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Heat Transfer Performance Study of Mono and Hybrid Nano Fluid in a Double-Pipe Heat Exchanger

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Abstract:

Ability of nanoparticles to transmit heat can be improved using hybrid nanofluids. The hybrid nanofluid employed in the current work is prepared with Magnesium Oxide and Graphene nanoparticles. Six samples of different nanofluids are prepared for testing. In order to prepare samples1 and 2, de-ionized (DI) water is combined with 0.01% by weight of magnesium oxide nanoparticles and 0.01% by weight of graphene nanoparticles, respectively. Magnesium oxide and Graphene are combined with DI water at a weighted ratio of 0.005% to prepare Sample 3. Samples 4, 5, and 6 were made by adding an additional 50 ml of Ammonium hydroxide (NH_4OH) to the previously made sample 1, 2 and 3 respectively. With the exception of sample4, all samples improved significantly in terms of thermal conductivity, with sample2 measuring the highest value at 0.69 w/m-k. and highest increase in heat transmission performance over water is noted for sample 2 by 57.5%.

Key words: Thermal conductivity ; Combined heat transfer coefficient ; Nanofluids ; Graphene

Keywords: Combined Heat Transfer Coefficient, Dynamic Viscosity, Heat Exchanger, Hybrid Nano Fluid and Thermal Conductivity

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I. Introduction

Heat exchanger is an equipment used for effective transfer of heat from one to another medium. In the past years, experiments have been done to augment heat transfer of heat exchanger, to lessen the heat transmission time and finally, to increase energy utilization efficiency. The passive methods are widely used for generating turbulence, increasing the heat transfer exterior area and usage of nanofluids to increase heat exchanger's the thermal performance of the. In order to increase heat transmission passively, AydmDuhmes et al. researched heat transfer (HT) in addition to pressure drop in concentric tube type heat exchanger (HX) by way of swirl entry. He reported an augmentation upto 120% in nusselt number meant for swirl flow in counter flow at 45^0 angles of swirl [1]. To compare the HT properties and fluid friction of air-cooled tube heat exchangers with mounted ribs and grooves, MohamedL.Elsayed ab et al [2] used numerical analysis. Lesser and greater exergy and entropy effectiveness are identified for the pipes through high-performance assessment criteria (PAC). The selection of grooved tubes rather than ribbed tubes was supported by the findings of the technical comparison for recapitulation. This is primarily because ribbed tubes exhibit greater PAC and exergy efficiency at the similar flow situation while having reduced flow irreversibility. In their research, Ahmed A. Abdelfattah et al. numerically analyzed thermal performance of an air crossflow in a semi-circular tube at Reynolds values between 103 and 104. Diverse angle of attack between -90° and 90° were taken into account. Three fin alignments (front, double and rear fin) with various extent and depth values were used to evaluate the effect of finned structures at zero attack angle. Around a 15-degree attack angle, the semi-circular cylinder performs best, while the level surface facing the current results in the worst performance.

Finning also lessens the irreversibility, which considerably enhances performance. The top performance was reached utilizing the double-fin layout with the rear and front fin patterns delivering rather comparable results [3]. The heated bot-tom surface channel's thermo-hydraulic functioning (THF) studies have been conducted with elliptic, hollow, wavy and straight top surface trapezoidal baffles by A. Mahmoud et al. Height of baffle (H), Width of baffle (S), Length of baffle (L), Reynold number (Re) corner angle (α) and angle of inclination (β), and are six variables under investigation. According to the findings, Re, α, and H are the factors on THP that work the best.

The ideal conditions are attained at α= 16°, β = 0°, and baffle sizes of L = 25 mm, H = 20 mm and S = 26 mm, according to the thermal hydraulic efficiency values. For all baffle forms, a staggered plan is preferred to an aligned one under ideal conditions, according to the normal value of the thermal improvement factor (TIF). The wavy top surface trapezoidal baffles in staggered plan at Re = 5000 [4] captures the largest TIF of 1.2. To determine the thermal and hydraulic properties of bank of staggered semi-circular tubes in cross-flow of airflow, Ahmed A. Abdelfattah et al., study [5] presents a numerical investigation. Using various fin lengths, the effects of including longitudinal fins are also examined. At constant pumping power and pressure drop the simple semi-circular tube array outperforms the round one through improvements in heat transfer of up to 28% and 11%, respectively. Performance is also greatly enhanced by the addition of longitudinal fins to the semi-circular tube array. Due to their improved thermal characteristics and flow features, nanofluids have gathered a lot of research interest over the past 20 years. Due to these benefits, nanofluids are promising heat transfer fluids that can be used to increase HT. The term "nanofluid," also known as "mono nanofluid," refers to a colloidal suspension of very small, less than 100-nanometer (nm) elements suspended in a host fluid (such as water). Form, dimension, category and concentration of the nanoparticles in the host fluid are a few of the variables that affect mono nanofluid’s high heat conductivity. The enhanced thermal conductivity of mono nanofluids in comparison to their corresponding host fluids is caused by the significantly high conductive nanoparticle’s area-to-volume ratio [6-7].

