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# The Experimental Analysis of the Thermal Performance of a Shell and Tube Heat Exchanger Using a Nanocomposite Fluid

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***Abstract*: Nanofluid is a multiple phase solid liquid fluid that shows promise as a heat transfer fluid. Adding mono nanoparticles to a base fluid to increase heat transmission is a proven approach. Currently, researchers are concentrating on impregnating two or more nanoparticles in hybrid or composite form into base fluids called hybrid or nano composite fluid to increase heat transfer properties. The current work creates a novel nanocomposite particle ($TiO_2$-Ag). The produced nanocomposite particle is characterized using conventional procedures. High Resolution Transmission Electron Microscope (HRTEM) study confirms that silver (Ag) nanoparticles are bonded to the surface of titanium dioxide ($TiO_2$). The XRD peak and EDAX confirm the development of $TiO_2$–Ag nanocomposite particle concentration of silver (Ag) around 9.5 wt.% and titania (TiO2) 90.5 wt.%.**

***Keywords*: Composites, Heat transfer, Nanofluid, Nano particles.**

## 1. Introduction

In the twenty-first century, energy conservation will be one of the most difficult requirements to meet. So, academics, engineers, and scientists keep working on this critical issue. The improvements in industrial heating and cooling save energy, enhance heat transmission, and extend equipment life. Efficient energy utilization may save energy. One way to save energy is by converting it. Heat exchangers are a vital component in energy conservation measures. Heat exchangers are devices that transmit heat from one fluid to another with a temperature difference. It is widely utilized in engineering applications such as chemical, electricity, food, waste heat recovery, air conditioning, and refrigeration.

In a base fluid, nanofluid is a colloidal suspension of nanometer-sized particles (nanoparticles). Nanofluids are two-phase solid-liquid mixtures. Nanofluids are improved heat transfer fluids that may overcome the limitations of traditional fluids such as limited thermal conductivity. Nanofluids have been shown to have excellent thermal conductivity and stability.

Preparation of nanofluids is crucial. There are two main methods: one-step and two-step. A single step produces nanoparticles and disperses them in the base fluid. This approach has various modifications. In one process, called one-step direct evaporation, the nanofluid is created by solidifying the nanoparticles, which are initially gas phase. The two-step approach involves producing nanoparticles and dispersing them in a base fluid. Since inert gas condensation may yield nanoparticles in huge quantities, the two-step process is useful for bulk synthesis of nanofluids.

## 2. Literature Review

Choi (1995) defined nanofluid as a colloidal dispersion of nanometer-sized particles (nanoparticles) in a base fluid. Nanofluids are solid liquid two-phase fluids. Solid nanoparticles in the base fluid improve the effective thermal conductivity and hence the heat transfer properties. Adding a single nanoparticle to a base fluid to increase flow and heat transmission is a proven method. Nanoparticles with thermal conductivities orders of magnitude greater than base fluids and diameters lower than 100nm (Choi 1995).

High thermal conductivities, great stability, and little pumping power loss owing to pressure drop and pipe wall abrasion are advantages of correctly developed nanofluids (Selvakumar & Suresh 2012). Many heat transfer research projects recently focus on impregnating two or more nanoparticles in base heat transfer fluids to increase heat transfer properties.

A new kind of nanofluid, which is prepared by suspending two different types of nanoparticles named hybrid or nanocomposite particles in base fluid, is called hybrid or nanocomposite fluid. A hybrid nanoparticle is a substance which combines physical and chemical properties of different nanoparticles simultaneously and provides the properties in a homogeneous phase. Synthetic hybrid nanoparticles exhibit a remarkable physicochemical property that does not exist in the individual particles (Suresh et al. 2012).

Yarmand et al. (2015) created GNP-Ag nanocomposite powder via chemical reaction. GNP was acid functionalized for 3 hours in a strong acid solution of $HNO_3$ and $H_2SO_4$ (1:3) with bath-ultrasonication. Qadri et al. (2015) employed NaBH4 as a reducing agent to make graphene/cuprous oxide

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nanocomposite. Then 120 mg graphite oxide powder was sonicated for 30 minutes in 200 mL distilled water. A stable graphite oxide colloid was prepared by swirling 72 mg copper chloride (CuCl2) in 200 mL distilled water. In 20ml of distilled water (DI), 75 mg sodium borohydride was added as a reducing agent and the solution was maintained at 100°C for 24 hours. After cooling to 50°C, the solutions were centrifuged and the powder was dried at 100°C under vacuum.

