International Journal of Advanced Technology and Engineering Exploration, Vol 11(114)
ISSN (Print): 2394-5443 ISSN (Online): 2394-7454
http://dx.doi.org/10.19101/IJATEE.2023.10102112

Research Article

Thermophysical properties of MWCNT-Alumina/water nanofluid and their influence on the performance of free convection heat transfer

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Received: 02-September-2023; Revised: 20-May-2024; Accepted: 21-May-2024

Abstract

In the recent past, several studies have been done on the synthesis, characterization, and thermal management applications of nanofluids due to their phenomenal improvement in their thermal properties. This experimental study focuses on the impact of multi-walled carbon nanotubes (MWCNT)-Aluminum oxide (Al_2O_3)/water nanofluids on the effectiveness of free convection heat transfer. The nanofluids were manufactured using a 2-step approach by dispersing MWCNT and Al_2O_3 nanoparticles in water. Different percentage volume concentrations in the range of 0% to 0.6% were examined, along with different proportion ratios of MWCNT- Al_2O_3, specifically 75:25, 50:50, and 25:75. The primary motive of the current research was to synthesize and determine the thermophysical characteristics of the nanofluids, including thermal conductivity and viscosities. Subsequently, to determine the average heat transfer coefficient (HTC) under different heat flux conditions (3030, 4040, 4545, and 5050 W/m^2), experiments were performed for various volume fractions and proportion ratios of nanofluids. The findings of the study indicate that, the average HTC initially improves with increasing particle volume fraction, reaching its peak at a concentration of 0.1%. However, beyond this point, the HTC diminishes as the particle percentage volume concentration keeps to rise. Furthermore, the variations in the average HTC with heat flux were found to be similar for all proportion ratios of MWCNT-Al_2O_3 nanoparticles at the 0.1% volume fraction. This experimental investigation provides valuable insights into the convection characteristics of MWCNT-Al_2O_3/water hybrid nanofluids. The observed trends contribute to a better understanding of the optimal particle volume fraction and proportion ratios for achieving enhanced heat transfer in natural convection systems. These findings can guide the design and optimization of nanofluid-based thermal management systems in various engineering applications.

Keywords

Heat transfer, Thermal performance, Natural convection, Augmentation, Hybrid nanofluid.

1.Introduction

Thermal conductivity of the traditional fluids such as water, ethylene glycol (EG), propylene glycol (PG), and transformer oil is low compared to solids. So, these fluids offer less heat transfer performance. Choi [1] first coined the nanofluids by dispersing nanosized (< 100 nm) particles into the carrier fluid and observed the improved results. Nanofluids exhibit better thermophysical properties compared to conventional liquids. Among metallic, metallic oxide, and carbon-related materials, multi-walled carbon nanotubes (MWCNT) and Aluminum oxide (Al_2O_3) are the two types of nanoparticles commonly used to synthesize nanofluids.

It is difficult to comprehend how nanofluids behave and what effect they have on heat transfer processes. The behaviour of nanofluids is impacted by variables including particle size, concentration, and temperature, despite the fact that they have better thermal conductivity and other features [2–5]. The overall efficacy of nanofluids in real-world applications can also be impacted by problems with nanoparticle stability and aggregation. The requirement for more efficient heat transfer strategies motivates the study of the thermophysical properties of MWCNT- Al_2O_3/water nanofluid and their impact on natural convection. A fundamental method of heat transmission that results from changes in fluid density brought on by temperature gradients is called natural convection.

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Natural convective heat transfer finds many applications in various fields, such as the cooling of nuclear reactors, electronic cooling, the cooling of transformers, refrigeration & air conditioning (R&AC) etc.

Free convective heat transfer is the transmission of heat between a solid surface and a fluid medium due to natural convection, which is driven by density differences caused by temperature gradients [1]. Understanding and enhancing free convective heat transfer is crucial in various thermal management systems, including the cooling of electronic devices, solar collectors, and building heating and ventilation systems. Nanofluids offer the possibility of improving the efficiency of heat transfer processes in various engineering applications [2]. The notion behind the use of nanofluids for heat transmission improvement is to take advantage of specific thermal properties of nanoparticles to improve the heat transfer qualities of traditional heat transfer fluids. Nanoparticles are more thermally conductive than the base fluid, therefore they may effectively conduct heat and improve the thermal conductivity of nanofluids [3].

Several methods are used to evenly distribute nanoparticles throughout the carrier liquid during the manufacture of nanofluid. Common techniques include one-step techniques like direct mixing and laser ablation, as well as two-step techniques like the sol-gel method, chemical precipitation, and physical vapor deposition [4, 5].

The challenges of the previous literature associated with this research are as follows: Achieving homogenous dispersion of nanoparticles without any agglomerations in the carrier fluid that cause potential clogging of heat transfer equipment, thermophysical property characterization, stability, and long-term performance. Addressing these challenges requires interdisciplinary research efforts combining expertise in nanotechnology, fluid mechanics, heat transfer, and materials science [6–12]. Overcoming these challenges holds the promise of unlocking the full potential of nanofluids for improving heat transfer efficiency for several thermal requirements.

The objectives of the present study are to synthesize stable MWCNT, Al_2O_3-water hybrid nanofluids at various % volume fractions, measure thermophysical properties, characterize the prepared nanofluids, determine heat transfer coefficient (HTC), Nusselt number with % volume fractions and determine the optimum % volume fraction, and determine % enhancement in the average HTC at the optimum volume fraction.

The structure of this article is organized as follows: Section 2 converses the particulars of the existing research work reviewed related to this paper. Section 3 provides the synthesis of nanofluids and their characterization, and also discusses about experimental setup. In section 4, the results obtained by conducting the experiments are discussed. The discussion of the results obtained; the limits of the present work are deliberated in section 5. Conclusion and future work are deliberated in section 6.

