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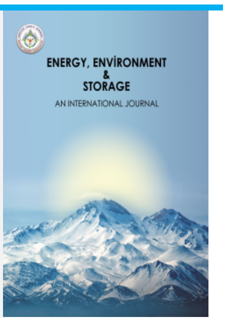

Experimental thermal performance investigation of double pipe heat exchanger using MWCNT/water nanofluid

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ABSTRACT. This paper presents an experimental study investigating the thermal performance of multiwall carbon nanotubes in a twin pipe heat exchanger using a water-based fluid. The research followed a two-step method, where a concentration of 0.01 weight percent of SDS surfactant was utilized to prepare the carbon nanotubes. The heat transfer coefficient, friction coefficient, and overall heat transfer coefficient of the nanofluid were compared to those of the base fluid. The results revealed that the addition of a small amount of multiwall carbon nanotubes significantly enhanced the thermal conductivity and heat transfer coefficient of the water-based fluid. Moreover, the heat transfer coefficient exhibited an increase with higher Reynolds numbers. When the nanofluid flowed counter currently and was in the outer tube, the highest values for the overall heat transfer coefficient and the heat transfer coefficient were determined as 2864 and 7655.7 W/m2K, respectively. The findings indicate notable improvements in the thermophysical and thermal characteristics of the nanofluid.

Keywords: CNT, Water-base fluid, Heat Transfer Coefficient, Heat exchanger, Thermal properties

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1. INTRODUCTION

Nanofluids, a novel class of adaptable fluids, are produced as a result of nanoparticles dispersing in common fluids. These particles are composed of metal fragments such as copper, silver, or metal oxides like aluminium and copper oxide. The dispersion of nanoparticles in common fluids improves their capacity to conduct heat by increasing their thermal conductivity. Micrometer-sized particles were previously added to the fluids to enhance their thermal conductivity; however, these particles lacked the necessary stability in suspension and precipitated too quickly, leading to rapid obstruction of the fluid passageway. In contrast, nanosized particles pose less of a problem as they form considerably more stable suspensions and have slower settling rates. Agglomeration or aggregation is one of the factors affecting the stability of nanofluids. This phenomenon is influenced by several variables, including particle size, particle composition, base fluid properties, and nanofluid preparation.

Carbon nanotubes (CNTs) have recently received attention as nanomaterials with distinctive thermal characteristics. Table 1 lists some works that aim to improve CNT nanofluids' thermal conductivity at room temperature. As determining a nanofluid's thermal conductivity during the preclinical stage is an expensive and time-consuming process, several academics have proposed that we anticipate better conductivity in nanofluids for this purpose.

Water is commonly used in heat transfer due to its high heat capacity and availability. However, water has a low thermal conductivity, and researchers have suggested that incorporating nanoparticles into water at the nanoscale, known as water-based nanofluids, can enhance its thermal properties. Aminian [9] evaluated and tested his neural network model using a total of 1273 experimental results.

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Table 1- Enhancement of CNT nanofluids' thermal conductivity

Ref.	Basefluid	Nanoparticle	Max.Improvement
[1]	Water	MWCNT	38.0%
[2]	Water	CNT	27.3%
[3]	Water	Graphene/MXene	65.34%
[4]	Oil	CNT	138%
[5]	Water	Aluminium Oxide	7.8%
[6]	$CaCO_3$	Y_2O_3	29.18 %
[7]	EG+ Water	CuO Al_2O_3 TiO_2	6.34% 4.87% 3.59%
[8]	EG	SWCNT	14.8%