### 3. Preparation and Characterization of $Tio_2$ - Ag Nanocomposite Particle

Sigma Aldrich provided 99 percent Silver Nitrate ($AgNO_3$) ACS reagent and 99.8% Titania ($TiO_2$) (IV) nano-powder with metal base. In addition to ascorbic acid, ethanol was acquired from Changshu Hongsheng Fine chemicals. The compounds employed in this investigation were analytical reagent grade and were not further purified.

The following steps were used to make nanocomposite: Step 1: Stirred and sonicated $TiO_2$ nanoparticles in ethanol for 30 minutes. Step 2: Add silver nitrate dissolved in distilled water to this white colloidal solution was magnetically stirred for 60 minutes. Step 3: Adding ascorbic acid dissolved in distilled water to the step 2 solution yielded a pale grey $TiO_2$-Ag composite colloidal solution. Step 4: This colloidal solution was rinsed many times to eliminate effluents. Step 5: This solution was filtered and dried for 12 hours at 90-100°C. Step 6: Mortar and pestle grinded the $TiO_2$-Ag. Figure 1 depicts the production of $TiO_2$-Ag nanocomposite particles.

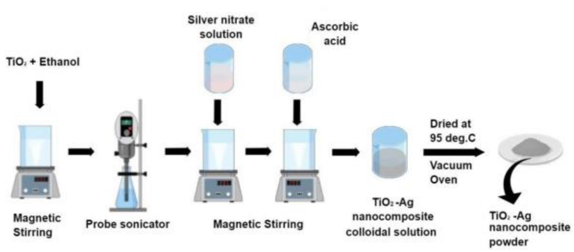



Fig. 1. Synthesis of $TiO_2$-Ag nanocomposite particle

### A. *Characterization of $Tio_2$ –Ag Nanocomposite particle*

Various methods are used to characterize nanocomposite particles. Characterization methods include FESEM, HRTEM with EDAX, XRD, and FT-IR. For topographical and elemental information on nanocomposites, FESEM is used. Compared to traditional SEM, FESEM generates pictures with better spatial resolution. even at 1 nanometre – 3–6 times better. EDAX (energy dispersive X-ray) spectra analysis indicates the composition of nanocomposite particle, XRD pictures show the crystal structure of nanocomposites. FT-IR spectroscopy examines the surface chemistry of solid and liquid particles.

The nanocomposite particle morphology, shape, and size were determined by FESEM (ULTRA 55, Carl Zeiss, Germany), HRTEM (FEI, TITANTHEMIS equipped with EDAX). The Rigaku smart lab X-ray diffractometer identified the $TiO_2$–Ag nanocomposite's crystalline structure. The nanocomposite particle was scanned between 10° and 80° of the 2 positions. FTIR picture produced using Bruker Alpha instrument. Figure 2 shows a FESEM image of a TiO2–Ag nanocomposite particle. In general, nanocomposite particles range in size from 75nm to 220nm.

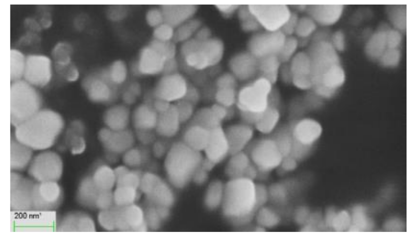
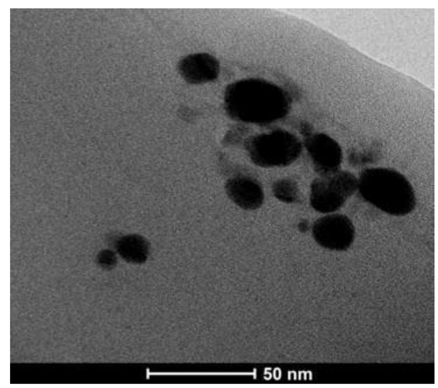
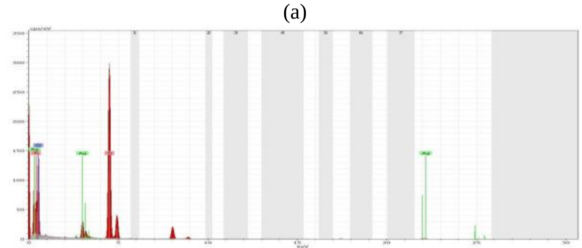



Fig. 2. FESEM image of $TiO_2$ – Ag nanocomposite

The FESEM result is corroborated by HRTEM, as shown in Figure 3(a). The HRTEM picture shows a spherical nanocomposite particle with silver (Ag) nanoparticles bonded to the surface of Titanium dioxide ($TiO_2$). The EDAX spectrum of $TiO_2$-Ag nanocomposite shown in Figure 3(b) significantly supports the creation of $TiO_2$–Ag nanocomposite particle and also validates the presence of Titanium, Silver, and Oxygen components in nanocomposite.