2.Literature review

Ravi and Sambasiva [2] synthesized Al_2O_3-water nanofluids for investigating the free convection HTC along a slender cylinder experimentally for particle concentrations in the range of 0.05 to 0.6% and observed higher thermal performance at 0.1% particle concentration. Dey and Sahu [3] examined the free convection heat transfer performance of Zinc oxide (ZnO), alumina-water nanofluids over a cavity (20 cm × 15 cm × 10 cm) experimentally up to 0.05 % concentration. Constant heat flux and constant temperatures are applied at left and right walls respectively. Kamran and Qayoum [4] prepared Ferric oxide (Fe_3O_4)-water nanofluid for studying the thermal performance of cubic enclosure with two sides covered with a material polylactic acid (PLA) and observed the augmentation in Nusselt number with a rise in particle percentage volume concentration. Scott et al. [5] investigated the free convection performance of MWCNT, alumina-water hybrid nanofluids over right-angled cavity at particle volume fractions of 0 to 0.2 % and Rayleigh number in between 2.81×10^8 and 8.58×10^8 and observed the maximum improvement in average HTC and average Nusselt's number of 44% and 49% respectively at 50 ^oC compared to carrier fluid. Murshed et al. [6] reviewed the experimental research on nanofluids, their usage of heat transfer augmentation, and their applications and perceived the better HTC at lower volume fractions of nanofluid, and deteriorated performance at higher concentrations. Ilyas et al. [7] explored the free convective heat transfer in a vertical rectangular enclosure using MWCNT-thermal oil nanofluid of 0 to 1% concentration, Prandtl number between 415 and 600 and were performed at the heat flux of 1594 to 3150 W/m^2 and observed that the thermal conductivity plays a pivotal role in thermal performance and the remaining thermophysical properties also have some influence. Rostami et al. [8] reviewed the literature based on free convection heat transfer using nanofluids over different geometries through experimental and numerical methods. Cao et al. [9] done numerical simulation for natural convective heat transfer over an embedded hot plate in a square enclosure by taking titania (TiO_2)-water nanofluid as a cooling medium and the effect of a change in inclination angle from 0 to 45 ^oC, particle concentrations up to 6% and they noticed an improvement in HTC of 21% for a low Rayleigh number.

Islam et al. [10] and Ibrahim et al. [11] numerically investigated the free convection performance in an inclined enclosure under a magnetic field of 0 to 5 % nanoparticle concentration using the Lattice Boltzmann method and noticed improved HTC with increased particle concentration. Several researchers measured the thermal conductivity and viscosity of the prepared mono and composite nanofluids [12–16]. Xian et al. [17] performed the experimentations to study the effect of ultrasonic duration and surfactant on the thermal property and viscosities of hybrid nanofluids. Several researchers [18–23] synthesized nanofluids to determine their thermo-physical properties. Giwa et al. [24] experimentally investigated the electrical conductivity in addition to thermal and rheological properties. Kanti et al. [25] experimentally and computationally determined entropy generation, drop in pressure and thermal property of fly ash-Cu based nanofluid. Suhaimi et al. [26] prepared mineral oil-carbon nanotube (CNT) nanofluid for transformer applications and observed an improvement in breakdown efficiency. Tiwari et al. [27] investigated the effect of sonication, surfactant, stability(3S) on the rheology of hybrid nanofluid. Nwaokocha et al. [28] examined experimentally the thermal performance of MgO-ZnO nanofluid. Rotsami et al. [29] used the artificial neural network (ANN) technique to forecast the thermal conductivities of the prepared nanofluids. Vaishnav et al. [30] synthesized zirconia nanofluids for transformer cooling applications. Kumar and Sarviya [31], Kumar and Shaik [32] reviewed the synthesis, characterization methods of hybrid nanofluids. Maaza et al. [33] used a novel radiolysis method to prepare nanofluids. Jebali et al. [34] synthesized ZnO based nanofluids for highly efficient heat transfer applications. Aureen et al. [35] prepared polyvinyl alcohol (PVA)- copper oxide (CuO) nanofluid using the facile one pot method to obtain stable nanofluid. Mudidana et al. [36], Agnihotri and Lad [37] reviewed literature to study synthesis and characterization methods. Surakasi et al. [38] prepared water-TiO_2 nanofluids to study the heat transfer characteristics and observed an improvement in thermal conductivity and viscosity. Ali and Salam [39], Urmi et al. [40] reviewed the literature for studying the thermophysical characteristics and stability of nanofluids.

Most of the studies from the reviewed literature were concentrated on the natural convective HTC using various nanofluids in an enclosure of various cross sections. Very few studies focused on free convective heat transfer along a vertical slender cylinder. But no studies were reported using MWCNT-Al_2O_3/water nanofluids for investigating free convective heat transfer along a vertical cylinder. So, in the present work, free convective HTC is investigated along a vertical cylinder experimentally using MWCNT-Al_2O_3/water nanofluids. *Table 1* represents the summary of the parameters of the study taken in the literature review. *Figure 1* represents the pie chart, which shows various materials used as base fluids and nanoparticles to study the influence of nanofluid.

Table 1 Summary of the parameters of the study taken in literature review

Reference	Geometry used for heat transfer problem / Scope of work	Base fluid	Nano particle material	Particle volume fraction
[2]	Cylindrical enclosure	Water,	Al_2O_3	0 to 0.1%
[3]	Cubic enclosure	Water	ZnO, Al_2O_3	0 to 0.05%
[4]	Cubic cavity	Water	Fe_2O_3	0 to 0.8%
[5]	Square cavity	Water	Al_2O_3, MWCNT	0 to 0.2%
[7]	Vertical rectangular enclosure	Thermal oil	MWCNT	0 to 1% mass fraction
[9]	Square enclosure	Water	TiO_2	0 to 0.06
[10]	Prismatic enclosure	Water	Cu	0 to 0.1
[11]	Inclined cavity	Water	Al_2O_3	0 to 5%
[12]	Synthesis, Characterization only	Water	GO, Si	0 to 0.25%
[13]	Role of ultrasonication on	Water	ZnO, CuO	0 to 1%