Table 2- Experimental equations proposed for nanofluid thermal conductivity

Correlations	*Nanofluids*	*Ref.*
$\frac{k_{eff}}{k_f} = 1 + 64.7\varphi^{0.746}(\frac{d_r}{d_p})^{0.369}(\frac{k_p}{k_f})^{0.747} * Pr^{0.9955} * Re^{1.2321}$	*Al_2O_3/Water*	*[13]*
$\frac{(k_{af}-k_{bf})}{k_{bf}} = 0.764\varphi + 0.0186T - 0.46$	*Al_2O_3/Water*	*[14]*
$\frac{(k_{af}-k_{bf})}{k_{bf}} = 3.761088\varphi + 0.017924T - 0.30734$	*CuO/Water*	
$\frac{k_{eff}}{k_f} = A + B\varphi$	*TiO_2/Water*	*[15]*
$\frac{k_{eff}}{k_f} = 0.99 + 0.25(100\varphi) - 0.001T - 0.002d_p - 0.18(100\varphi)^2 + 0.619 * 10^{-5}T^2 + 1.31 * 10^{-5}{d_p}^2 + 0.049(100\varphi)^3 - 7.66 * 10^{-7}T^3$	*Al_2O_3/Water*	*[16]*
$\frac{k_{eff}}{k_f} = 1 + 3.5\varphi + 2.5\varphi^2$	*Al_2O_3/Water*	*[17]*
$\frac{k_{eff}}{k_f} = \frac{\varphi}{0.17581 - 0.0003692(T - 273)} + 1.0026$	*CNT/Water*	*[18]*
$\frac{k_{eff}}{k_f} = \frac{(360.69 + T)}{(455.59 - 11080\varphi)}$	*CNT/Water*	*[19]*
$k_{nf} = k_{bf}(1 + 7.74\varphi)$	Al_2O_3 / SiO_2	*[20]*
$\frac{k_{nf}}{k_f} = 0.9472 - 0.052\varphi + 0.001482T + 0.00663(\varphi * T)$	TiO_2-Ag/ Water	*[21]*
$\frac{k_{nf}}{k_f} = 1 + 6.2299\ (\frac{\varphi}{100})^{0.9371} + (\frac{T}{333})^{10.2685}$	TiO_2-CuO/C/ EG	*[22]*
$\frac{K_{nf}}{K_{bf}} = \frac{\alpha(1 + \beta T)}{1 + \exp\left(\frac{\delta - \emptyset}{\theta}\right)} + \gamma T$	MWCNT/Oil	*[23]*

The key physical characteristics of nanofluids include temperature, thermal conductivity of the base fluids, solid particles, and nanoparticle volume fraction. A total of 26 different types of nanofluids were tested, including Al2O3-water/EG, CuO-water/TO/EG/MEG/paraffin, Al-water/EG/EO/TO, TiO2-water/EG, ZnO-water/EG, SiO2-water/EG/oil, MWCNT-water/EG/oil/R113, and Ag-water. The particle diameter used ranged from 10 to 150 nm.

Lotfi et al. [10] conducted a study on the enhancement of heat transfer using multiwall carbon nanotubes in water within a shell and a metal horizontal heat exchanger. According to their findings, the addition of multilayer nanotubes improved heat transmission compared to the base fluid. Jafargholi et al. [11] examined the flow of nanofluids, including single-walled carbon nanotubes with a water-based fluid, in a double-pipe heat exchanger. The nanofluids circulated as internal cooling and hot water in the annular heat exchanger zone, with a Reynolds number of 8000. The results demonstrated a 25% increase in heat flux compared to pure water when utilizing single-walled carbon nanotubes. Hosseinian & Meghadadi [12] investigated the effects of introducing carbon nanoparticles (5-15 nm) on the heat transfer of a twin-pipe non-metallic PVDF heat exchanger. The findings showed that the heat transfer coefficient increased with increasing temperature, concentration, and flow rate. The most significant enhancement in heat transfer was observed with an increased flow rate. As the concentration and temperature increased, the heat transfer coefficient of the nanofluid improved compared to that of pure water, with the concentration having a greater influence than the temperature. The study also demonstrated that the utilization of carbon nanotubes could increase the heat transfer coefficient by up to 75%, which is a significant improvement compared to other types of nanofluids. Table 2 presents several modified equations developed by various researchers for calculating the thermal conductivity of nanofluids.