(a)



(b)

Fig. 3. (a) HRTEM image of $TiO_2$–Ag nanocomposite particle and (b) EDAX spectra of $TiO_2$-Ag nanocomposite particle

Due to the strong Bragg reflections created, the XRD peaks confirmed the development of $TiO_2$–Ag nanocomposite particles. Figure 4 shows that the XRD data for the $TiO_2$–Ag nanocomposite particle match the JCPDS File No. 21-1272 and 870720 for $TiO_2$ and silver, respectively. The interplanar spacing peaks are endorsed to the anatase phase of $TiO_2$, and Ag nanoparticles are connected to the surface of $TiO_2$. The Scherrer technique estimates average crystallite size at 65 nm, which is in line with previous characterization investigations like FESEM and HRTEM.

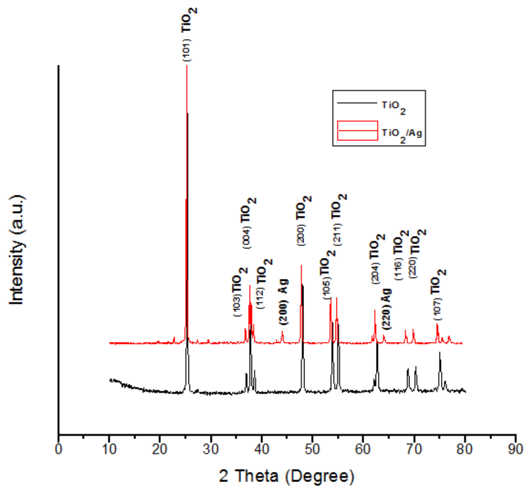


Fig. 4. XRD image of $TiO_2$–Ag nanocomposite particle

Figure 5 shows the FT-IR spectra recorded in the 500–4000 cm-1 wavenumber band. The stretching vibration of the hydroxyl group produces a strong wide band about 3420 $cm^{-1}$. This was induced by Ti–O–H stretching vibrations (Yuan et al. 2010). The spectral peak at 3451$cm^{-1}$ verifies the existence of hydroxyl (OH) groups. Similarly, the band about 1630 $cm^{-1}$ is due to the H–O–H bond bending vibration on $TiO_2$. The resulting spectra has a peak at 1604 $cm^{-1}$. This illustrates physically adsorbed water and hydroxyl group vibrations stretch and flex on oxide surfaces (Ahmed et al. 2013). The band between 880 and 450 $cm^{-1}$ is connected with $TiO_2$ vibrational modes (Zhao et al. 2007). The resulting spectra shows a prominent band about 766 $cm^{-1}$.