Peng et al. [8] have analysed effect of nano particles on characteristics of HT in a horizontal, smooth tube filled with nanofluid based on refrigerants and predicted a correlation using R113 refrigerant and CuOnano particle. According to their findings, refrigerant-based nanofluid has a higher heat transfer coefficient than pure refrigerant. Wongcharce and Elamsaard [9] have analysed the friction besides thermal performance features of CuO/DI water nanofluid experimentally through a circular tube furnished with altered twisted tape with alternative axis, for varying nanofluid concentrations from 0.3 to 0.7 % by volume. They have decided that the maximum thermal performance has been attained using CuO/DI water nanofluid at 0.7 % volume. Using various nanoparticle concentrations, Peclet numbers, and Reynolds numbers, Heris et al. [10] carried out an experimental study of the laminar flow forced convection heat transfer with Al2O3/water nanofluid inside a circular pipe with constant wall temperature. They discovered that the heat transfer coefficient increases as nanoparticle concentration in nanofluid increases. Sandipan Deb et al. [11] performed experiments to demonstrate the impact of surface wettability on Silicon Dioxide (SiO_2) Thin Film (TF) nanocoated surfaces during the nucleate boiling heat transfer using the saturated refrigerant R-141b at atmospheric pressure. Results obtained demonstrate that at atmospheric pressure, wall superheat is reduced and heat transfer coefficient (HTC) is additionally enhanced on all thin film nanocoated surfaces. It has been found that surface wettability increases the vapour bubble departure radius of hydrophilic surfaces and decreases the frequency of bubble emissions.

Data presented in the Table 1. shows the heat transfer enhancement studies carried out by various researchers using nanofluids.

Table 1. Shows the heat transfer enhancement studies carried out by various researchers using nanofluids

Reference	Type of particle	BaseFluid	Volume Fraction (%)	Particle size (nm)	Maximum Enhancement (%)	Temperature
Masuda etal.	Al_2O_3	Water	1.3--4.3	13	32.40	
	SiO_2	Water	1.1-2.4	12	1.10	31.84°C-86.85°C
	TiO_2	Water	3.1--4.3	27	10.80	
Leeetal.	Al_2O_3	water/EG	1.0--4.3*I* 1.0-5.0	38.4	10*I*18	Room
	CuO	Water/EG	1.0-3.42*I* 1.0--4.0	23.6	12/23	temperature
Wanget al.	Al_2O_3	Water/EG	3.0-5.5*I* 5.00-8.00	28	16	
	Al_2O_3	EO/PO	2.25-7.40*I* 5.0-7.1	28	*30*	At room temperature
	CuO	Water/EG	4.5-9.7*I* 6.2-14.8	23	34/54	
Eastman etal.	Cu	EG	0.01--0.56	<10	41	At room temperature
Xieetal.	Al_2O_3 Al_2O_3	Water/EG PO/glycerol	5.0 5.0	60.0 60.0	23*/129* 38/27	At room temperature
Dasetal.	Al_2O_3 CuO	Water Water	1.0--4.0 1.0--4.0	38.0 28.6	24.0 36.0	21°c-51°c
Murshedetal.	TiO_2 TiO_2	Water Water	0.5-5.0 0.5-5.0	15 sphere 10x40rod	30.0 33.0	At room temperature

Mono nano fluids do not, however, have combined high heat conductivity, stability and hydrothermal characteristics. Metallic (like copper) nanofluids, for instance, exhibit strong thermal conductivity but with low diffusion stability. This is the case since they don't establish bonds with the nearby aquatic molecules due to the fact that metal nanoparticles are typically hydrophobic. When utilized in thermal applications, such less stable nanofluids run the risk of causing sedimentation, blockage, and malfunctions in the system and fouling. While surfactants may be used to stabilize metal nanofluids, this compromises their thermal stability since the surfactants cover the surfaces of the nanoparticles. Surfactants also make metal nanofluids even more viscous, which requires a lot of pumping effort and causes significant pressure drop. Alternatively, because nanoparticles of metal-oxide are often hydrophilic and may establish links through the neighboring water molecules, metal-oxide nanofluids (such Al_2O_3) demonstrate high diffusion stability. Contrarily, metal-oxide nanofluids are inappropriate for use in thermal systems owing to their lower heat dismissal rates and lower thermal conductivity than metal nanofluids [12]. Hybrid nanofluids, that has recently been explored has overall hydrothermal properties superior to mono nanofluids. The hybrid nanofluid is made by diffusing two dissimilar types of nanoparticles. (non-metal, metal, metal-oxide) in the host fluid. The presence of two distinct types of nanoparticles has a thermal impact that is additive, enhancing overall hydrothermal characteristics. Hybrid nanofluids are said to have superior thermal conductivity than mono nanofluids, even at low particle concentrations. One type of nanoparticle forming a thermal route with another type of nanoparticle lessens the total thermal contact resistance amid the nanoparticles and base fluid’s neighboring molecules resulting in synergy effect on thermal conductivity in the hybrid nanofluid [13]. Although hybrid nanofluids have potential heat transfer properties, there hasn't been much research on using them to solve issues with heat dissipation in systems with high heat flux. This is because of the fact that hybrid nanofluid research is still in its early phases, with a focus more on comprehending its essential properties than its usefulness in thermal systems.