Reference	Geometry used for heat transfer problem / Scope of work	Base fluid	Nano particle material	Particle volume fraction
	Thermophysical properties			
[14]	Rheological behaviour only	Engine Oil	MWCNT, WO_3	0 to 0.6%
[15, 20]	ANN prediction of Rheological behaviour only	Ethelyne glycol, Water + EG (30:70)	Ag, Si	0.2 to 2%, 0.1 to 1.5%,
[16,18, 29]	ANN prediction of thermal conductivity only	Water,	TiO_2, SiO_2, PS, MWCNT- CuO	0 to 0.31%,
[17]	thermos physical properties and stability	Water	G, TiO_2	0.1 to 0.025%
[19, 24]	Thermal conductivity and viscosity measurement	Water + EG (60:40), Water	TiO_2, SiO_2, MWCNT- Fe_2O_3	0.5 to 3%, 0.1 to 1.5%
[23]	Rectangular enclosure	Water	Cu - Al_2O_3, TiO_2 -Al_2O_3	0 to 1%
[25]	Copper tube	Water	Fly ash-Cu	0.5 to 2%,
[26, 30]	Transformer application	Mineral oil,	Carbon nano tube (CNT), ZrO	0.01 to 0.2 g/L,
[27]	Viscosity measurement	DI water, Silicone oil, EG	CeO_2, MWCNT (80:20),	0.25 to 1.25%,
[28, 41–43]	Square cavity Semicircular cavity	Water Water	MgO-ZnS Cu	0.05 %, 0.1 % 0-5%
[32–35]	Thermophysical Properties	Water, methanol, castor oil, Water, $C_2H_6O_2$ Water-PG (60:40), PA	Cu-MXene, Ag ZnO CuO	0.01 to 0.05 %, 0.125%, 0.5%
[37]	Synthesis and characterization	Kerosene	Magnetic nanoparticles with coated oleic acid	
[38]	Synthesis and characterization	Water	TiO_2	0.125 - 0.5%
[44, 45]	Lattice Boltzmann method	EG	Cu - Al_2O_3	0.125 - 0.5%
[6,8,21,22,31, 36,39,40]	Comprehensive review			

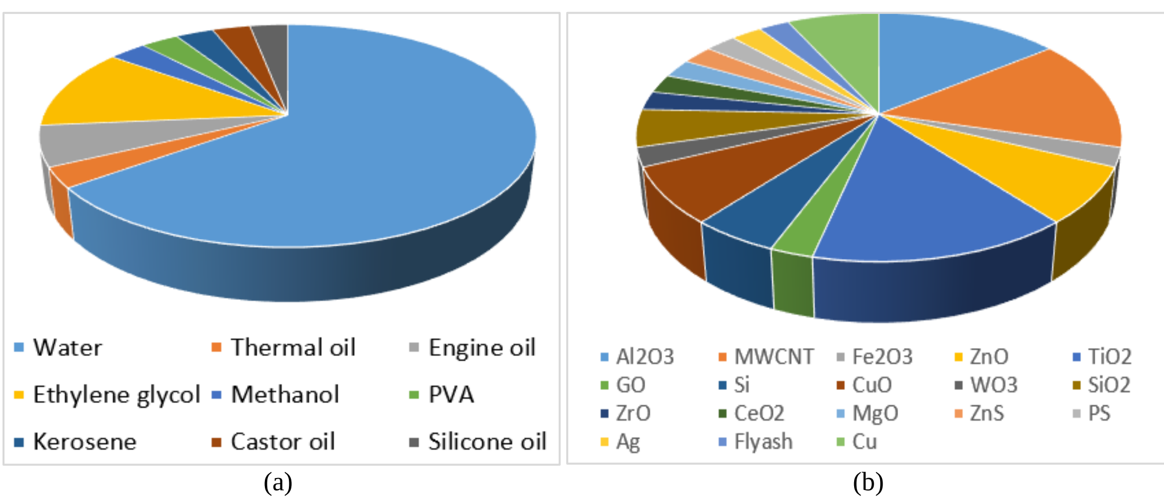


Figure 1 Type of materials used as (a) base fluids and (b) nanoparticle

3.Materials and methods

In the present work, MWCNT- Al_2O_3/water nanofluids are synthesized for various volume concentrations of 0 to 0.6 % and proportions of MWCNT- Al_2O_3 in the ratios 75:25, 50:50, 25:75 respectively using the two-step method. MWCNT and Al2O3 nanoparticles are purchased from Nanolabs, Jamshedpur, Jarkhand, India and the properties of the nanoparticles are indicated in *Table 2*.

Table 2 Physical and thermophysical properties of nanoparticles

S. No.	Property	MWCNT	Al_2O_3
1	Size of particle	25 to 40 nm	30 to 40 nm
2	Colour	Black	white
3	Thermal conductivity	3006 W/mK	40 W/mK
4	True density	2100 Kg/m^3	3890 Kg/m^3
5	Specific surface area	200 m^2/g	136 m^2/g

Total quantity of nanoparticles (MWCNT- Al_2O_3) is determined from the Equation 1

$$\text{Volume concentration} = \frac{\frac{mass_{np}}{\rho_{np}}}{\frac{mass_{np}}{\rho_{np}}+\frac{mass_{bf}}{\rho_{npbf}}} \qquad (1)$$

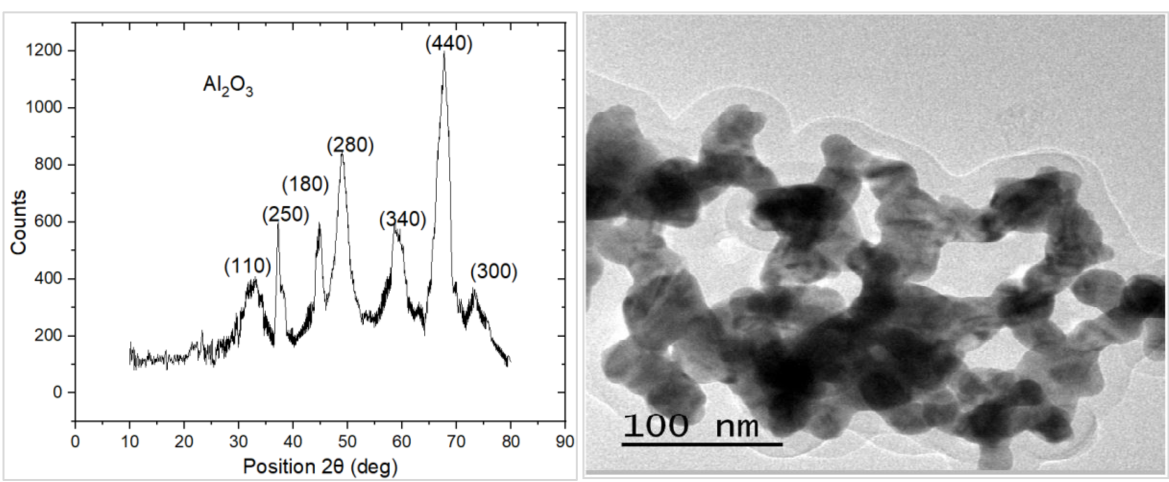
In order to prevent rapid settlement of the nanoparticles, oleic acid equal to 0.1 times the quantity of nanoparticles is added to the nanofluid as a surfactant after the necessary number of nanoparticles has been taken, dispersed in the carrier fluid and thoroughly agitated for 30 minutes using a magnetic stirrer. After that, the nanofluid is sonicated for three hours to create a stable nanofluid with the use of an ultrasonic sonicator (20 kHz). The total weight of nanoparticles as a function of volume concentration is displayed in *Table 3*.