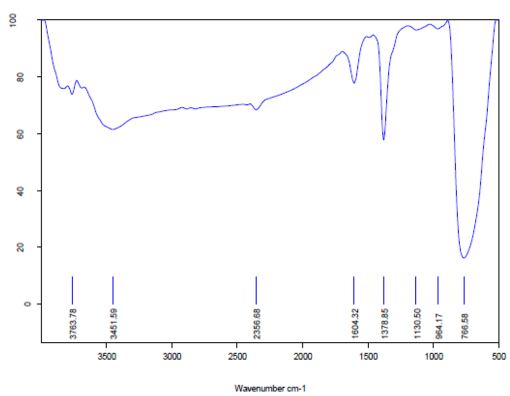


Fig. 5. FT-IR spectrum of $TiO_2$-Ag nanocomposite particle

### 4. Preparation, Properties and Stability of $TiO_2$ – Ag/Distilled Water Nanocomposite fluid

Thermal conductivity, viscosity, density, and specific heat are essential nanofluid qualities. This chapter measures and presents two important properties in heat transfer studies: thermal conductivity and viscosity. Stability is one of the main obstacles to long-term practical use of nanofluids. Sedimentation test and zeta potential are two regularly used procedures to assure stable dispersion of nanocomposite particles in base fluid. Nanocomposite particle ($TiO_2$-Ag) is weighed using a high precision weighing scale (ATY224 SHIMAZDU). The density of nanocomposite particles is 4825.6 $kg/m^3$. 2 Steps to create $TiO_2$-Ag/distilled water nanocomposite fluid Ultrasonication is the most effective method for dispersing nanoparticles, resulting in a homogeneous suspension of nanoparticles in the base fluid. For the manufacture of nanocomposite fluid, a probe sonicates (Rivotek Ultrasonic Processor Sonicates Stainless Steel probe tip, 30 kHz, 120 W) was used. First, add the needed amount of $TiO_2$-Ag nanocomposite particle to the base fluid (distilled water) and mix for 30 minutes at 650 rpm. On the probe sonicate, the solution is ultrasonically pumped at 30 kHz for 15 seconds on, 15 seconds off. Sec OFF digital cyclic timer for nanoparticle dispersion in the base fluid. Preparation of nanocomposite fluids with $TiO_2$–Ag concentrations of 0.1–0.4 vol% in distilled water.

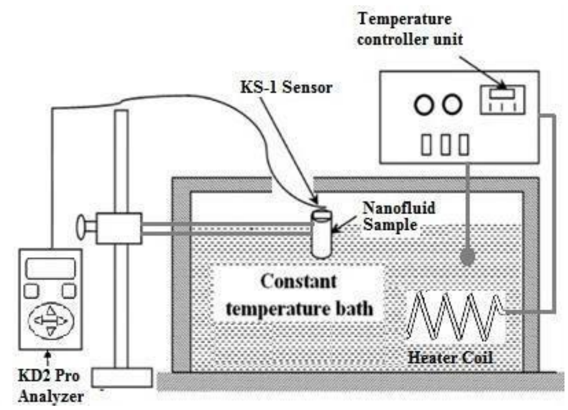


Fig. 6. Thermal conductivity measuring unit

Thermal conductivity of nanocomposite fluid as a function of volume concentration and temperature. It is 0.68 W/mK at 35°C for volumetric concentrations of 0.1, 0.2, 0.3, and 0.4. At 60°C, 0.4 vol% nanocomposite fluid has maximum thermal conductivity of 0.904W/mK. $TiO_2$-Ag/distilled water thermal conductivity rises by 10.62, 11.60, 8.75, and 22.10 percent from 35°C to 60°C, respectively. As shown in Figure 7, the thermal conductivity of the $TiO_2$-Ag/water nanocomposite fluid is linearly related to temperature.

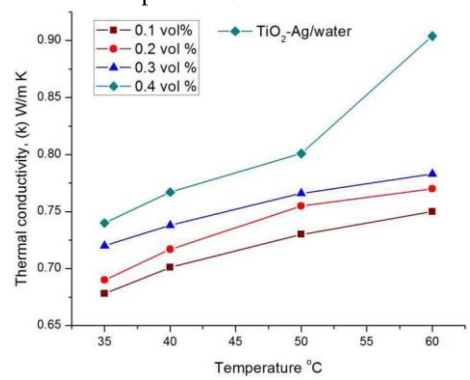


Fig. 7. Thermal conductivity for $TiO_2$-Ag/distilled water

Moreover, during thermal conductivity measurements, nanocomposite particle breakdown occurred for 0.3 and 0.4 % $TiO_2$-Ag/water at higher temperatures The increased kinetic energy of nanocomposite particles in high temperature liquids enhances the collision effect and hence increases the thermal conductivity of nanocomposite fluids as seen in the thermal conductivity plot for 0.4 vol% $TiO_2$-Ag/water at 60°C. However, increasing collision increases agglomeration, leading to faster and more sedimentation of nanocomposite particles. Figure 8 shows that at 0.3 and 0.4 volumetric concentrations, $TiO_2$ and Ag nanocomposite particles dissociate, generating two unique colour fluids: light grey (Ag/water) at the bottom and milky white ($TiO_2$) at the top.