The compatibility between particles of the various nanoparticles utilized in a hybrid nanofluid has an vital influence on the hybrid nano liquid’s thermal performance. For instance, due to problems with inter-particle compatibility, the hybrid nanofluids thermal conductivities (copper carbon nanotube and gold carbon nanotube) are poorer than those of simple nanofluids. Hybrid nanofluid’s enhanced ability to transfer heat has been found to be influenced by a number of variables, such as nanoparticle production, thermal conductivity, manufacturing techniques, compatibility, form, and creation of a suitable thermal network with fluid molecules [14]. Scientists have experimented with nanofluids made up of many kinds of nanoparticles and found decrease in thermal conductivity(K) for the nano fluid occurred more quickly at concentrations below 1% than at greater concentrations. The enhanced particle agglomeration at greater concentrations was attributed for this outcome. According to experimental data, the mixture solutions thermal conductivity often rises by way of temperature and nanoparticle weight percentage. This is comparable to nanofluids containing one kind of nanoparticle. Researchers frequently coupled different kinds of carbon nanotubes using metal or metal-oxide nanoparticles. Zadkhast et al. [15] used KD2 Pro Thermal Properties Analyzer for measuring thermal conductivity of copper oxide and Multi-Walled Carbon Nanotube (CuO-MWCNT) water nanofluid. The K of the nanofluid was detected to rise with temperature, with temperature having a major impact on the increase at lower concentrations of nanoparticle. The increase in thermal conductivity attributed to temperature was believed to be the result of improved Brownian motion, whereas the rise attributed to concentration was considered to be the result of a larger surface area aimed at heat conduction and likely nanoparticle clustering. However, because of nanoparticles high surface energy, they are more likely to agglomerate, which makes it challenging for them to sufficiently disperse in the fluids. Several researchers used mechanical (such as agitation) and chemical (such as pH adjustment and the inclusion of surfactants) strategies to slow down coagulation and create stable nanofluids. The mechanical approach for creating nanofluids comprises magnetic stirring, ultra-sonication, etc. According to the literature, sonication lowers the size of nanoparticle clusters, which leads to the enhancement of nanofluid stability. The most popular technique for enhancing the dispersion behavior of nanofluid is the addition of chemical compounds called surfactants to reduce the liquid’s surface tension and lengthen the dispersion period of the particle. Rashmi et al [16] used Gum arabic to increase the stability of the carbon nanotube-water nanofluid. Al_2O_3/distilled water nanofluid was created by Choudhary et al. [17] employing sodium Dodecyl Sulfonate (SDS) as a stabilizer. In addition to adding a surfactant, pH control is another method for enhancing the constancy of nanofluids. Owing to strong repulsive forces, the stable suspension is produced by altering the pH of the nanofluid. Samal et al. [18] used Oleic acid to study the result of pH change on the stability of Al-Cu nanoparticle dispersion in water. According to the authors, adding Oleic acid to the dispersion increased stability as evidenced by zeta potential measurements. Al_2O_3/distilled water nanofluid dispersion's pH values were modified by Choudhary [17] using NaOH and HCl. They came to the conclusion that fluid electro kinetic characteristics directly influence stability.

The resolve of the HTE study is to create compact HX with the highest possible efficiency while maintaining the lowest possible cost, weight, and size. Due to their fascinating thermophysical characteristics and myriad potential advantages, nanofluids have piqued the interest of researchers across many different disciplines. This paper attempts to compile theoretical and investigational studies on the usage of nanofluids in heat exchanger applications to improve HT. Additionally, a few difficulties and problems with the application of nanofluids are recognized, and recommendations for future research have been compiled. Studies on the heat transfer capabilities of high surface area graphene are scarce.Studies on the impact of pH and hybrid nanofluids are also scarce. The goal of the current study is to use mono and hybrid nanofluid to improve the con-centric tube heat exchanger's ability to transfer heat. It is to investigate how nanoparticles with superior thermophysical properties behave in terms of enhancing heat exchanger performance and to examine the impact of nanofluid pH on heat exchanger performance. This research is unique in that it develops nanofluids with higher convective heat transfer behavior through a concentric tube HX and examines how concentration, flow rate, pH, and hybridization affect heat transfer coefficient.

II. Materials and Methods

The thermophysical properties that impact the thermal behavior of nanofluids are discussed in this section. Density, specific heat, and dynamic viscosity are calculated using the mixture formulae given below [19]. The results obtained were observed to be quite closer to the experimental results as reported by many researchers. Fluid's thermal conductivity is measured using the transient hot wire method.

The density formula is given as

$$\rho_{hnf} = \varphi_{np1}\rho_{np1} + \varphi_{np2}\rho_{np2} + (1 - \varphi_{np1} - \varphi_{np2})\,\rho_{bf} \quad (1)$$

The specific heat formula is given as

$$\rho_{hnf}C_{phnf} = \varphi_{np1}\rho_{np1}C_{pnp1} + \varphi_{np2}\rho_{np2}C_{pnp2} + (1 - \varphi_{np1} - \varphi_{np2})\,\rho_{bf}C_{pbf} (2)$$

The viscosity formula is given as

$$\mu = \mu_0(1 + 2.5\varphi) \ (3)$$

Where nanoparticle 1 and nanoparticle 2 are denoted as np1 and np2, density as ρ, volume fraction as φ, specific heat as Cp. Symbols μ and μ_0 are the dynamic viscosity of hybrid nanofluid and base fluid, while hnf and bf are the subscripts used for hybrid and base fluid respectively. In the present work MgO and Graphene nanoparticles are used for preparing hybrid nanofluids.Magnesium oxidenanofluid is one of the most encouraging materials in the metal oxide collection. According to the literature, this material has a low dynamic viscosity rise and a notable increase in heat conductivity.Magnesium oxide has one of the highest thermal conductivities and specific heats at 48.4 W/m-k and 877 J/kg-k, respectively. MgO has better thermal properties than other metal oxide particles, making it one of the most sought-after materials for creating nanofluids. The thermal conductivity of MgO-Ethylene Glycol nanofluid was examined by Xie et al. [20] as a measure of nanoparticle concentration. According to Verma et al. [21], replacing water with MgO/water at a concentration of 0.75% vol in a flat plate type solar collector increased thermal and energy efficiencies by up to 9.34% and 32.23%, respectively. MgO/water nanofluid was put in a heat tube by Menelik et al. [22], who found that doing so increased the heat pipe's efficiency by 26%.