Table 3 Weight of MWCNT+Al_2O_3 nanoparticles according to concentration of nanofluid

S. No.	Concentration of nanofluid	Weight of MWCNT+Al_2O_3 nanoparticles (gm)
1	0.05	1.964
2	0.1	3.928
3	0.2	7.856
4	0.4	15.712
5	0.6	23.568

3.1Characterization of nanoparticles

Figure 2 depicts the X-ray diffraction (XRD) analysis of Al_2O_3 nanoparticles, and it shows the characterization of the nanoparticles like phase identification, type of crystal structure and size. As per the diffraction peaks, which occurred at 33^o, 38^o, 45^o, 48^o, 58^o, 67^o and 73^o positions and are observed in *Figure 2*, Al_2O_3 nanoparticles are referred to tetragonal phase and the size of crystalline is determined from Debye-Scherrer relation shown in Equation 2 and size of the particles is found to be approximately 45 nm. The transmission electron microscope (TEM) image of alumina nanoparticles is also shown in *Figure 2.*

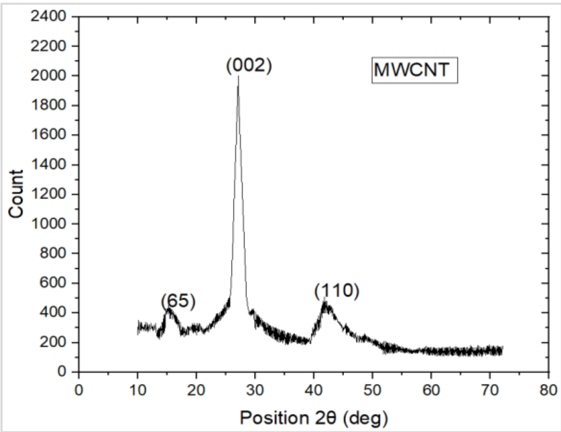


(a) (b)

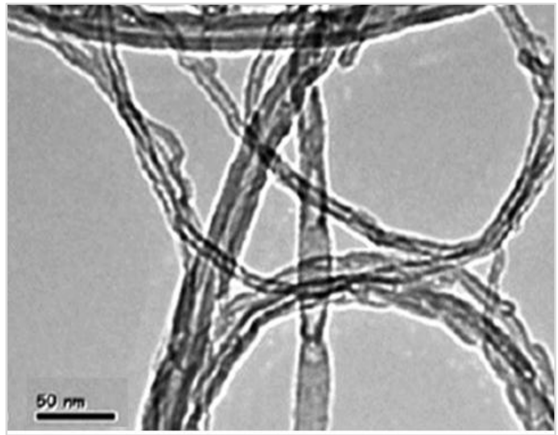
Figure 2 XRD, TEM analysis of Al_2O_3 nanoparticles

$$\text{Nanoparticle crystalline size } D = \frac{K\lambda}{\beta Cos\theta} \qquad (2)$$

Where K is the Scherrer constant (0.98), β is the full width at half maximum or line broadening in radians, θ is the Bragg angle, λ is the X-Ray wave length. Similarly, *Figure 3* shows the characterization of MWCNT nanoparticles and it depicts the diffraction peaks occurring at 15°, 27° and 42° positions and the size of the particle is found to be approximately 25 nm and the particles are well graphitized. The TEM image of MWCNT nanoparticles is shown in *Figure 3*. After getting the nanoparticles, they are dispersed in the water, which is taken as the base fluid, in the required proportions suited to the % particle concentration of the nanofluid. The amount of nanoparticle is calculated from the Equation 1.



(a)



(b)

Figure 3 XRD, TEM analysis of MWCNT nanoparticles

3.2Thermo-physical properties of nanofluids

After measuring the total mass of the nanoparticle, the individual masses of MWCNT and Al_2O_3 are calculated as per the ratios 80:20, 60:40, 50:50, 40:60, 20:80 respectively. It is very important to measure the thermal conductivity and viscosity of the prepared nanofluids to determine HTC. Thermal conductivity and viscosity of the synthesized hybrid MWCNT-Al_2O_3 /water nanofluids are measured using a thermal analyzer (KD2 Pro) and a Brooke field viscometer respectively. Prior to that measurement, these instruments were calibrated by measuring the thermal conductivity and viscosity of water and comparing the values of standard American society of heating, refrigeration and air-conditioning engineers (ASHRAE). The validation of these instruments is shown in *Figure 4* and *Figure 5* respectively and the deviation is observed for thermal conductivity and viscosity at 1.5% and 3.5% respectively.

Thermal conductivities and viscosities of the prepared MWCNT – Al_2O_3 water nanofluid for different temperatures from 30 to 70 °C and particle volume fractions from 0 to 1 % are shown in *Figures 6* and *7* respectively. Variation of thermal conductivity of MWCNT – Al_2O_3 water nanofluid at 0.1% volume fraction in different proportions of MWCNT and Al_2O_3 nanofluids is shown in *Figure 8* and observed that the thermal conductivity is higher if the proportion of MWCNT is higher at the same total volume fraction and temperature. *Figure 9* depicts the variation of dynamic viscosity of MWCNT – Al_2O_3 water nanofluid at 0.1% volume fraction in different proportions of MWCNT and Al_2O_3 nanofluids. It is observed that the dynamic viscosity is higher if the proportion of MWCNT is lower at the same total volume fraction and temperature.

