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Application of high surface area graphene for enhanced heat transfer co-efficient – An experimental study

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ABSTRACT

Increased heat transmission has contributed significantly to cost and energy savings. The desire for compact gadgets with the finest performance, correct working, and long lifespan is being fuelled by today's scientific and technological advancements. The researchers were able to introduce a fresh kind of fluid with a mixture that was referred to as "Nanofluids" due to their superior thermal transfer capabilities compared to regular fluids. Applications for nanofluids in the electrical and other cooling industries are numerous. In this work, hydrogen exfoliated Graphene of two types i.e. multilayer Graphene designated as L- type and monolayer Graphene designated as A^+-type is diffused in pure deionized (DI) water and also in deionized water blended with ammonium hydroxide (NH_4OH) to prepare the Graphene-based nanofluid samples. In a concentric-pipe heat exchanger, the prepared nanofluids are utilised to calculate the heat transfer co-efficients. Samples are experimentally investigated to study the outcome of weight concentration and pH on The Heat Transfer Co-efficient (HTC). Results have shown that the HTC is higher for all nanofluid samples than that of water at all the flow rates studied. Six nanofluid samples are prepared with two volume fractions of 0.005% and 0.01%. Three samples were prepared with each of L-type Graphene and A^+-type Graphene materials. For sample1 which is prepared by dispersing 0.5 gm of L-type Graphene in 10 L of water, the improvement in combined heat transfer co-efficient observed was 14.5 % over water. For sample 2 prepared by adding a further 50 ml of NH_4OH to the sample 1 enhancement over water is observed to be 20.2%. 1 g of L-type graphene is dissolved in ten litres of water to create Sample 3, which has a 24.5% improvement in combined HTC. For the nanofluid samples 4, 5 and 6 prepared with A^+-Type Graphene, the corresponding increase in combined heat transfer co-efficient s observed were 44.6 %, 50.2%, and 53.6% respectively. In comparison to L-type samples, nanofluid samples made with A + -type Graphene were shown to provide better thermal performance.

1. Introduction

To achieve improved heat exchange objectives, deionized (DI) water, motor oil, ethylene glycol (EG) and other common fluids are used in many industrial applications. The productivity and life of equipment's are determined by the thermal performance in terms of the fluid's efficiency in transferring heat. Conventional fluids have limited heat conductivity as compared to their solid equivalents. High thermal conductivity solid particles are frequently added to these fluids to speed up the rate at which heat is transferredTo address these problems, Choi, Eastman, and colleagues [1] introduced a novel fluid called nanofluid, in which basic fluids are combined with nanoparticles. Since then, several researchers have examined how dispersed nanofluids consisting of diverse nanomaterials transmit heat.

1.1. Issues in nanofluids preparation

Dispersing nanoparticles(NP) creates nanofluids of high thermal conductivity material as a stable suspension in the base liquid. The fundamental issue with nanofluids is stability, which is vital for the

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Nomenclature

A	surface area (m^2)	μ	dynamic viscosity of nanofluid
C_p	specific heat of fluid (J/Kg-K)	μ_0	dynamic viscosity of water
D	diameter (m)	b_f	base fluid
L	length (m)	c_i	cold fluid inlet
Q	heat transfer rate (Watts)	c_o	cold fluid outlet
T	temperature (K)	h_i	hot fluid inlet
U	combined heat transfer coefficient (W/m^2-K)	h_o	hot fluid outlet
k	thermal conductivity (W/m-K)	h_o	hot fluid outlet
m	mass flow rate (Kg/sec)	n_f	nanofluid
HTC	Heat Transfer Coefficient	n_p	nanoparticle
φ	volume fraction		
ρ	density		

use of heat transfer fluid. However, the presence of both large and small particles may result in problems like agglomeration and sedimentation. Despite the use of several approaches to increase nanofluid stability, more study is still needed. For various forms of nanofluid, the ideal period for sonication and magnetic stirring has not yet been identified. Additionally, the ideal surfactant concentration has not yet been established [9,10]. Particle size distribution and concentration fluctuations are shown to affect the thermal conductivity of nanofluids. It is essential to prepare and characterise nanofluids since these factors greatly influence their dispersion and stability [11]. A range of physical treatment techniques based on a two-step procedure, including stirrer, ultrasonic disruptor, ultrasonic bath, and high-pressure homogenizer, were extensively evaluated to show their applicability for producing stable nanofluids [12].

The size and shape of the nanomaterials, the pH and temperature of the base fluid, and the presence of additives, nanomaterials proportion in the base fluid, and other features all influence the property of thermal conductivity. In nanofluids, the heat transmission mechanism is just as important as thermal conductivity. Using nanofluids with strong heat transmission capabilities reduces the unit's overall size and increases its efficiency. As a result, in addition to steady-state thermal conductivity, It is crucial to determine how well different nanofluids transmit heat in dynamic flow situations. Several groups have measured heat transfer capacities for various flow regimes like laminar flow and turbulent flow.

1.2. Investigations with metallic-nanofluids

A variety of nanostructures, have been studied as additions to a variety of base fluids (BF). Metallic NPs such as Gold (Au), Copper (Cu), and Silver (Ag) come into this group due to their high thermal conductivity. The biggest issue, however, was their availability and accompanying expense. Different element oxides, including alumina (Al_2O_3), titania (TiO_2), silica (SiO_2), copper (CuO), and zinc (ZnO), were also examined because of their greater thermal conductivity, availability, and lower price. Researchers have demonstrated that the thermal conductivity of Al_2O_3 and CuO nanoparticles distributed in water and EG-based nanofluids is improved [2]. In a horizontal pipe heat exchanger with laminar flow conditions and Al_2O_3 particles, Yang et al. [3] investigated the impact of several nanofluids on heat transfer rate, and Heirs et al. [4] discovered a 40% increase in heat transfer rate.