Graphene has been the focus of various studies recently due to its significant properties. According to these studies, graphene nanoparticles have a number of advantages over other materials, including improved stability, reduced corrosion, an increased surface to volume ratio, a lack of erosion and clogging, a reduced need for pumping force increased thermal conductivity as well as substantial energy savings [23]. Graphene refers to sheets of hexagonally organized, sp2bonded carbon atoms that are one atom thick. In order to create exfoliated graphene-based nanofluids, Ag nanoparticles, MWCNT, and Hydrogen Exfoliated Graphene (HEG), were used by Baby and Ramaprabhu [24] and reported convective heat transfer increase by 570% for a Reynolds number of 250 and a volume concentration of 0.005%. The preparation of nanofluid is crucial since it greatly affects the properties and stability of the final product. The necessary samples for the current study were prepared using a two-step process. Magnesium oxide and graphene nanoparticles are bought from Adnano technologies Shimoga Karnataka. Technical specifications of procured samples are given in Table 2 and Scanning electron microscopic images are presented in Figure 1 and Figure 2 respectively. Ten liters of DI water are combined with the measured samples. Details of prepared samples are given in Table 2.To ensure uniform dispersion the samples are centrifuged for 30 minutes using a mechanical stirrer. Visual observations re-vealed that MgOnanofluid at 0.01wt% had good stability for 14days while Graphene at same concentration remained stable for 22days with only minor precipitation. To understand the influence of pH on nanofluid's performance NH_4OH is added to a few samples. By adding 25w/W NH_4OH pH of the solution is measured to be 9.

Table 2. Technical specification of Graphene and Magnesium Oxide samples from Ad-nano technologies Shimoga Karnataka.

Parameter	**Graphene A**	**Magnesium Oxide**
Purity	>99%	99%
Bulk Density	0.006 g/cc	0.6 g/cc
AverageThickness (z)	0.8-1.60	20-50 nm
number of layers	1-3	_
surface area	200.0-700.0 m^2/g	110-130 m^2/g
Average lateral Dimension x& y	< 1μm	–
Physical form	Fluffy, Light black powder	Spherical
Chemical formula	C	MgO
Color	Black powder	White Powder

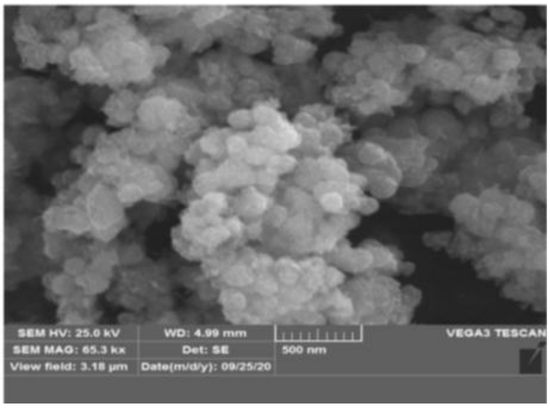

Fig.1.SEM image of MgO.

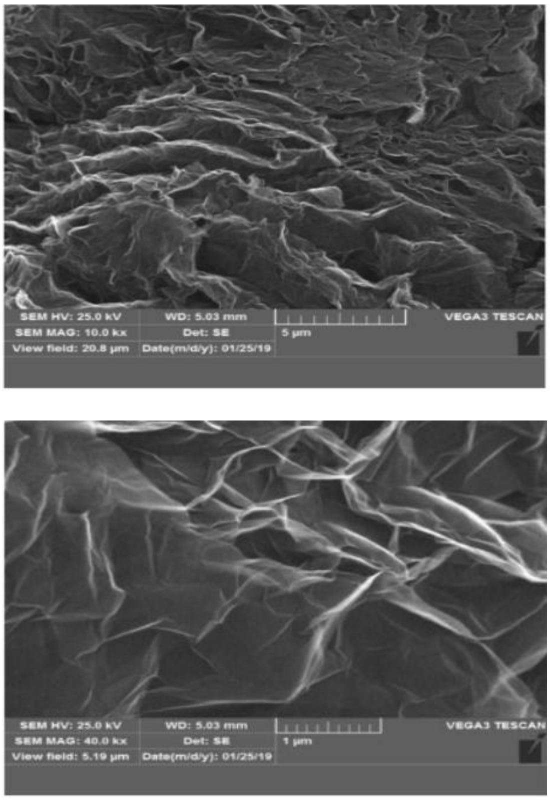

Fig.2.SEM images of Graphene A

Table 3. Details of prepared nanofluid samples

Sample	Description
1	DI water
2	1.0 gm MgO in 10 liters of water
3	1.0 gm Graphene in 10 liters of water
4	0.5 gm MgO + 0.5 Graphene in 10 liters of water
5	1.0 gm MgO+ 50 ml NH_4OH in 10 liters of water
6	1.0 gm Graphene + 50 ml NH_4OH in 10 liters of water
7	0.5 gm MgO + 0.5 Graphene + 50 ml NH4OH in 10 liters of water