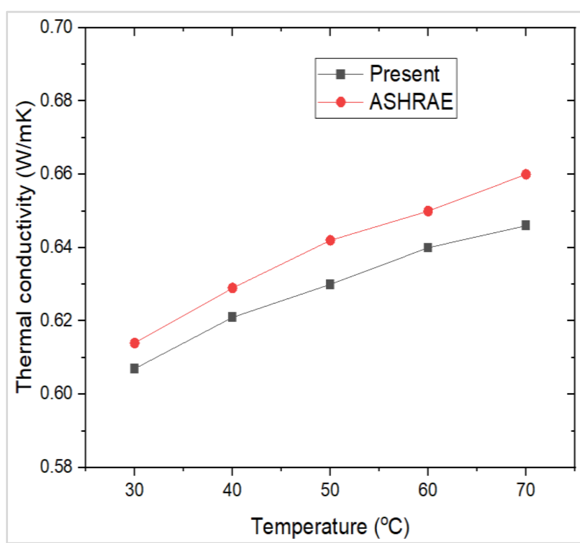


Figure 4 Validation of Thermal conductivity measurement-water as medium (KD2 Pro)

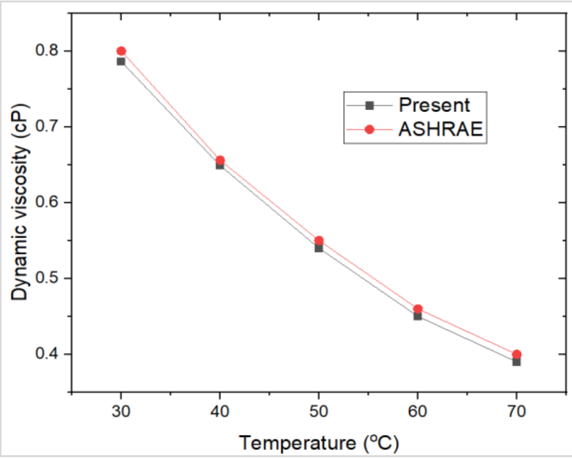


Figure 5 Validation of viscosity measurement (Brook field viscometer) – water as medium

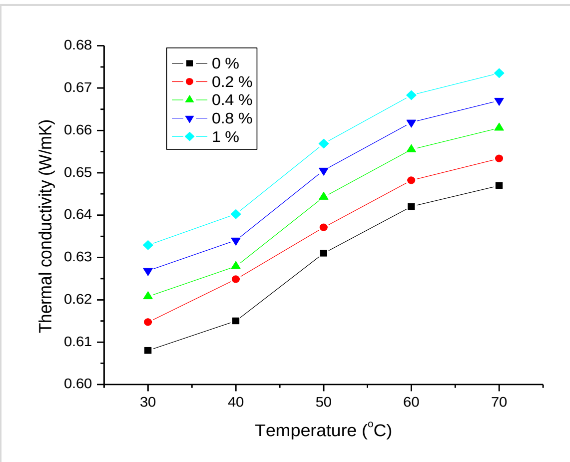


Figure 6 Thermal conductivity of MWCNT – Al_2O_3 water nanofluid (25:75 ratio)

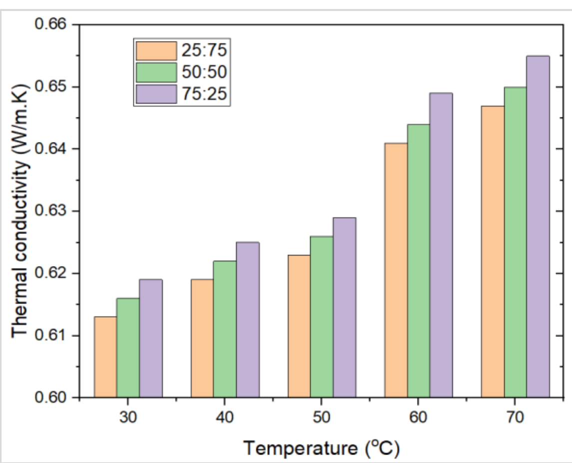


Figure 7 Thermal conductivity of MWCNT – Al_2O_3 water nanofluid at 0.1% volume fraction in various proportions

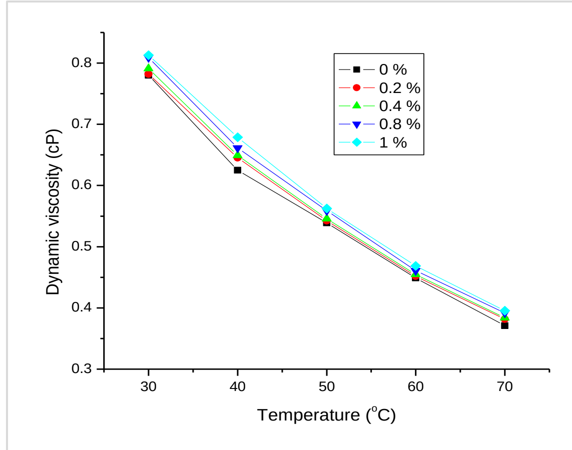


Figure 8 Dynamic viscosity of MWCNT – Al_2O_3 water nanofluid (25:75 ratio)

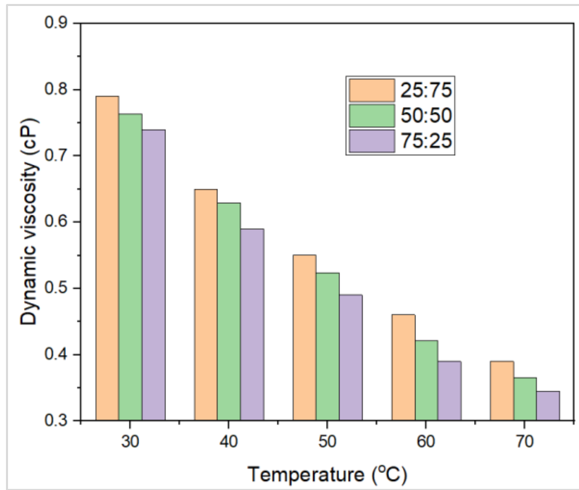


Figure 9 Dynamic viscosity of MWCNT – Al_2O_3 water nanofluid at 0.1% volume fraction in different proportions of nanoparticles

3.3Experimental setup

The experimental setup, as depicted in *Figure 10*, consists of a vertical cylinder made of brass with a diameter of 12.7 mm and a length of 250 mm. The cylinder is placed inside a square, cross-sectioned enclosure made of aluminum. The enclosure is filled with the liquid medium under investigation. All the fans in the room were switched off during the conduction of experiment in order to avoid forced convection conditions. To maintain a constant temperature on the enclosure walls, an additional enclosure is provided. This second enclosure serves to circulate cooling water, which helps regulate the temperature. The flow rate of the circulating water is adjusted to balance the heat energy absorbed by the liquid from the vertical cylinder with the heat taken away by the circulating water. This ensures that a steady-state condition is achieved during the experiments. Each of the experiments is repeated three times to ensure the repeatability of the readings.