Table 1
Technical specification of graphene.

Description	Graphene- L Type	Graphene -A$^+$ Type
purity	>99%	>99%
Number of layers	5–10	1–3
Thickness	5–10 nm	0.8–1.6 nm
Average lateral Dimension (X&Y)	10 μm	<1 μm
Surface Area	60–200 m^2/g	200–700 m^2/g
Bulk Density	0.45 g/cm^3	0.006 g/cm^3
Physical form	Fluffy	Fluffy
Colour	Black powder	Black powder

1.3. Investigations with non-metallic nanofluids

However, with the exception of a few studies on carbon nanotubes, The heat transfer mechanism of carbon-based nanofluids (CNTs) has received little attention in research [5]. Graphene is a wonderful substance with an immense variety of extraordinary capabilities, earning it the nickname "wonder material." Unique mechanical, thermal, electrical, and optical properties are among graphene's amazing qualities. The Graphene synthesis technique dubbed the 'Scotch tape approach, was incredibly easy. Mechanical exfoliation of graphite (drawing one layer away from the bulk with adhesive tape) could be used to isolate Graphene monolayers. Another aspect that aids in improving thermal conductivity along with heat transmission is the material's surface area. Hydrogen-exfoliated Graphene has a high surface area of about 450 m^2/g [17].

Traditional carbonaceous materials like graphite and carbon black were also explored because of their multiple uses and nearly ten-fold better heat conductivity than water [13]. Among carbon-based materials utilised for NFs, graphene (Gr) has attracted significant scientific attention due to its exceptional thermal conductivity, which is perhaps in the range of 2,500–5,000 W/m. K. with large surface area and other noteworthy properties [14]. In comparison to thoroughly studied metal oxide NF, gr-based NF has a substantially higher thermal conductivity and does so at a much lower concentration. It also has a lower density and viscosity increase, all of which are essential for determining the required pumping power [15,16].

When graphene oxide was added to water at 20 °C at an amount of 0.25 wt%, Hajjar et al. [6] analysed the results and found that the fluid's thermal conductivity increased by roughly 33.9 percent. The convective heat transfer co-efficient increased by 35.6 percent for 0.1 wt% of graphene nanofluid, according to research by Ghozatloo et al. [7] on the thermal performance of a shell and tube heat exchanger. Shadeghinezhad et al. [8] compared the performance of a heat pipe carrying graphene nanoparticles to that of deionized (DI) water using a sintered wick heat pipe, and they discovered a maximum reduction in thermal resistance of 48.14 percent. Additionally, it was demonstrated that, in comparison to a horizontal position, the maximum thermal conductivity improvement for the heat pipe containing graphene nanoparticles was considerable at a 60-degree inclination.

Though Graphene has got outstanding potential in terms of superior thermo-physical properties very limited research work is carried out using Graphene Nanofluid. The innovative aspect of the current work is to investigate its potential for improving heat transfer using fluids containing L-type and A-type graphene nanoparticles in a range of concentrations. In this work, graphene-based NFs of the two types previously described have been chosen to investigate how well they transport heat in a twin pipe heat exchanger.

1.4. Potential applications

The current effort is concentrated on creating graphene-based nanofluids for heat exchangers, which have several uses in the fields listed below:

- Oil and gas production
- Refrigeration and HVAC industries
- Paper and pulp industries
- Oil refinery and petro-chemical industries
- Pharmaceuticals

2. Materials and methods

Graphene nanoparticles purchased from Ad Nano Technologies Shimoga, Karnataka are used to create nanofluid.. Two types of Graphene nanoparticles Graphene-L and Graphene-A$^+$ are procured from the supplier. Graphene-L produced by the chemical exfoliation method is low surface area graphene having high-aspect-ratio used in metal composites to improve electrical and thermal conductivity as well as mechanical stability.

Graphene-A$^+$ is ultra-pure high-surface graphene produced by the hummers method. It is a highly attractive nanofiller suitable for electronic, elastomers, polymers, and metal composites to improve mechanical, electrical thermal, and barrier properties. The physical form of both types is fluffy black powder images which are shown in Fig. 1& Fig. 2.Fig. 3Fig. 4

The technical information for the sample that the supplier provided is presented in the below.

Nano-particles are procured from Ad-nano technologies Shimoga, Karnataka, India. The measured samples are mixed in 10lts

Fig. 1. Graphene-L Sample.

Fig. 2. Graphene-A$^+$ Sample.