Table 3 provides an overview of research conducted on the utilization of nanoparticles in water-based fluids, including the operating conditions and the rate of improvement achieved with different nanoparticles

In an experiment, Balaga et al. investigated the thermal conductivity of f-MWCNT-Fe_2O_3 hybrid nanofluids at different individual component ratios of Fe_2O_3 and f-MWCNT as 4:1, 3:2, 1:1, 2:3, and 1:4 for total weight concentrations of 0.01%, 0.02%, and 0.03% in the range of temperatures from 30 °C to 60 °C. The experimental results showed that the thermal conductivity improved up to 2:3 and then decreased for all total concentrations when the weight ratio of MWCNTs in total weight rose due to the unfavorable effects of MWCNT aggregations. It follows the same pattern as the temperature and overall concentration rise. When comparing 60 °C to 30 °C, the greatest increase in thermal conductivity remained at 13.53% at 0.02% of total weight concentration. Eventually, a correlation based on the experimental findings was developed to predict the thermal conductivity of f-MWCNT-Fe_2O_3/deionized water hybrid nanofluids [41].

Table 3- Thermal conductivity enhancement for water based nanofluid

Ref.	Nano particle	Size (nm)	Φ	Temp.	Enhancement (%)	Method
[23]	MWCNT	15-30	0.25-1	294–344 K	20	-
[24]	MWCNT	10-50	0.25–1	-	11.3	Two step
	SiO_2	12	-		3	
	CuO	33			5	
[25,26]	Ag	60, 63	1-4	323–363 K	125	Two step
[27]	MWCNT	-	0-1	-	19.6	Two step
[28]	MWCNT	100	0-0.6	298 K	38	Two step
[29]	MWCNT	-	0.01-3	15–75 °C	64	Two step
[30]	MWCNT -Ag	-	0-0.04	28-50 °C	37.3	Two step
[31]	Al_2O_3	-	0-0.4	20-50 °C	24	Two step
[32]	Al_2O_3	-	0.5- 6.0	15-40 °C	28	Two step
[33]	Al_2O_3	8–282	1.86-4	297-300 K	20	Two step
[34]	Al_2O_3	36,47	-	5- 40°C	31	-
[35]	Al_2O_3	43	0.33–5		10	-
[36]	ZnO	20-40	0.05-5.0	295-350 K	21	-
[37]	MgO	20,40,50, 60	0.005, 0.01, 0.015, 0.02	-	22	-
[38]	Al_2O_3-CuO	CuO: 29 Al_2O_3: 40 nm	0.5 – 2.0	23 – 25 °C	90–95	Two step Sonication time was 16 h
[39]	Al_2Cu	30,70,100	1-2	-	106	-
	Ag_2Al	-	1-2	-	150-210	-
[40]	MWCNT	-	0.01-0.1	25-60 °C	287	24 h sonication

Huang et al. created EG-water-based MCNT nanosuspensions using a two-step process. The rheological characteristics of prepared samples at various volume fractions and temperatures were examined through either experimental work or theoretical analysis. The findings demonstrated that, when the effective volume percentage of aggregations was taken into account, the experimental viscosity values might have effectively matched the modified K-D model. Additionally, this research revealed an intriguing pattern in the behavior of the viscosity vs. shear rate curve as temperature decreased. The association among MCNT aggregate conditions and temperature was revealed, as well as the variety of shear behavior of nano-suspensions, using the particle aggregation transformation procedure [42].