Thermocouples of the K-type are securely attached to the surface of the vertical cylinder. These thermocouples are used to measure the surface temperature at specific points along the length of the cylinder. Additionally, another thermocouple is suspended freely in the liquid at a level corresponding to the measured surface temperature of the vertical cylinder.

A digital temperature indicator is connected to all the thermocouples, allowing for precise measurement and indication of the temperatures at specified locations on the cylinder's surface and in the liquid. The experiments are conducted at various heat flux levels, ranging from 3030 W/m^2 to 5050 W/m^2. This range of heat flux values allows for the investigation of heat transfer performance under different thermal conditions.

Overall, this experimental setup provides a controlled environment to measure the temperature distribution and analyze the heat transfer characteristics of the MWCNT-Al_2O_3/water nanofluids. The combination of thermocouples, temperature indicators, and the carefully designed enclosure ensures accurate and reliable data collection, enabling a comprehensive understanding of the convective heat transfer process within the system.

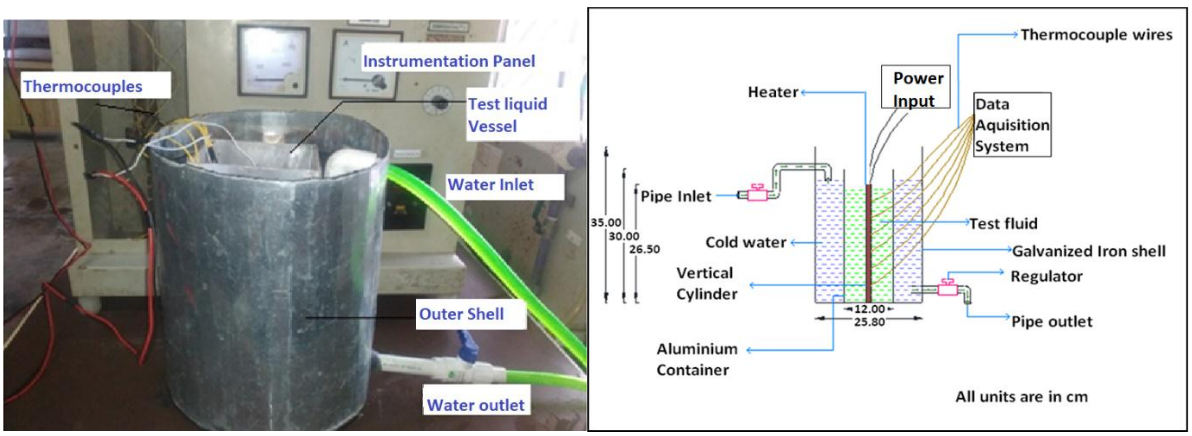


Figure 10 Experimental setup and its schematic representation

4.Results

For each heat flux and volume fraction, experiments are performed and the temperatures of surface at specified points and fluid are recorded. The average temperature of the surface of a vertical cylinder is determined by taking the average of all temperatures. The average HTC is determined from the Equation 3.

Average HTC $\bar{h} = \frac{Q}{A(T_s - T_f)}$ (3)

Average Nusselt number Nu = $\frac{\bar{h}}{K} L$ (4)

In *Figure 11* of the experimental studies, the change of the average HTC (h) with particle volume concentration is depicted for different heat fluxes ranging from 3030 W/m^2 to 5050 W/m^2. Specifically, the graph represents the behavior of the MWCNT-Al_2O_3 water nanofluid with a proportion ratio of 25:75. The observed trend indicates that as the particle volume fraction of the nanofluid increases, the average HTC initially augments until reaching a concentration of 0.1%. Beyond this point, the average HTC starts to diminish. This behavior can be explained by considering the influence of particle volume fraction on two important properties: thermal conductivity and viscosity.

At low particle volume fractions (up to 0.1%), the improvement in thermal conductivity dominates over the increase in viscosity. The incorporation of MWCNT- Al_2O_3 nanoparticles into the base fluid enhances the thermal conductivity of the nanofluid. This increased thermal conductivity enables more efficient heat transfer within the system, resulting in an improvement in the average HTC.

However, as the particle volume fraction continues to increase beyond 0.1%, the improvement in viscosity becomes more prominent compared to the enhancement in thermal conductivity. The higher volume fraction of nanoparticles leads to an increase in the viscosity of the nanofluid. This increased viscosity hinders the fluid flow and, consequently, reduces the performance of heat transfer. As a result, the average HTC starts to decrease.

Therefore, up to a particle volume fraction of 0.1%, the dominance of improved thermal conductivity outweighs the negative impact of increased viscosity, resulting in an overall increase in the average HTC. However, beyond this threshold, the negative influence of increased viscosity becomes more significant, leading to a reduction in the average HTC. As the volume fraction increases beyond 0.1%, the viscosity of the nanofluid obstructs the fluid flow, reducing buoyancy forces. Due to this reason, heat transfer performance is reduced at higher volume fractions.

This discussion emphasizes the importance of optimizing the particle volume fraction when designing nanofluid-based heat transfer systems. It highlights that there exists an optimal range of particle volume fractions where the balance between thermal conductivity enhancement and viscosity increase maximizes heat transfer performance. This understanding can guide the selection and optimization of nanofluid compositions to achieve improved heat transfer efficiency in various engineering applications. The same trend is observed in the case of Giwa et al. [41], it is observed that the maximum HTC is observed at 0.1% volume concentration for Al_2O_3-MWCNT water based nanofluids. Also, it is observed in the Giwa et al. [24] study that the maximum HTC obtained at 0.05% volume fraction for Fe_2O_3-MWCNT water based nanofluids is represented in *Figure 12.*

In the experimental study, *Figure 13* illustrates the change in average HTC with heat flux for different proportions of MWCNT- Al_2O_3 water nanofluid at a fixed volume fraction of 0.1%. It is worth noting that the proportions of MWCNT and Al_2O_3 nanoparticles directly influence the composition and characteristics of the nanofluid. The observed trend in *Figure 13* indicates that the average HTC demonstrates a similar variation for all the tested proportions of MWCNT- Al_2O_3 nanofluid at the 0.1% volume fraction. This similarity suggests that the proportion ratios do not significantly impact the heat transfer performance within the examined range.