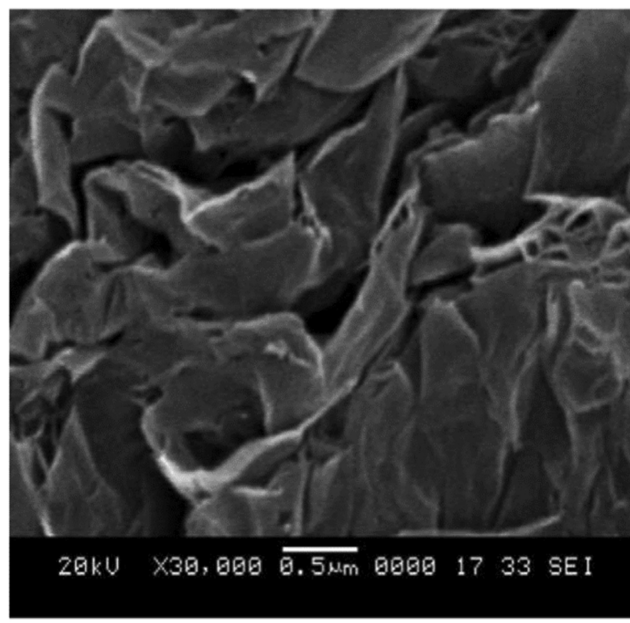


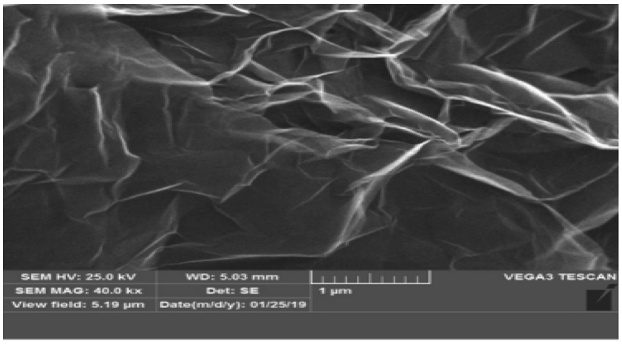
Fig. 3. SEM Image of Graphene -L.

of DI water. To ensure uniform mixing and stable suspension the samples are centrifuged for 30 min. Altogether seven samples are prepared as given in Table 2. A base with a specific heat value higher than water, NH_4OH has a specific heat value of 4740 J/Kg-K. The pH of the solution is increased to 9 by adding NH_4OH. To understand how pH affects the thermal performance of nanofluid, NH_4OH is introduced. Table 3 Shows thermophysical properties of prepared samples using correlations given for density , specific heat ,visocity and thermal conductivity

To evaluate the fluid dynamics and heat transmission capacities of nanofluids, the density must be known. Most authors prefer to use classical mixture law:

$$\varphi(Volume\ fraction) = \frac{\frac{m_{np}}{\rho_{np}}}{\frac{m_{np}}{\rho_{np}} + \frac{m_{bf}}{\rho_{bf}}} \quad (1)$$

m_{np}, m_{bf}, ρ_{np}, ρ_{bf} are mass and density of nanoparticle and base fluid respectively



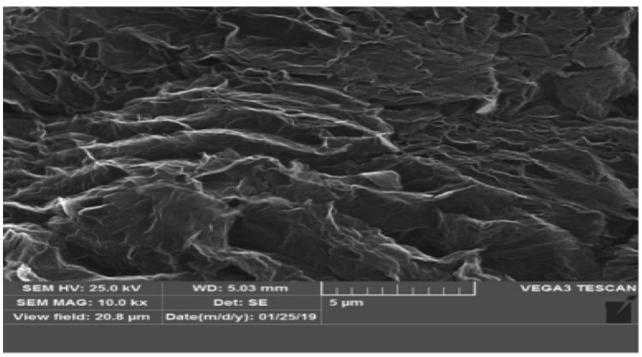


Fig. 4. SEM Image of Graphene A+.

Table 2
Details of prepared samples.

Sample	Description
1	Pure DI Water
2	0.5 gms Graphene L Type in 10 lts of water
3	0.5 gms Graphene L Type (in 10 lts of water) + 50 ml NH_4OH
4	1.0 gms Graphene L Type in 10 lts of water
5	0.5 gms Graphene A+ Type in 10 lts of water
6	0.5gms Graphene A+ Type (in 10 lts of water) + 50 ml NH_4OH
7	1.0 gms Graphene A+ Type in 10 lts of water

$$\rho_{nf=}\rho_{np}\varphi + (1-\varphi)\rho_{bf} \tag{2}$$

ρ_{nf}, ρ_{np}, ρ_{bf} are density of nano fluid, nanoparticle and base fluid respectively

$$Cp_{nf=}\frac{\varphi(\rho C\rho)_{np} + (1-\varphi)(\rho Cp)_{bf}}{\rho_{nf}} \tag{3}$$

C_{Pnf}, C_{Pnp}, C_{Pbf}, are specific heat of nanofluid, nanoparticle and base fluid respectively

$$\mu = \mu_0(1 + 2.5\Phi) \tag{4}$$

μ_0 is the dynamic viscosity of water and μ the is dynamic viscosity of nanofluid.

Numerous correlations have been established in estimating the nanofluid's thermal conductivity k_{nf} as a function of the nanoparticle and base fluid thermal conductivities k_{np}, k_{bf} and the nanoparticle volume fraction φ.

According to the model developed by Hamilton and crosser

$$k_{nf} = k_{bf}\frac{k_{np} + (n-1)k_{bf} - (n-1)(k_{np} - k_{bf})\varphi}{k_{np} + (n-1)k_{bf} + (k_{np} - k_{bf})\varphi} \tag{5}$$

K_{nf}, K_{np}, K_{bf} are thermal conductivity of nano fluid, Nanoparticle and base fluid respectively value of n is 3 for spherical particle.