Table 4 shows the computed densities, specific heat capacities, and viscosities of the samples using Eqs. (1), (2), and (3). The working fluid's thermal conductivity is the main factor that controls convection heat transfer. By using nanoparticles, the underlying fluid's thermal conductivity can indeed be increased, thus improving convective heat transfer. Since each system has a threshold, raising the solid filler concentration alone won't improve thermal conductivity because, beyond a certain point, doing so will also rise the viscosity, which will negatively impact the fluid's performance and attributes. The unusual rise in the heat transport of nanofluids has been attributed, according to researchers, to the random mobility of particles known as "Brownian motion".

Table 4. Thermo Physical Properties of Prepared Samples

Sample	Density kg/m^3	Sp Heat (J/kg-K)	Viscosity Pas
1	998	4178	$8.90 X 10^{-4}$
2	1068	3880	$9.51 X 10^{-4}$
3	1052	3921	$9.84 X 10^{-4}$
4	1065	3850	$9.67 X 10^{-4}$
5	1575	2580	$13.86 X 10^{-4}$
6	1390	2194	$15.83 X 10^{-4}$
7	1520	2675	$14.91 X 10^{-4}$

Only very small particles can experience Brownian motion, and the effects of Brownian motion become less pronounced as particle size increases. The produced sample's thermal conductivity is currently measured using the transient hot wire method.

2.1 Transient Hot Wire Method

A precise thin metal wire, made of Tantalum or Platinum, is used in this technique to act as both a heat source and a heat sensor. A certain voltage is supplied to the wire as it is submerged in the nanofluid, heating it. Afterward, the heat will dissipate into the nearby liquid at a pace determined by the liquid's thermal conductivity. As a result of the relationship between changes in temperature and changes in wire resistance, the thermal conductivity is calculated. The nanofluid's thermal conductivity is measured by means of Tempos Thermal Property Analyzer shown in Figure 3. It is composed of a Tempos controller and sensors that are linked to resistivity probes in order to evaluate the thermal conductivity of fluid. The probe is safely positioned in the water bath with the test fluid in the test tube which has its temperature set to the appropriate level. The digital metre is turned on once the necessary temperature has been reached to estimate the thermal conductivity of the test fluid.

Fig. 3. Tempos Thermal Property Analyzer for thermal conductivity measurement

The equipment measures thermal conductivity by the transient heat line source method. The probe used in this apparatus is a needle with an internal heater and temperature sensor. Heater is run by current, and system continuously measures temperature. When the probe is inserted into a nanofluid, the temperature sensors' time dependence is analyzed to calculate the nanofluid's thermal conductivity. The instrument is sensitive to even minor vibrations and hence the whole setup is kept on the anti-vibration table. Thermal conductivity K (W/m-K) of MgO, Graphene, and Hybrid (MgO + Graphene) samples is measured using the above instrument. Recorded values are tabulated below. For the study a concentric tube heat exchanger is used. Cold water is made to flow through outer pipe in the first run and in the second run nanofluid is made to flow. Utilizing measured variables like temperature, mass flow rate, and other thermophysical properties, the convective heat transfer coefficient for each run is calculated for a particular flow rate, and results are compared. For the study while hot water flow rate in inner pipe is kept constant discharge rate of cold fluid in outer pipe is altered.

Table 5. Thermal Conductivity Values of the prepared samples

Sample	K without NH_4OH at 30^0C	K with NH_4OH at 30^0C
MgO	0.6152	0.5889
Graphene	0.6936	0.6829
Hybrid	0.6321	0.6202

III. Experimentation

The experiment uses a concentric pipe heat exchanger, as perceived in Figure 4. The copper inner pipe has a length of 1100 mm, an ID of 21 mm, and an OD of 25 mm. Steel pipes with an ID of 32 mm and an OD of 38 mm make up the outer pipe. A thermowell is used to completely isolate the outer pipe from the outside. The device has four sensors for temperature, a pair of rotameters to calculate the flow rates of hot and cold water, and a heater to heat the fluid. Before the start of experiment statistical analysis is carried out on the temperature sensor and roto meter to measure error in readings. All the temperatures at different positions are recorded with the help of thermocouples for every experiment the temperature readings are monitored and recorded till the steady state is reached the experiment is continuously conducted for water fluid at same working conditions to understand the error in the readings. The error bars graph is shown in the Figure 4. By considering mean and standard deviation the error bars are presented., Thermocouple of BenwikTI make and roto meter of control make are the two measuring instruments used in the experiment, Standard error from calibration reports for thermocouple is ± 0.2 and for rotameter it is ± 0.125.

