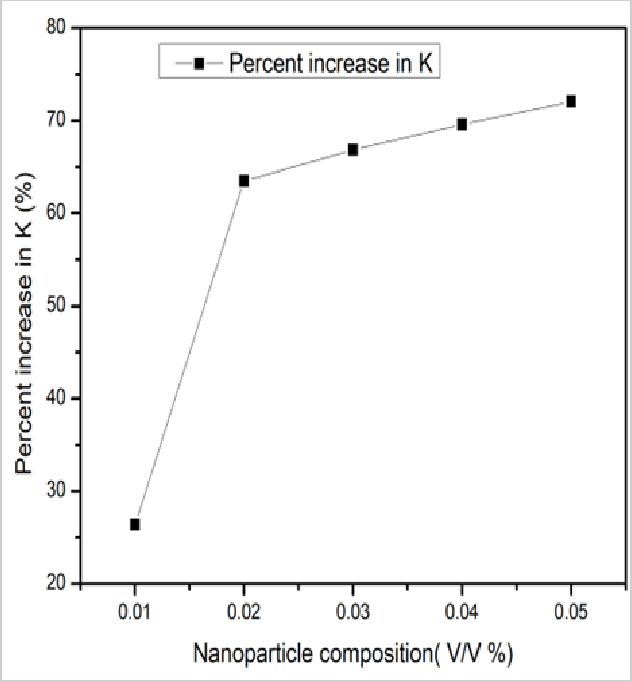


Fig. 6. The Influence of CNTs Composition on The Percent Increase in Thermal Conductivity of Nanofluids (CNTs-H_2O)

3.2 Effect Of Heat Input On The Thermal Conductivity Of Nanofluid

Fig. 7 shows the influence of changing power input to the heating element of TCLGC heat conduction unit on the average values of thermal conductivities of the nanofluid and nanoparticles with water by varying its concentration from 0.01-0.05 v/v %. The input power to the heating element is varied 30-120 Watts. The legend quantitatively shows the sample number such as S1-S5 having concentrations 0.01-0.05 v/v %, respectively. Moreover, the results show that thermal conductivity of monofluid (water) is lower from all the samples at all power inputs. It is noted that the difference between the thermal conductivity of the nanofluids for all the samples is greater at the lower input powers. As input power increases, the difference in thermal conductivity tends to decrease for all samples. This occurs because the rate of heat transfer by conduction increases with higher heat fluxes supplied to heat transfer fluids in their flow domain, showing a direct relationship. While the area and thickness remain constant, the temperature difference varies, leading to fluctuations in the thermal conductivity values. As a result, this behaviour becomes nonlinear. The heat transfer fluids demonstrated enhanced heat exchange capabilities when used in heat exchangers and solar thermal collectors operating at elevated temperatures or in warmer climates. This phenomenon is crucial for experimental investigation.

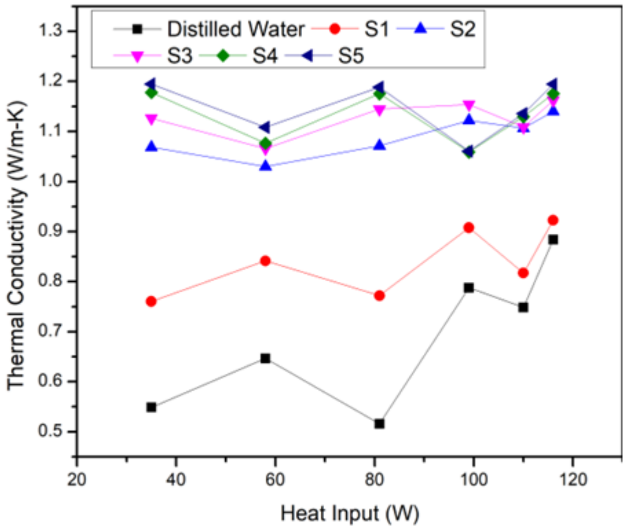


Fig. 7. Effect of Heat Input of Thermal Conductivity Measuring Apparatus On The Thermal Conductivity Of Sample

4. Conclusion

The present study investigates the thermal conductivity of the CNTs-H_2O based nanofluids that can used as a heat transfer fluid inside the solar thermal collectors. The following conclusions are drawn from the present study.

- It is observed that from 0.02-0.03 v/v %, the rise in the value of thermal conductivity is 45 % but further increasing the concentration up to 0.05 v/v %, there is only an 8 % increment in thermal conductivity.
- As the percentage of the nanoparticles increases, the dissipation of pressure also increases inside the flow domain. So, it is very important to investigate both the thermal and hydraulic aspect of heat transfer fluids when nanoparticles are employed in base fluid
- Therefore, the present study can be very effective in the experimental and numerical study of thermal characteristics of solar thermal collectors by employing carbon nanotubes at the best concentration for utilization as nanoparticles in CNTs-H2O based nanofluids.
- The thermal properties of these nanofluids are higher when they are integrated with solar thermal collectors in warmer conditions.

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