Dalkilic et al.'s experimental investigation included a measurement of the thermal conductivity of CNT-SiO_2 hybrid nanofluids based on distilled water. Using a two-step process with three different CNT-SiO_2 concentrations and four different mass ranges, nanofluids were created. SiO_2 has a density of 2200 kg/m^3, a thermal conductivity of 1.4 W/mK, and an average particle size of 7 nm. CNT has a density of 2620 kg/m^3, a thermal conductivity of 25 W/mK, and an average particle size of 6–10 nm. Samples spent 3 hours in an ultrasonic homogenizer set at its highest power. In order to prevent changing the volumetric percentage of nanofluids, the temperature of the nanofluids was controlled throughout the sonication process. A thermal conductivity meter was used for all thermal conductivity measurements. Di-water was used to calibrate the thermal conductivity meter. Thermal conductivity was measured at temperatures ranging from 25 °C to 60 °C for every 5 °C. Using di-water, measurements have been validated, and the results were displayed as a thermal conductivity-temperature graph. Details of the minimum and maximum thermal conductivity improvements were published. It has been noted in the literature that thermal conductivity changes with temperature due to different volumetric fractions and that this definitely leads to an increase in thermal conductivity. Figures also showed improvements in the thermal conductivity of di-water at various temperatures and volume fractions. The literature provided almost well-known relationships along with their expected rates. Additionally, this study provided comparisons with other studies. For other researchers, a useful association was suggested [43]. Chandrasekar et al. report on experimental investigations and theoretical determinations of the efficient thermal conductivity and viscosity of Al_2O_3/H_2O nanofluid. In order to create the nanofluid, Al_2O_3 nanoparticles were first synthesized using a microwave-assisted chemical precipitation process, and then they were dispersed in distilled water using a sonicator. For the research, a room-temperature Al_2O_3/water nanofluid with a nominal diameter of 43 nm was used at various volume concentrations (0.3–3%). Measurements of the thermal conductivity and viscosity of nanofluids reveal that the viscosity increase is significantly greater than the thermal conductivity increase. With increasing nanoparticle volume concentrations, nanofluids become more viscous and thermally conductive. The well-known Maxwell and Einstein models are not used in the development of theoretical models to forecast the thermal conductivity and viscosity of nanofluids [44]. Nanofluids, which are a combination of conventional fluids with added nanoparticles of various types and volumes, represent a new class of fluids currently under investigation. The ability to manipulate or design the different thermo-physical properties of these fluids, both collectively and individually, holds significant potential for improving overall system performance. Of particular interest is the potential to enhance the thermal conductivity of these fluids by incorporating nanoparticles made of highly thermally conductive materials. Common base fluids include water, ethylene glycol, oil, and other fluids, while the nanoparticles can be composed of metals, metal oxides, carbon nanotubes, or graphene [45–54].

There is little research on the use of carbon nanotubes in different base fluids, and because carbon nanotubes have a very high thermal conductivity, they have a high potential to improve the thermal properties of water, the most common base fluid in heat transfer applications. Therefore, in the current research, the role of carbon nanotube nanoparticles in the water-base fluid has been investigated.

2. NANOFLUID SYNTHESIS TECHNIQUE

In the current work, carbon nanotubes with a carboxyl group functionalized were employed. These tubes had an inner diameter of 5–10 nm, a length of 10–30 m, and a purity of over 98% by weight. Figure 1 displays the nanoparticles' SEM pictures. The most popular technique for determining the overall morphology of multi-walled carbon nanotube samples, quantitative evaluation of sample purity, and nanotube dimensions is scanning electron microscopy (SEM). This technique can be used to determine the morphology and dimensions of MWCNT (in powder form). The shape of the exterior of multi-walled carbon nanotubes can also be determined. According to ASTM D 4541, a scanning electron microscope using a 20 kV electron beam was used to collect data on the features of the sample's surface. Using measurement software, it was established that MWCNTs had an inner diameter of around 5–10 nm, a length of 10–30 micrometers, and an average distance between layers of 0.34 nm.

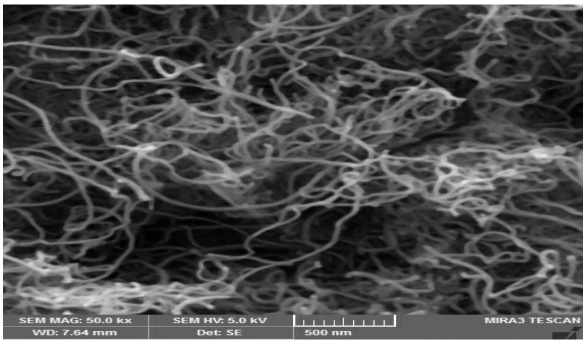

Figure 1 -SEM image of MWCNT

The nanofluid was prepared in a two-step method by adding the specified amount of carbon nanotubes to the aqueous base fluid, placing it on the magnetic stirrer for one hour, and then placing it in an ultrasonic bath for 15 minutes. The 2:1 weight ratio of sodium dodecyl sulfate surfactant was added to the base fluid, placed on a magnetic stirrer at 700 rpm, and finally placed in an ultrasonic bath for one hour, and the water-based carbon nanotube was obtained. In Figure 2, the effect of using an ultrasonic bath in the diffusion and preparation of nanofluids is visible.