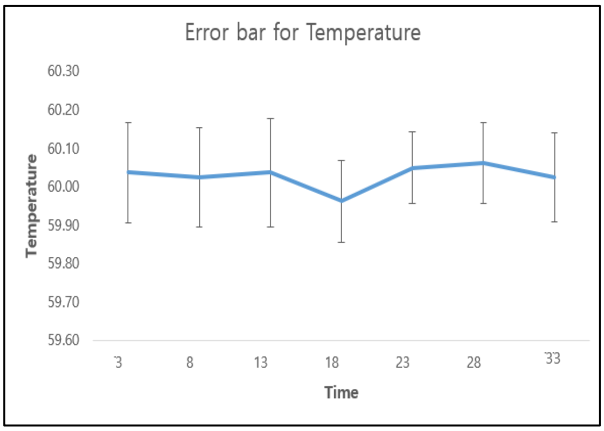

Fig. 4. Error plot representing temperature variation with time

The outer pipe is made to carry the nanofluid at 28 ± 2^0C while the inner pipe is made to carry hot plain water heated to 60 ± 2^0C. As the rate of cold nanofluid flow changes from 0.5 liters per minute to 2.2 liters per minute, flow rate of hot water is maintained constant at 1.25 lpm. Temperature measurements are taken during the experiment in counter flow method and temperature values i.e., Hot water inlet T_{hi}, Hot water outlet Tho, Coldwater inlet T_{ci}, Coldwater outlet T_{co} is recorded for each of the Coldwater flowrates i.e., 0.5 lpm, 0.8 lpm, 1 lpm, 1.2 lpm, 1.5 lpm,1.8 lpm, 2 lpm and 2.2 lpm. Experiment is continued for sample 1 to sample 7. In summary heat, transfer coefficient values are determined for plain water, and all samples of nanofluids. The results are compared and discussed in the following section

Fig. 5. Parallel and Counter flow heat exchanger for experimentation

Equations used for determining combined heat transfer coefficient U are given below.

Heat lost by hot water $Q_h = m_h C_{pw}(T_{hi} - T_{ho})$ (4)

Heat gained by cold nanofluid $Q_c = m_c C_{nf}(T_{co} - T_{ci})$ (5)

Mean heat transfer $Q_m = \frac{Q_h + Q_c}{2}$ (6)

The surface area of pipe $A = \pi x D x L$ (7)

Log mean Temperature difference

$$LMTD = \frac{(T_{hi}-T_{co})-(T_{ho}-T_{ci})}{ln\frac{(T_{hi}-T_{co})}{(T_{ho}-T_{ci})}} \quad (8)$$

Combined heat transfer co-efficient $U = \frac{Q_m}{A\ x\ LMTD}$ (9)
The mass flow rates of hot and cold water are denoted by the letters m_h and m_c in the equations above. The specific heat capacities of hot water and cold fluid, respectively, are C_{pw} and $C_{nf.}$

3.1 Uncertainty analysis

In the present study the experiments have been conducted on heat exchanger.The Uncertainty analysis is done by the following strategy. From a set of variables,
the performance parameter heat transfer coefficient U is calculated=U(X_1, X_2, X_3....X_N) (10)
X_i is the observations made during experimentation. For uncertainty analysis the basic equation is given by

$$\delta U = \sqrt{\left\{\sum_{i=1}^{N}\left[\left(\frac{\partial U}{\partial x_i}\right)\delta x_i\right]^2\right\}} \quad (11)$$

$$\frac{\delta U}{U_o} = \left[\left(\frac{U_m}{m}\right)^2 + \left(\frac{U_{\Delta T}}{T}\right)^2 + \left(\frac{U_{LMTD}}{LMTD}\right)^2\right]^{1/2} \quad (12)$$

In the above equation δ_U represents overall uncertainty in the experimentation and δX_i is uncertainty in one variable. The above equation is applicable for observations made on continuous experiments and each observation was independent.Variables involved in the calculation of U are mass flow rate m , ΔT the difference in temperature between the inlet and outlet temperatures, and LMTD.

$$= \sqrt{0.0032 + 0.0032^2 + 0.2^2}$$

$$= 0.207\%$$

IV. Results and Discussions

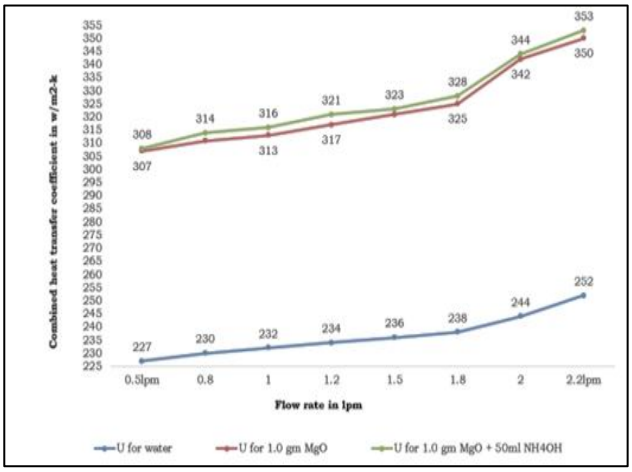

Fig. 6. Combined heat transfer coefficient of water, MgO nanofluid and magnesium oxide plus NH_4OH nanofluid