2.1. Experimentation

A concentric pipe heat exchanger as shown in Fig. 5 is employed for the experiment. The inner pipe is 1100 mm long, ID 21 mm, and OD 25 mm constructed of copper. Steel is used for the outer pipe of internal dia 32 mm and outer dia of 38 mm. A thermowell is used outside of the outer pipe to prevent heat loss to outside environment. The device has four temperature sensors, two rotameters to measure the flow rates of hot and cold water, a heater to warm the fluid, and four temperature sensors. Cold nanofluid at 28 ± 2 °C is configured to pass through the outer pipe while hot plain water heated to 60 ± 2 °C is permitted to flow through the inner pipe. While the flow rate of cold nanofluids varies from 0.5 to 2.2 L per minute, hot water flows at a consistent rate of 1.25 Lpm. The test is conducted in counter flow mode and values for temperature i.e., hot water inflow T_hi, hot water outflow T_ho, cold water inflow Tci, cold water outflow Tco is noted for every cold-water flow rate. i.e., 0.5 lpm, 0.8lpm,1lpm,1.2lpm,1.5lpm 1.8 lpm, 2lpm and 2.2lpm. For samples one through seven, the experiment is repeated. In conclusion, the values of the heat transfer co-efficient and Nusselt number are calculated for plain water, and the results are contrasted with those obtained for prepared samples.

Equations used for determining combined heat transfer coefficient U

$$\text{Heat lost by hot water } Q_h = m_h C_{pw}(T_{hi} - T_{ho})) \tag{6}$$

$$\text{Heat gained by cold nano fluid } Q_c = m_c C_{nf}(T_{co} - T_{ci}) \tag{7}$$

$$\text{Mean heat transfer } Q_m = \frac{Q_h + Q_c}{2} \tag{8}$$

$$\text{The surface area of pipe } A = \pi DL \tag{9}$$

$$\text{Log mean Temperature difference } LMTD = \frac{[(T_{hi} - T_{ho}) - (T_{co} - T_{ci})]}{ln\left(\frac{T_{hi} - T_{ho}}{T_{co} - T_{ci}}\right)} \tag{10}$$

$$\text{Combined heat transfer co-efficient } U = \frac{Q_m}{A * (LMTD)} \tag{11}$$

Table 3
Thermo physical properties of Di water and prepared samples.

Properties	Volume fraction	$\rho(kg.m^{-3})$	$Cp(J.kg^{-1}.K^{-1})$	$K(W.m^{-1}.K^{-1})$	μ(Pa.s)
Water (10lts)	–	998	4178	0.61	8.9×10^{-4}
Graphene Ltype (0.5 gms in 10lts of water)	1.1×10^{-4}	997.9	4183	0.6102	8.902×10^{-4}
Graphene Ltype (1.0 gms in 10lts of water)	2.22×10^{-4}	997.88	4178	0.6104	8.905×10^{-4}
Graphene L type + NH4OH (0.5gms in 10lts of water + 50mlNH4OH)	2.2×10^{-3}	993	4200	0.8	10×10^{-4}
Graphene A type (0.5 gms in 10lts of water)	8.25×10^{-3}	989.8	4178	0.625	9.08×10^{-4}
Graphene A type (1.0 gms in 10lts of water)	16.4×10^{-3}	989	4176	0.64	10×10^{-4}
Graphene A type + NH4OH (0.5gms in 10lts of water + 50mlNH4OH)	0.15	986	4200	0.82	13.7×10^{-4}

Fig. 5. Parallel and Counterflow Heat Exchanger test setup.

In the above equations, m_h and m_c are hot water and cold water mass flow rates. C_{pw} and C_{nf} are specific heat capacities of hot water and cold fluid respectively.

3. Results and discussion

The values of the combined heat transfer co-efficient s (HTC) for the prepared samples and water are calculated and shown in the Table 4 below. In column two combined HTC values for a flow rate of 0.5lpm in the outer pipe are given. Similarly in the remaining columns combined HTC values for varying flow rates in the outer pipe are presented.

Fig. 6a to 6.f are drawn taking the cold fluid flow rate on X-axis and the combined HTC on Y-axis. In Fig. 6a combined HTC values of water and sample, 2 are superimposed in order to make comparison easy. The same procedure is followed in the remaining figures.

As the flow rate rose from 0.5 lpm to 2.2 lpm combined HTC increased from 227 W/m^2K to 253 W/ m^2K for water which is an 11.4% increase. Similarly, for sample 2 percentage increase is 11.9 as shown in Fig. 6.a. Chaotic movement of fluid particles due to increased flow rate is responsible for larger heat transfer

Table 4
Calculated values of overall heat transfer co-efficient (HTC) or combined heat transfer co-efficient (HTC) at different flow rates.

Samples	Flow rate 1 0.5lpm	Flow rate 2 0.8lpm	Flow rate 3 1.0lpm	Flow rate 4 1.2lpm	Flow rate 5 (1.5lpm)	Flow rate 6 (1.8 lpm)	Flow rate 7 (2.0 lpm)	Flow rate 8 (2.2 lpm)
1	227	230	231	233	236	238	248	253
2	260	263	265	267	270	272	286	292
3	274	276	278	280	284	287	303	308
4	283	286	287	290	294	298	314	319
5	328	333	334	337	341	344	363	372
6	339	345	347	350	353	357	376	386
7	346	351	353	358	362	366	385	394