Figure 2- Before using ultrasonic bath (a) & Sample after the ultrasonic bath (b)

3. RESULTS

Experiments were done on a double-pipe heat exchanger with an inner tube diameter of 19 mm and an outer tube diameter of 39 mm and a length of 4.5 meters. Thermometers were installed at the entrance of each meter of the outside pipe as well as at the inlet of each pipe to measure fluid temperature. The results were obtained for nanofluids at 0.01 % wt, and the test method was that first pure and hot water were pumped by two pumps with different flow rates, and to check all cases, once cold water was pumped into the outer tube and once into the inner tube, and both counter-current and co-current were examined. The same experiments were done for nanofluids, and the results were compared. To prevent heat loss, the heat exchanger was insulated with glass wool, and the copper heat exchanger was selected. The average temperatures of the hot fluid and the cold fluid in the input and outlet sections were used to calculate the physical parameters of the nanofluid and base fluid. Figure 3 shows the schematic of the apparatus that was used in this research.

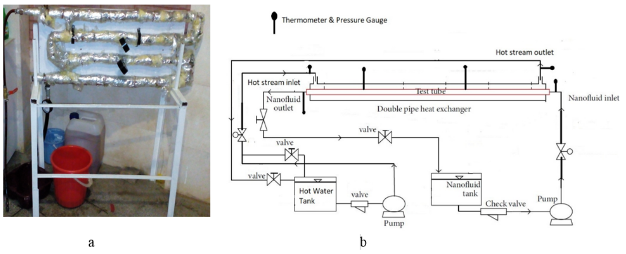

Figure 3- a) Real aparatus b) Schematic of set-up section

First, the thermophysical properties of nanofluid and base fluid, including thermal conductivity and viscosity, have been studied. The density and heat capacity of nanofluid and base fluid were almost the same, so their diagrams were not drawn. In Figure 4.a, the graph of the nanofluid thermal conductivity coefficient versus temperature shows that the samples were tested at three temperatures of 298, 308, and 318 K. It has been demonstrated that when temperatures rose, the thermal conductivity coefficient of nanofluids increased. The increase in both intermolecular collisions and the Brownian motion of the nanoparticles within the base fluid may be to blame for this. The viscosity variations in response to temperature are also depicted in Figure 4.b. These changes are almost linear, with viscosity decreasing with increasing temperature.

Experimental measurements of the viscosity, density, and other physical characteristics of nanofluids have been made and accounted for in the calculations. Plots of the hot and cold fluid pump discharges were made for two cases, four states of the Nusselt number diagram, the overall heat transfer coefficient, the heat transfer coefficient, and the friction factor in terms of Reynolds number.

Figures 5.a to 5.d show the Nusselt number in terms of the Reynolds number. These graphs are plotted for four states, including once considered hot fluid in the inner tube, once in the outer tube, and once flow was co- and counter-current. The mean Nusselt number for nanofluids as well as water increases with increasing Reynolds numbers. This behavior is seen for all nanofluid states, and the highest Nusselt number was 163 that was obtained for the case that the hot fluid was flowing into the outer tube and the flow was counter-current. It can be concluded that when the hot fluid is in the outer tube and the nanofluid is in the inner fluid and the flow is counter-current, it is best to improve the Nusselt number.