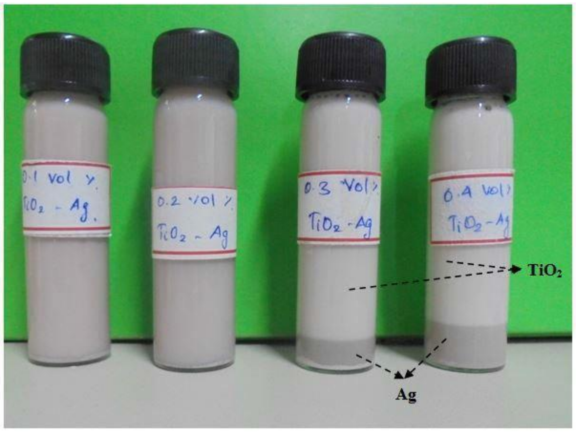



Fig. 8. Disassociation in $TiO_2$-Ag/distilled water

The thermal conductivity investigation shows that 0.2 vol% has a greater thermal conductivity than 0.1 vol%. A zeta potential test is used to assess the stability of 0.2 vol% $TiO_2$-Ag/distilled water.

Table 1
Regression parameters of proposed models for $TiO_2$-Ag/water

| Models | MSE | RMSE | S | R-sq | R-sq (adj) |
|---|---|---|---|---|---|
| Model 1 | 0.0008536 | 0.02921 | 0.0325 | 80.95% | 78.01% |
| Model 2 | 0.0006203 | 0.0249 | 0.0286 | 86.13% | 82.65% |
| Model 3 | 0.0004586 | 0.02146 | 0.0274 | 90.43% | 84.04% |

The best model's margin of deviation (MOD) and absolute average deviation (AAD) are also examined (AAD percent). Figure 9 shows the MOD for all developed models. Each model's maximum MOD is 6.62 percent, -4.9 percent, and -3.9 percent. Models 1, 2 and 3 have minimal MODs of 0.48, 0.1% and -0.15%. The absolute average deviation (AAD%) of models 1, 2 and 3 is 1.7%, 1.5% and 1.3%, respectively. The thermal conductivity of nanocomposite fluids rises with temperature and fraction. The dependent parameters for forecasting the thermal conductivity ratio are temperature (T) and volume concentration (V). The present work develops regression equations for the thermal conductivity ratio of nanocomposite fluids using curve fitting. Model 1 is linear, Model 2 and 3 are nonlinear. Model 2 contains the interaction (T) and Model 3 includes a higher degree of predictors. The adjusted R2 may be used to compare the explanatory power of models with varying predictor counts.

The modified R2 increases only if the additional term improves the model beyond chance. Adjusted R2 drops as terms are increased. Model 3's R2 and R2 (adj) are better than Models 1 and 2. Model 3 likewise exhibits lower MSE, RMSE, and S than Models 1 and 2. Figure 10 compares the expected and experimental values. With its low error and high accuracy, Model 3 may be used to forecast the thermal conductivity ratio of nanocomposite fluids.