However, it is crucial to consider the underlying reasons for the higher average HTC observed for the 75:25 proportion (MWCNT: Al_2O_3) compared to the other two proportions. This discrepancy can be attributed to the higher thermal conductivity of MWCNT in comparison to Al_2O_3. MWCNT possess exceptional thermal conductivity due to their unique structure, which enables efficient heat conduction along their length. On the other hand, Al_2O_3 nanoparticles exhibit lower thermal conductivity in comparison.

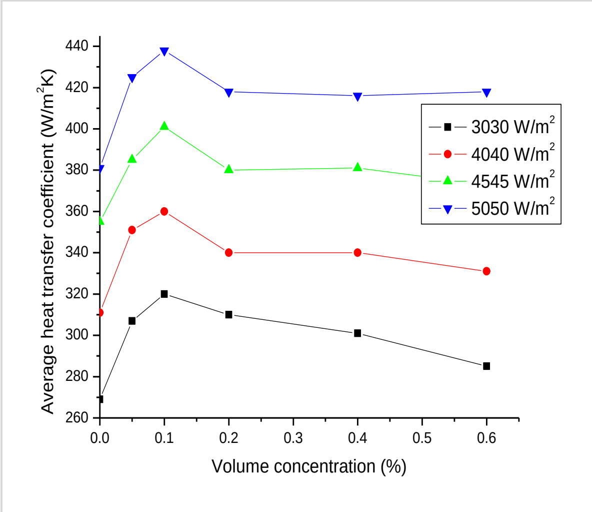


Figure 11 Average HTC with particle volume concentration for different heat flux for MWCNT – Al_2O_3 water nanofluid (25:75 ratio)

As a result, the nanofluid with a higher proportion of MWCNT (75:25) benefits from the enhanced thermal conductivity contributed by MWCNT, leading to higher buoyancy forces that cause improved heat transfer performance and, consequently, a higher average HTC. Similarly, the variation of the average Nusselt number is calculated using Equation 4 for various volume fractions of nanofluid and different heat fluxes at a 25:75 proportion and is shown in *Figure 14*. It also indicates that the average Nusselt number is at its maximum at a volume concentration of 0.1%.

While the difference in thermal conductivities between MWCNT and Al_2O_3 nanoparticles plays a significant role in determining the heat transfer characteristics, it is important to consider other factors such as nanoparticle dispersion, interactions, and convective heat transfer mechanisms within the nanofluid system. These factors can also influence the observed heat transfer behavior and should be taken into account when interpreting the results. Overall, the higher average HTC observed for the 75:25 proportion of MWCNT- Al_2O_3 nanofluid at the

0.1% volume fraction can be attributed to the superior thermal conductivity of MWCNT compared to Al_2O_3. This understanding highlights the importance of nanoparticle selection and composition optimization in nanofluid-based heat transfer systems. This system is aiming to achieve enhanced thermal performance and improved energy efficiency. The variation of the average Nusselt number with the volume fraction of nanofluid for different proportions of 25:75, 50:50 and 75:25 at 5050 W/m^2 heat flux is shown in *Figure 15*.

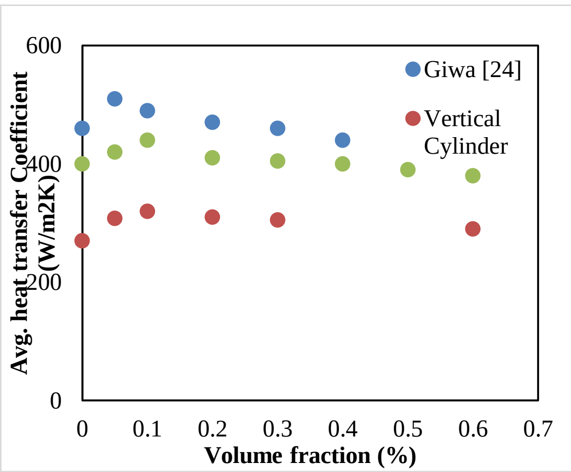


Figure 12 Comparison of HTC with literature

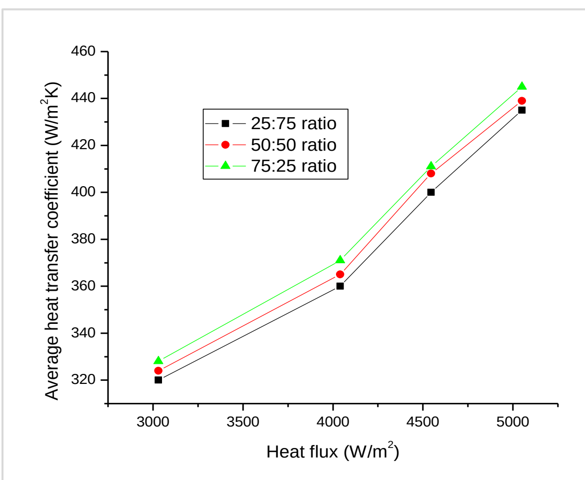


Figure 13 Average HTC with heat flux for various proportions of MWCNT-Al_2O_3 water nanofluid at 0.1 % volume fraction

A complete list of abbreviations is presented in *Appendix I.*

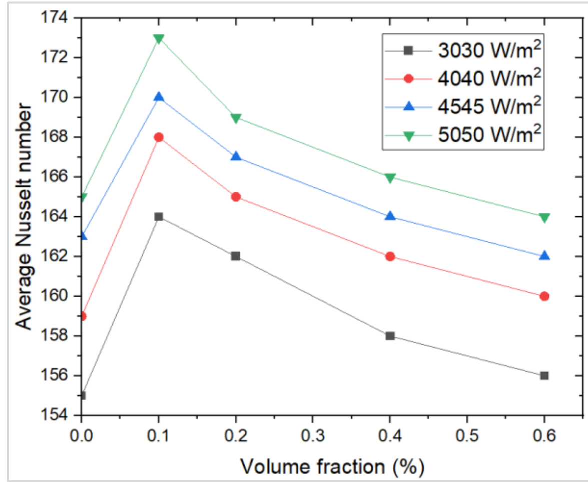


Figure 14 Average Nusselt number with % volume fraction for different heat flux at 25:75 proportion of nanoparticles