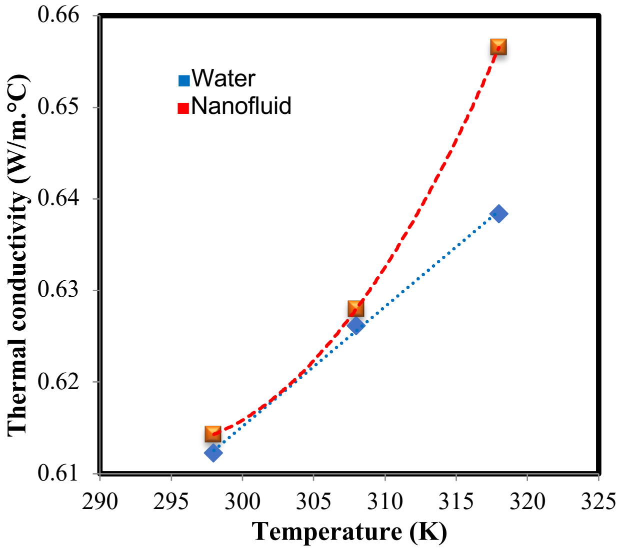

Figure 4.a.- Thermal conductivity coefficient of nanofluids versus temperature

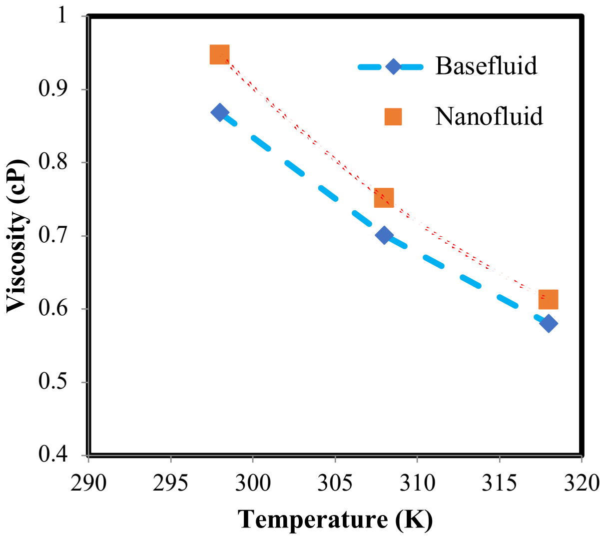

Figure 4.b.- Viscosity of nanofluids versus temperature

The Nusselt number, which measures the ratio of heat transferred through conductors to heat transferred through displacement at the system's boundary, is a measure of heat transfer, and a rise in the Nusselt number denotes a rise in heat transmission. The heat transfer coefficients of the base fluid and the nanofluid in each of the four states are plotted in Figures 6.a to 6.d. The convective heat transfer coefficient reached its highest value of 5226 W/m2.K when the nanofluid was flowing within the inner tube and the current was going against it.