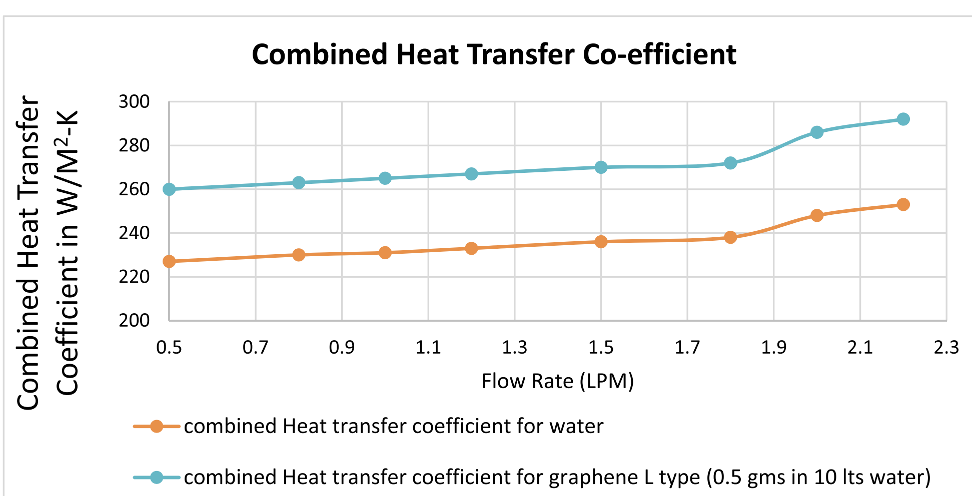


Fig. 6a. Combined heat transfer co-efficient Vs flow rate for 0.5 gm graphene L type in 10lts water.

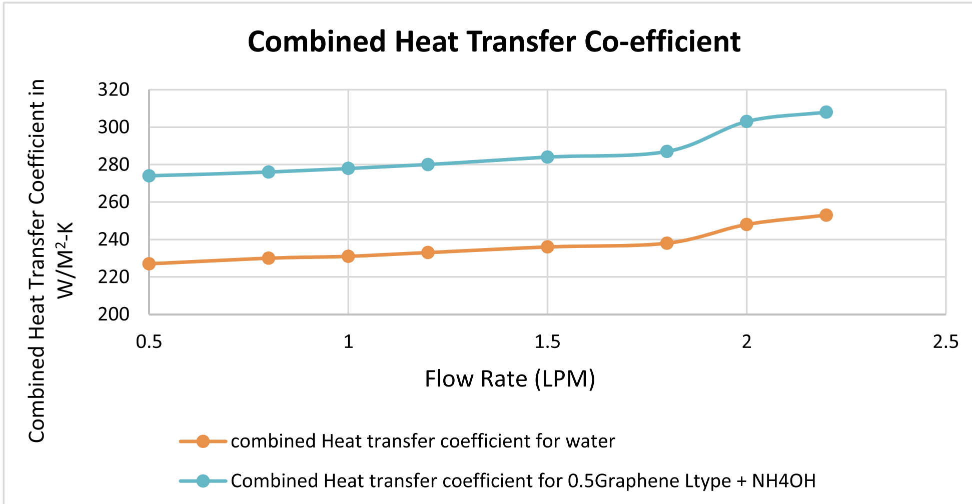


Fig. 6b. Combined heat transfer co-efficient Vs flow rate for 0.5 gm graphene L type + NH_4OH in 10 lts water.

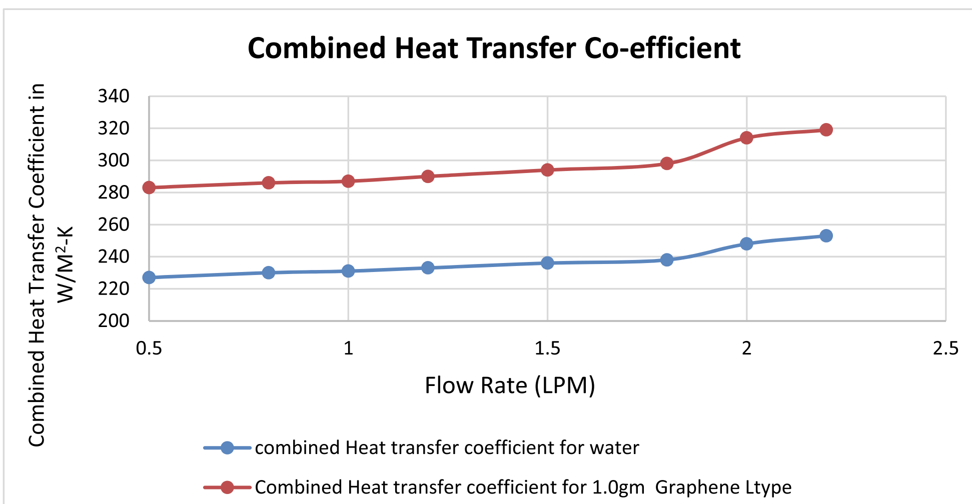


Fig. 6c. Combined heat transfer co-efficient Vs flow rate for 1.0 gm graphene L type in 10 lts water.

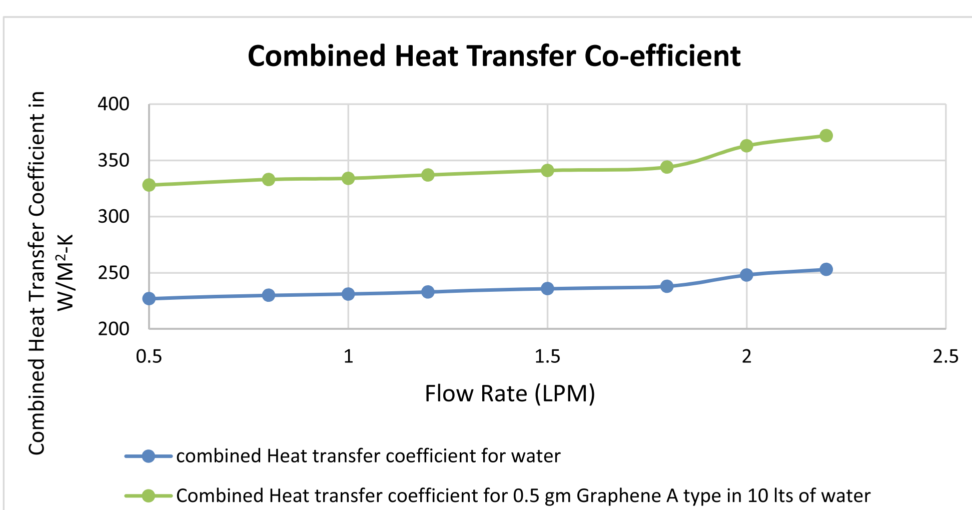


Fig. 6d. Combined heat transfer co-efficient Vs flow rate for 0.5 gm graphene A[+] type in 10 lts water.