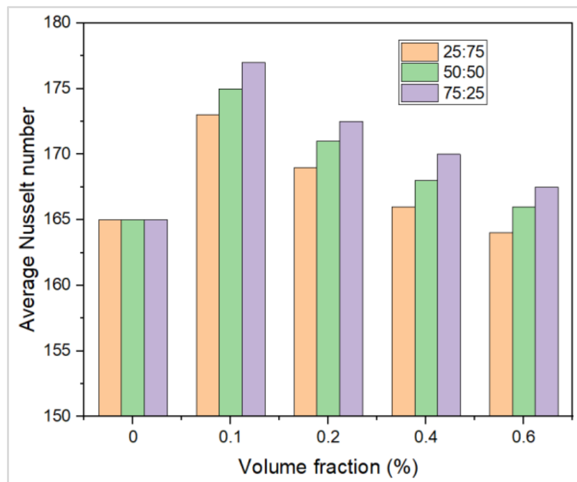


Figure 15 Variation of average Nusselt number with % volume fraction for different proportions of MWCNT and Al_2O_3 nanoparticles at 5050 W/m^2 heat flux

5.Discussion

The results of the present study are interpreted in terms of thermophysical property analysis, mechanisms responsible for enhancement in the performance of heat transfer, and optimum % volume fraction. The thermal conductivity of MWCNT-Al_2O_3 nanoparticles is very high compared to the base fluid. So, the thermal conductivity of the hybrid nanofluid increases with % volume fraction of nanoparticles. Similarly, the viscosity of MWCNT-Al_2O_3 /water nanofluid also increases with the volume fraction nanoparticle. This phenomenon will help augment the heat transfer performance.

In addition to this, mechanisms like Brownian motion (random movement of nanoparticles in the base fluid), thermophysical interactions between nanoparticles and the base fluid change the fluid flow characteristics, which leads to improved heat transfer performance. This study presents the optimum volume fraction of nanoparticles as 0.1%, at which the average HTC will be the maximum for the given free convective environment.

When the average HTC is measured with a volume fraction up to a particle volume fraction of 0.1%, the average HTC increases because the benefits of enhanced thermal conductivity exceed the drawbacks of increased viscosity. But beyond this point, the detrimental effects of higher viscosity become more pronounced, resulting in a decline in the average HTC. Buoyancy forces decrease when the volume fraction rises above 0.1% due to the viscosity of the nanofluid obstructing fluid flow. The performance of heat transfer will therefore be diminished with increasing volume fractions.

When this finding is compared to previous research, the pattern Giwa et al. [41] found is similar. For Al_2O_3-MWCNT water-based nanofluids, the highest HTC is found at a volume concentration of 0.1%. Additionally, the highest HTC for Fe_2O_3-MWCNT water-based nanofluids produced at 0.05% volume fraction is noted in the Giwa et al. [24] work and is shown in *Figure 10*.

The findings of this study have important implications for the design and optimization of thermal management systems utilizing MWCNT-Al_2O_3/water nanofluids. The identified optimal particle volume fraction and the understanding of the heat transfer behavior under different heat flux conditions can assist in the development of efficient and effective heat transfer systems for various engineering applications.

5.1Limitations of the study

The current study is limited to lower concentrations of nanofluid and it is not concentrated on the long-term stability of the nanofluid. Also, this study is not aimed at economic factors like cost, availability of the material, corrosion effect of nanoparticles on container walls, etc.

6.Conclusion and future work

This experimental study focused on investigating the potential of MWCNT- Al_2O_3/water nanofluids for enhancing natural convective heat transfer. The average HTC exhibited a significant enhancement with increasing particle volume fraction up to a concentration of 0.1%. Beyond this concentration, further increases in particle volume fraction led to a reduction in the HTC. Therefore, the optimal particle volume fraction for enhancing heat transfer in natural convection systems lies at 0.1% for MWCNT-Al_2O_3/water nanofluids. The variations in the average HTC with heat flux were found to be similar across different proportion ratios of MWCNT- Al_2O_3 nanoparticles at the 0.1% volume fraction. This suggests that heat transfer performance is relatively independent of the specific proportion ratios within this range. Variation in the average Nusselt number with % volume fraction for different heat fluxes at 25:75 proportions of nanoparticles was observed, and the maximum average Nusselt number occurred at 0.1% volume fraction. The synthesized MWCNT-Al_2O_3/water nanofluids exhibited altered thermophysical properties compared to pure water, including enhanced thermal conductivity. These changes in thermophysical properties contribute to the improved heat transfer characteristics observed in the experiments.

However, it is worth noting that further investigations are needed to explore additional factors such as nanoparticle size, shape, and surface modification, as well as the long-term stability and reliability of the nanofluids. The environmental impact and economic feasibility of using these nanofluids in practical applications can be studied in the future.

Acknowledgment

The authors extend their sincere appreciation to the management of the GMR Institute of Technology for their steadfast support and commitment to advancing research excellence, which have been pivotal in the realization of this endeavor.

Conflicts of interest

The authors have no conflicts of interest to declare.

Data availability

None.

Author's contribution statement

Ravi Babu. S: Concept, experimentation, draft writing, revision of paper, **Pradeep Kumar. P:** Methodology, **Sasikumar. G:** Review and editing, **Basha. S.A:** Data analysis and editing.

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Appendix I

S. No.	Abbreviation	Description
1	3S	Sonication, Surfactant, Stability
2	Al_2O_3	Aluminum Oxide
3	ANN	Artificial Neural Network
4	ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers
5	BN	Boron Nitride
6	CeO_2	Cerium Oxide
7	CNT	Carbon Nano Tube
8	CuO	Copper Oxide
9	EG	Ethylene Glycol
10	Fe_2O_3	Ferric Oxide
11	Fe_3O_4	Ferroso Ferric Oxide
12	GO	Graphene Oxide
13	HTC	Heat Transfer Coefficient
14	MgO	Magnesium Oxide
15	MHD	Magneto Hydro Dynamic
16	MWCNT	Multi-Walled Carbon Nanotubes
17	PG	Propylene Glycol
18	PLA	Polylactic Acid
19	PVA	Polyvinyl Alcohol
20	R&AC	Refrigeration & Air Conditioning
21	SiO_2	Silica
22	TEM	Transmission Electron Microscope
23	TiO_2	Titania
24	WO_3	Tungsten Trioxide
25	XRD	X-Ray Diffraction
26	ZnO	Zinc Oxide
27	ZnO_2	Zinc Peroxide
28	ZnS	Zinc Sulphate