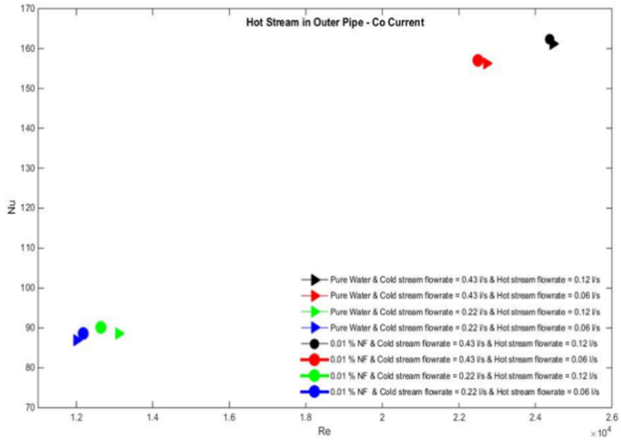

Figure 5.a- Nu vs. Re-Hot Stream in Outer Pipe - Co Current

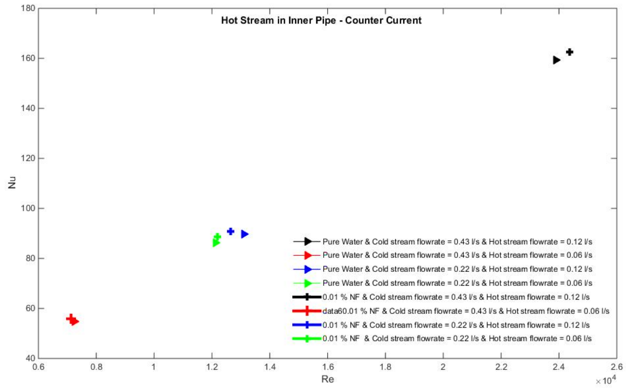

Figure 5.b- Nu vs. Re Hot Stream in Inner Pipe - Counter Current

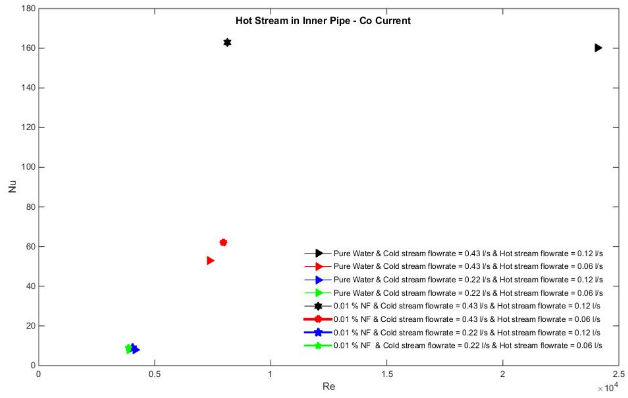

Figure 5.c- Nu vs. Re Hot Stream in Inner Pipe - Co Current

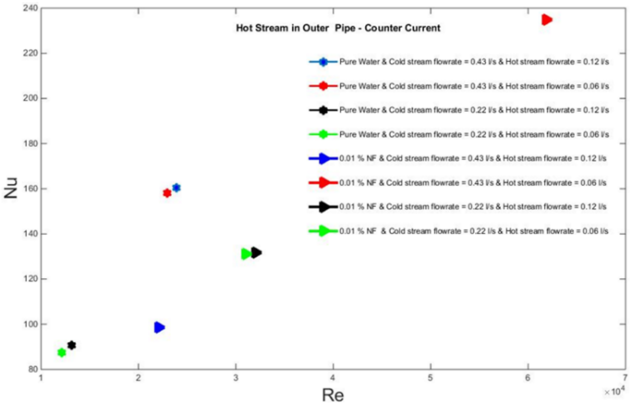

Figure 5.d- Nu vs. Re Hot Stream in Outer Pipe - Counter Current

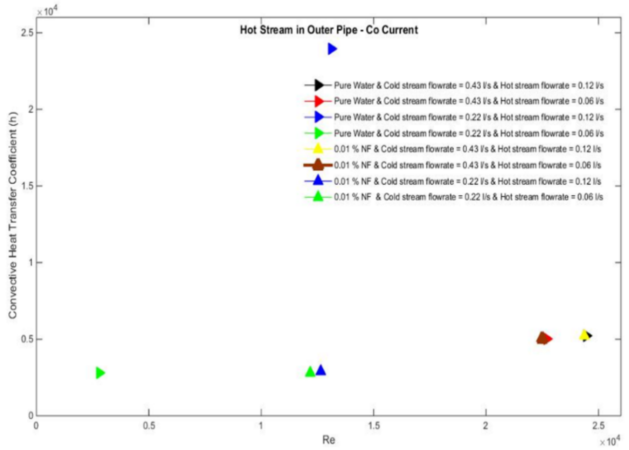

Figure 6.a) h vs. Re Hot Stream in Outer Pipe – Co-Current

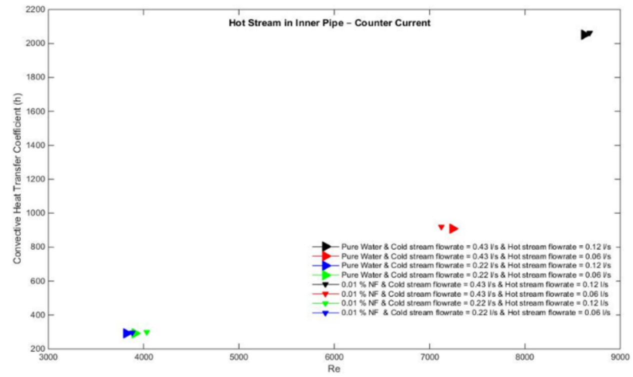

Figure 6.b) h vs. Re Hot Stream in Inner Pipe – Counter-Current

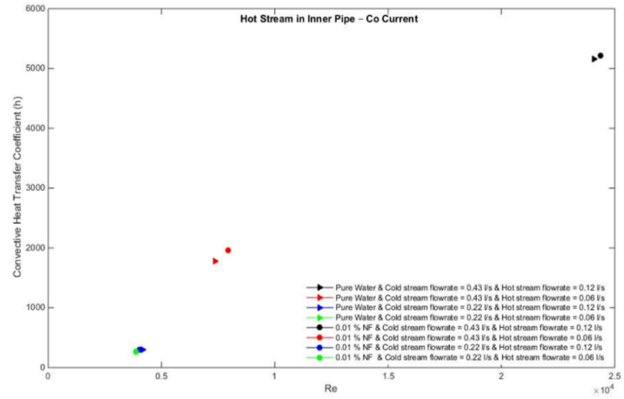

Figure 6.c) h vs. Re Hot Stream in Inner Pipe – Co Current

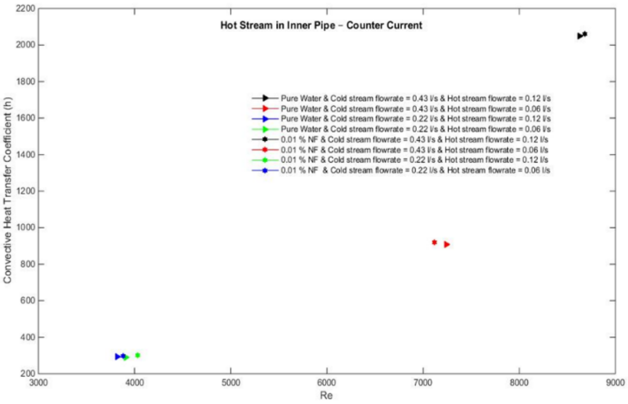

Figure 6.d) h vs. Re Hot Stream in Inner Pipe – Counter Current

The coefficient of heat transfer measured at 5226 W/m2 K, with a hot fluid flow rate of 0.32 kg/s and a cold fluid flow rate of 0.09 kg/s, was maximum whenever the nanofluid had been circulating in the outlet pipe and the movement was counter-current. The rate of heat transfer also rises with growing nanofluid flow and countercurrent, which causes a rise in the coefficient of heat transfer. The heat transfer coefficient (h), which depends on the fluid characteristics, surface roughness, and kind of flow regime, increases as the fluid velocity rises (laminar or turbulence). The Nusselt number is not an appropriate criterion for measuring the increase in heat transfer in nanofluids, so it is recommended to use the convective heat transfer coefficient.

The convective heat transfer coefficient rises as the fluid masses' convective rate rises. On the other hand, the heat transmission will work better if the nanoparticles are evenly dispersed throughout the base fluid, which is consistent with the convective heat transfer coefficient. Fewer nanoparticles are anticipated to boost their transmission efficiency because the number of nanoparticles rises with increased pressure impact as a result of rising transmission costs.

4. CONCLUSION:

In the present study, a nanofluid containing 0.01 wt% carbon nanotubes in a water-based fluid was used, and the method of dispersion of nanoparticles was such that carbon nanotubes were first dispersed in the presence of sodium dodecyl sulfate surfactant. An ultrasonic bath was also used, and the results for the four states were investigated by considering the co-current and counter-current flow for the hot fluid, which was pure water with an inlet temperature of 80 °C, and the nanofluid. In general, the results of this study can be summarized as follows:

- In comparison to pure water, the Reynolds number, the coefficient of heat transfer, and the overall coefficient of heat transfer all increased as the amount of carbon nanotubes increased.
- The nanofluid pressure drop was also investigated, with no significant change in the nanofluid pressure drop relative to the base fluid.

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