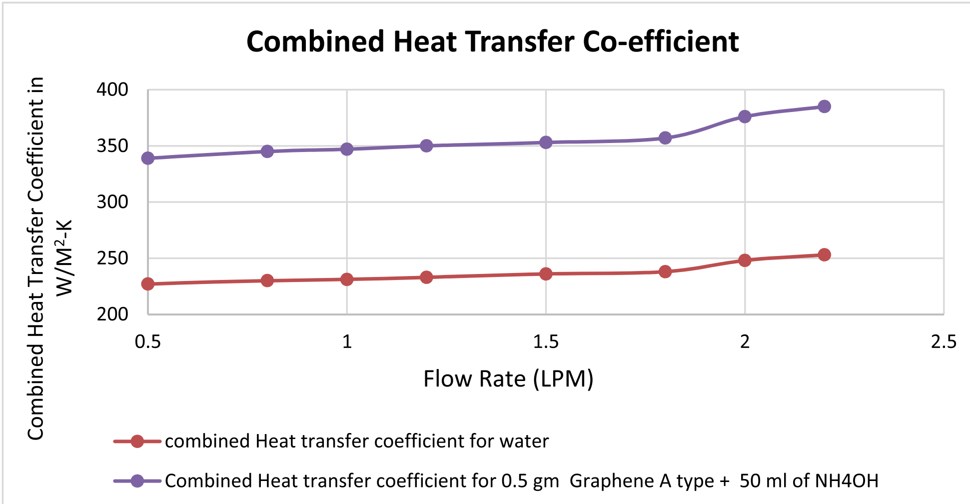


Fig. 6e. Combined heat transfer co-efficient Vs flow rate for 0.5 gm graphene A+ type + 50mlNH_4OH in 10 lts water.

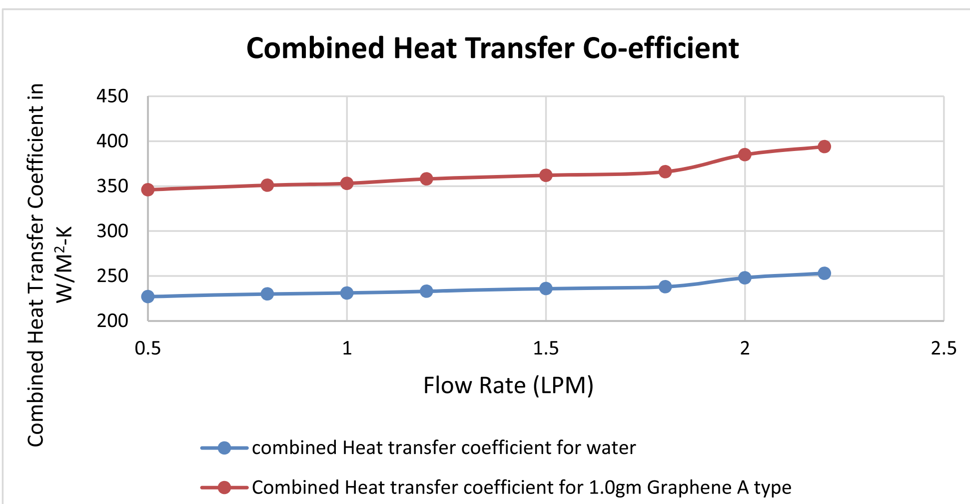


Fig. 6f. Combined heat transfer co-efficient Vs flow rate for 1.0 gm graphene A+ type in 10lts water.

Table 5
Calculated values of Nusselt number versus Reynolds number for different samples.

Reynold's Number	Nusselt Number for Plain Water	Nusselt Number for Plain Water + 0.5gm Graphene L type	Nusselt Number for Plain Water + 0.5gm Graphene L type + NH_4OH	Nusselt Number for Plain Water + 1.0gm Graphene L type	Nusselt Number for PlainWater + 0.5gm Graphene A+ type	Nusselt Number for PlainWater + 0.5gm Graphene A+type NH_4OH	Nusselt Number for PlainWater + 1.0gm Graphene A+ type
198.5	409	470.5	494	510	577.3	601.5	595
317.7	414.8	474	497.6	515.4	586.1	612.1	603.7
397	416.6	477.7	501.2	517.2	587.8	615.7	607.2
476.5	420.2	481.3	504.8	522.6	593	621	615.8
595.6	425.6	486.7	512.1	529.8	600.2	626.3	622.6
714.7	429.2	490.3	517.5	537	605.4	633.4	629.5
794	447.2	515.6	546.3	565.9	638.9	667.1	662
873.5	456.2	526.4	555.3	574.9	654.7	683.1	677.7

co-efficient across all samples. Additionally, for sample 2, the overall heat transfer co-efficient across water is 14.98, 14.35, 14.72, 14.6, 14.41, 14.3, 15.32, 15.42 at cold fluid flow rates of 0.5 lpm, 0.8lpm, 1.0 lpm,1.2lpm,1.5lpm, 1.8lpm, 2.0lpm and 2.2 lpm. Given that nanoparticles have been added to the basic fluid, this may be the result of Brownian motion and particle clustering.