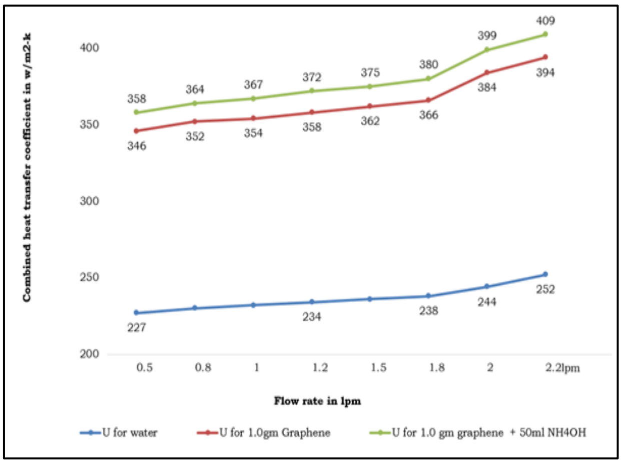

Fig. 7. Combined heat transfer coefficient of water, Graphene nanofluid and Graphene plus NH_4OH nanofluid

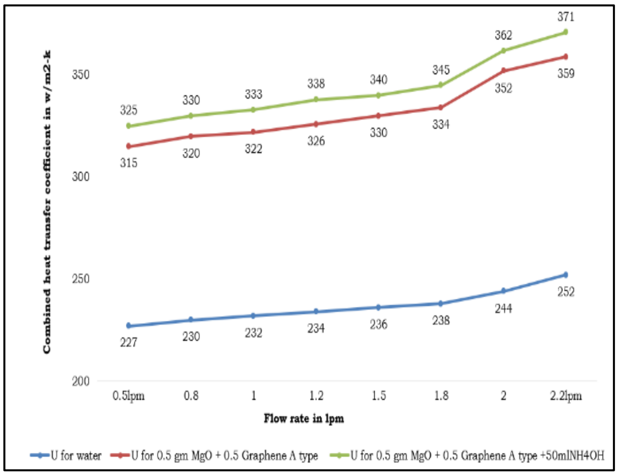

Fig. 8. Combined heat transfer coefficient of water, MgO plus Graphene
hybrid nanofluid and MgO plus Graphene plus NH_4OH hybrid nanofluid.

The figures show the relationship between combined heat transfer coefficient taken on Y-axis and the flow rate on X-axis. The results reveal convection heat transfer coefficient rises with discharge rate for all samples, as shown by all the figures. This is due to turbulence created by chaotic motion of fluid and nanoparticles. Addition of even small concentration of nanoparticle in base fluid produces dramatic enhancement of K and U. Particle material, particle size and shape, pH value of the flu-id,Brownian motion,clustering of particles liquid layering around the particles all have favorable impact on thermal performance of nanofluid. Figure 6 shows that use of magnesium oxide nanofluid has considerable improvement on heat transfer performance. Combined heat transfer coefficient has increased by 35.2% and 35.7 % for sample2 (MgO)and sample 5 (MgO + NH_4OH) at 0.5lpm. Corresponding increase at 2.2 lpm are 38.9 % and 40.1%.As flow rate increased from 0.5lpm to 2,2lpm convective heat transfer coefficient improved from 307 w/m^2K to 350 w/m^2K a 14% increase for sample2 and similarly for sample 5 percentage increase with respect to flow rate is 14.6%. Increase in heat transfer coefficient is the result of enhancement in fluid thermal conductivity due to addition of nanoparticles.The possible mechanism that aids the increase includes particle collision,Brownian motion and particle clustering. The constant bombardment of nanosize particles at the boundary layer transfers a significant amount of heat from the boundary to the main stream fluid, increasing the heat transfer coefficient

The variation of U with flow rate for sample 3 and sample 6 are shown in Figure 7.Heat transfer coefficient increased by 13.87 % and 14.24% for sample 3 and sample 6 as the flow rate increased to 2,2 lpm from 0.5 lpm.Sample3 (Graphene) nanofluid is observed to produce a combined heat transfer coefficient of 52.4% higher value while sample 6 produced 57.5% higher value compared with pure water at a flow rate of 0.5 lpm. Also, a significant increase of 55.7% and 61.6% in combined heat transfer coefficient values for both samples is seen at 2.2 lpm. Similar improvement is observed at other inter-mediate flow rates. Graphene's superior thermal performance when compared with magnesium oxide is due to better thermal conductivity and lower density and higher surface area when compared to magnesium oxide nanofluid. Though the addition of NH_4OH is observed to enhance combined heat transfer coefficient value marginally the increase in properties like density and viscosity could increase the pumping power. Therefore, addition of NH_4OH may not yield any better result compared with its nanofluid.

Figure8. shows performance of hybrid nanofluids. Heat transfer coefficient increased by 13.6 % and 14.15% for sample4 and sample7 with enhancement in flowrate to 2.2lpm. From the figure combined heat transfer coefficient for sample 4 is seen to increase by 38.9% at 0.5 lpm and 41.9 % at 2.2 lpm. Similarly for sample 7 at 0.5 lpm the increase in value is about 43 % at 0.5 lpm and 46.6% at 2.2 lpm. Though the performance of hybrid nanofluid is better than MgO mono nanofluid it is lower than Graphene mono nanofluid's performance. It may be due to poor compatibility between two particles. From the study it is evident that increasing pH with addition of NH_4OH resulted in marginal increase in U for both MgO and Graphene samples.Graphene nanofluid's heat transfer ability is superior when compared with MgO due to its favourablethermo physical properties like high K, low density and high surface area. Heat transfer coefficient results of hybrid nanofluid is better than mono (MgO) nanofluid but its performance is lower than Graphene nanofluid. Again, reason can be attributed to Graphene's high K, low density and high surface area. From the results obtained correlations between dimensionless heat transfer coefficient i.e., Nusselt number (Nu), Reynoldsnumber (Re) and Prandtlnumber (Pr) is derived for all samples. Derived correlations are given in Table 6.