For the sample3 as the flow rate of cold fluid increased from 0.5 lpm to 2.2 lpm combined HTC increased from 260 W/m^2K to 292 W/ m^2K which is a 12.4% increase as shown in Fig. 6b. Moreover, the percentage increase in combined HTC over water is 20.7%, 20.0, 20.35, 20.17, 20.34, 20.6%, 22.2% and 21.74% at various cold fluid flow rates under study. So, the addition of NH_4OH in the

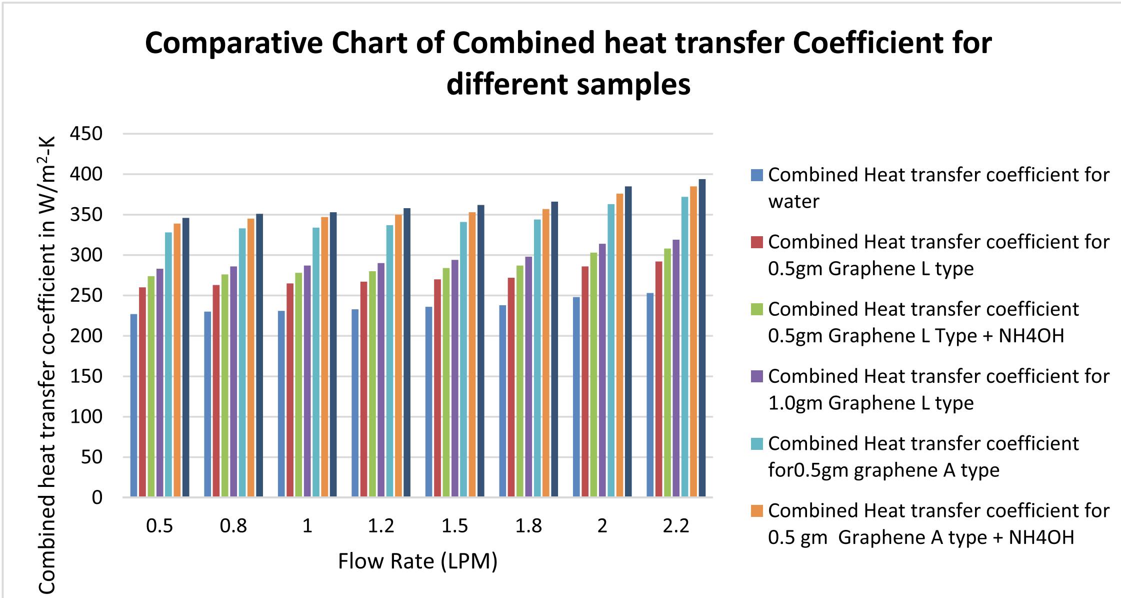


Fig. 7. Comparative chart of combined heat transfer co-efficient Versus flow rate for different samples.

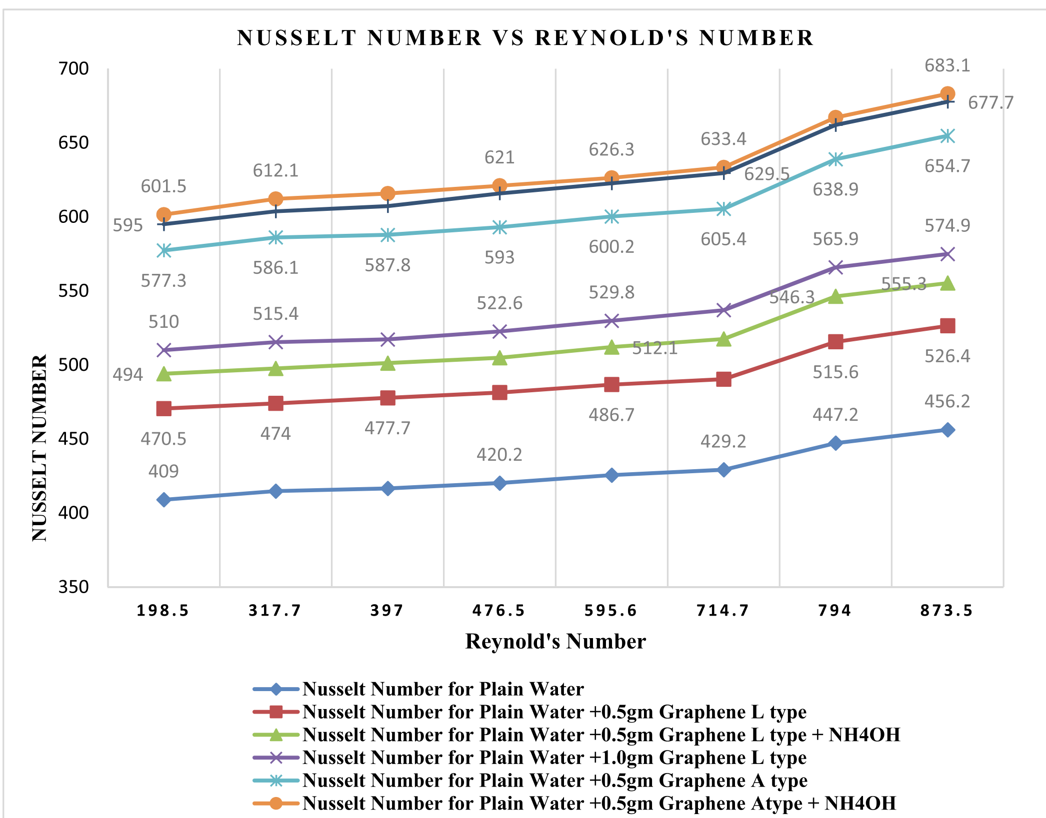


Fig. 8. Comparative chart of Nusselt number Versus Reynolds Number for different samples.

sample3 has resulted in an increase of the pH of the solution to 9 which has a positive effect on improving the combined HTC. The combined heat transfer co-efficient increased from an average of 14.5% for sample2 to 20.0% for sample3 which is a 5.5% further increase in combined heat transfer due to an increase in pH.

For sample 4 which is 1.0gm grapheme L-type in 10lts of water increase in combined heat transfer co-efficient over water is 24.67, 24.35, 21.24%, 24.46%, 24.58%, 25.21%,26.61%, 26.08% at various flow rates under study as shown in Fig. 6c. An increase in the concentration of graphene from 0.005% to 0.01% has a favorable outcome in increasing the combined heat transfer co-efficient from an average of 14.5% to 24.5%.

For sample 5 which is 0.5 gm graphene A^+ type in 10 L of water increase in combined heat transfer co-efficient over water is 44.5%,44.78%, 44.6%,44.64%,44.49%,44.54%, 46.37%, and 47% respectively as shown in Fig. 6d. So there is a remarkable improvement in heat transfer rate due to the addition of A^+ type graphene which has a high surface area of 450 m^2/g.

For sample 6 (Fig. 6e.) increase in combined heat transfer co-efficient over water is 49.34%, 50%,50.22%,50.2%, 49.58%,50%, 51.6%, 52.17 % which is the combined effect of pH and addition of high surface area graphene nanoparticles. For sample 7 (Fig. 6f.) increase in combined heat transfer co-efficient over water is 52.42, 52.61, 52.81, 53.65, 53.4, 53.78, 55.24, 55.73% at flow rates from 0.5lpm to 2.2 lpm. So there is on average 9% additional increase in combined heat transfer over sample5 and when compared with sample 2 (53.5–14.5) there is 39% increase due to synergy effect of chaotic movement, higher surface area and better thermo physical properties of graphene A^+ nano particles.

As shown in the comparative chart Fig. 7 increased flow rate, pH, and better thermo physical properties of graphene all have favourable effects in increasing the combined heat transfer co-efficient. As shown in Table 5 & Fig. 8 as the Reynolds number is increasing Nusselt number is also increasing for all seven samples this is due to an increase in turbulence. It is evident that the Nusselt number also rises with an increase in pH and nanofluid concentration. At Reynolds number 198.53 rate of increase in Nusselt number over water is 15%, 20.8%,24.7%, 41.1%, 47% and 45.5 for sample2 to sample7 respectively. Similarly at Reynolds, number 873.5 rate of increase in Nusselt number over water is15.4%,21.7%,26%,43.5%,49.7%, and 48.6% for sample 2 to sample 7 respectively, and a more or less similar rate of increase in Nusselt number is observed at other Reynolds number considered for the study. With the addition of nanoparticles, there is a significant increase in heat transfer at the boundary layer as constant bombarding of nanoparticles transfers a significant amount of heat from the boundary to the mainstream thereby increasing heat transfer co-efficient and Nusselt number.

4. Conclusions

- Better thermo-physical properties, higher surface area, and low density are the influencing parameters for the superior performance of Graphene nanofluid samples.
- For the three L-type Graphene nanofluid samples 1,2 and 3 at 2.2 lpm of flow rate, the increase in combined heat transfer co-efficient s observed over water are 15.4%, 21.7% and 26% respectively.
- Addition of A-type Graphene in samples 4,5 and 6, which has a high surface area when compared to L type has shown a remarkable effect on enhancing the overall heat transfer co-efficient at any given flow rate. These samples achieved 47%, 52.2 % and 55.73 % higher combined heat transfer co-efficient s over pure water at a flow rate of 2.2 lpm.
- Addition of NH_4OH resulted in a marginal improvement of 5% in the combined heat transfer co-efficient on both types of Graphene
- Rate of increase in combined heat transfer co-efficient is found to be maximum at 2.2 lpm and thereafter it is decreasing. So 2.2 lpm is the ideal flow rate.
- As the A-type Graphene is increased from 0.5gm to 1.0 gm Graphene in 10lts of water rate of increase in viscosity is 10% (10×10^{-4} Pa.s − 9.08×10^{-4} Pa.s) while the corresponding rate of increase in combined heat transfer co-efficient is only 5.9%. So it is suggested to use low particle volume concentration as an abnormal increase in viscosity may lead to more pumping power.
- For any given sample as Reynold's Number is increasing there is an increase in Nusselt Number for all the samples. However, the samples containing NH4OH i.e. sample 6 (683.1 at 2.2 lpm) have the highest increase when compared with other samples. It may be due to the combined effect of an increase in pH due to the addition of NH4OH and the high surface area of Graphene nanoparticles.

5. Future vision

The present work has shown promising results in terms of enhanced heat transfer co-efficient with A-type Graphene nanofluids in a laboratory double pipe heat exchanger. The same can be extended to any real-time applications such as; cooling medium for a water-cooled compressor or any device that uses water-cooled heat exchanger. Use of hybrid nanofluids prepared by mixing two or more different types of nanoparticles is another method of achieving higher heat transfer rates and efficiency that can be explored.

Data availability

No data was used for the research described in the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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