Table 6Derived correlations between Nusselt number (Nu), Reynold's number (Re) and Prandtl number (Pr) for the prepared samples.

Sample	Nu
1	$1.2\,(Re)^{0.077}(Pr)^{0.0015}$
2	$1.014\,(Re)^{0.072}(Pr)^{0.3}$
3	$1.26\,(Re)^{0.097}(Pr)^{0.087}$
4	$1.143\,(Re)^{0.077}(Pr)^{0.2}$
5	$1.56\,(Re)^{0.08}(Pr)^{0.06}$
6	$1.05\,(Re)^{0.077}(Pr)^{0.334}$
7	$1.35\,(Re)^{0.068}(Pr)^{0.196}$

In order to optimize the results Taguchi Design of experiments methods L_{25} orthogonal array is employed [25-26] (five flow rates and five composition) and results are shown in the Figure 9. From the figure flow rate of 2.2lpm and Graphene with NH_4OH is resulting in Maximum heat transfer coefficient. Compared to flow rate, nanofluid's composition is resulting in more enhancement with respect to water.

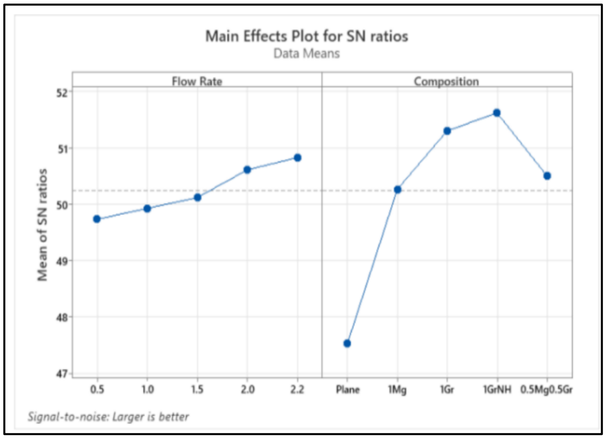

Fig.9. Effect of process parameters on Combined heat transfer coefficient

When base fluid is mixed with nanoparticles, the pressure drop caused by fluid friction typically increases. Using the DarcyWeisbach equation, the pressure drop in the pipe is calculated for each sample.

The pressure loss caused by viscous effects in a cylindrical pipe with uniform diameter D that is flowing fully is proportional to length L and can be calculated using the Darcy-Weisbach equation as

$$\frac{\nabla p}{L} = f_D.\frac{\rho}{2}.\frac{(\vartheta)^2}{D_H} \quad (13)$$

Where f_D is friction factor in pipe ϑ is flow velocity and D_H is hydraulic diameter of pipe. Using this relation pressure drop in Pascals is calculated for all the samples at 2.2 lpm and given in Table 7.

Table 7Pressure drop in pipe due to fluid friction

Sample	Pressure drops in Pascals
1	59.26
2	73.7
3	73.24
4	143.5
5	70.1
6	104.13
7	151.8

From the results it can be concluded that highest pressure drop is occurring for hybrid nanofluids i.e.,sample4 and sample 7.

V. Conclusions

When compared to Graphene mono nanofluid, a hybrid nanofluid consisting of an equal mixture of MgO and Graphene nanoparticles diffused in a water base fluid did not significantly improve the heat transfer coefficient.

In comparison to MgO nanofluid, hybrid nanofluid appears to have a higher thermal conductivity. A rise in viscosity and a reduction in density go hand in hand with this improvement in K.

The outcomes of the experiments demonstrated that the in-crease of K and heat transfer are significantly influenced by graphene nanofluid. In addition to thermal conductivity, factors like viscosity, particle size and shape, and surface area are seen to have a noteworthy influence on improving K.

Heat transfer coefficient of Graphene plus NH_4OH is highest among all samples. However, its viscosity is highest among all samples which may lead to more pumping power and its specific heat is lowest among all samples

From the results it is evident that graphene mono fluid (sample 3) is superior both in terms of heat transfer performance and in other thermo physical properties when compared to other nanofluid samples. This makes graphene mono nanofluid a good choice for forced heat transfer applications.

VI. Future scope

The impact of morphology and the use of various base fluids must be studied. It is important to look into the graphene nanofluid's longterm stability. It is possible to conduct addition-al research on the heat transfer capabilities of other graphene-based nanofluid composites.

Nomenclature

A : SurfaceIarea (m^2)
Cp :SpecificIheatIofIfluid (J/KgK)
D :DiameterI(m)
L :LengthI(m)
Q : Heat transferIrate (Watts)
T :TemperatureI(K)
U :CombinedIheatItransferIcoefficientI(W/m^2K)
K :ThermalIconductivityI(W/mK)
m :MassIflowIrateI(kg/sec)
Symbols φ : volumeIfraction
ρ : Density

μ_0 : DynamicIviscosityIofIwater**Subscripts**
bf :BaseIfluid
ci :ColdIfluidIinlet
co :ColdIfluidIoutlet
hi :HotIfluidIinlet
ho :Hot**I**fluid**I**outletnf:Nanofluid
np : Nanoparticle

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