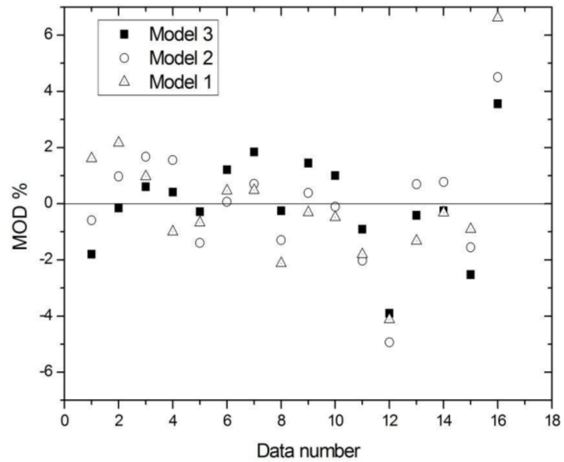



Fig. 9. MOD of developed models for $TiO_2$-Ag/distilled water

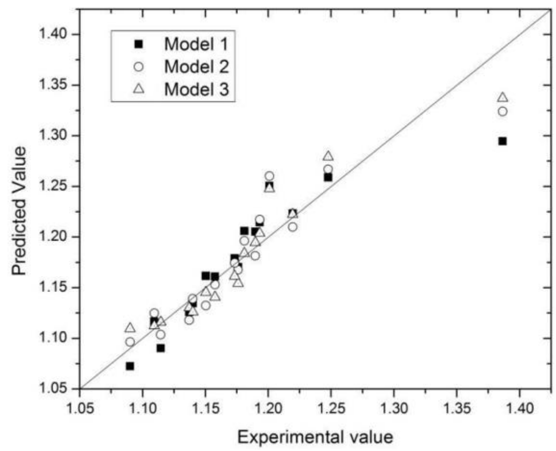



Fig. 10. Prediction of TCR for $TiO_2$-Ag/distilled water

## 5. Performance Investigation of Shell and Tube Heat Exchanger

Figure 11 depicts the experimental setup of the horizontal shell and tube heat exchanger employed in this study. There are two 0.5 hp pumps to circulate shell and tube fluids, thermocouples (K type) to detect temperatures at inlet and outlet for both shell and tube fluids, two float type flow meters to measure volume flow rate of fluids. The shell fluid (hot water) inlet temperature is controlled by a heater and thermostat, while the tube fluid input temperature is controlled by a vapor compression cycle refrigerator chilling tank. Table 2 lists the characteristics of the experimental shell and tube heat exchanger.

## 6. Results, Discussion and Conclusion

Assume that the tube side heat transfer coefficient, total heat transfer coefficient, and heat transfer rate are all constant. Comparing 0.2 vol% $TiO_2$-Ag/distilled water nanocomposite fluid to ordinary fluid water.

The volume flow rate ($V_t$) of the tube fluid (water and $TiO_2$-Ag/distilled water nanocomposite fluid) is varied in this investigation. The shell fluid flow rate is 2 lpm at 40°C. Figure 13 plots the computed tube side heat transfer coefficient vs tube fluid flow rate. Both base fluid and nanocomposite fluid heat transfer coefficient rises linearly with volume flow rate. Nanocomposite fluid has a greater heat transfer coefficient than base fluid at all flow rates. Thermal conductivity affects convective heat transfer coefficient and TBL thickness Due to the mobility of nanocomposite particles along the tube inner wall, the heat transfer coefficient of nanocomposite fluid is greater than traditional fluid (Wen & Ding 2004).

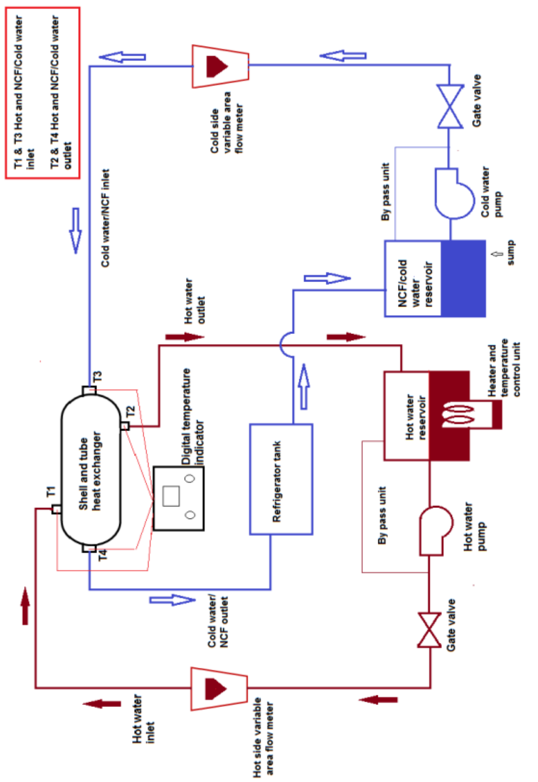



Fig. 11. Schematic view of shell and tube heat exchanger experimental set up

Table 2
Specification of shell and tube heat exchanger

| Descriptions | Specifications |
|---|---|
| Type of heat exchanger | Passage of a single shell and a single tube |
| The shell's inner diameter (Di) | 56 mm |
| The shell's outer diameter (Do) | 64 mm |
| The tubes outside diameter (do) | 14 mm |
| The tube's inner diameter (di) | 11 mm |
| the number of tubes | 4 |
| The baffle cut | 26% |
| The distance between baffles. (B) | 28.5 mm |
| length of the tube | 750 mm |
| Tube configuration | Square |
| Material for the shell and tube | Copper and stainless steel |
| A/C unit<br>Shell inner diameter (Di)<br>Shell outer diameter (Do)<br>Tube outer diameter (do)<br>Tube inner diameter (di)<br>Tubes<br>Snip a<br>Baffle spac (B)<br>Tube Length Tube Layout<br>Insulation in shell and tube | Foam and glass wool |

Fig. 12. Photographic view of experimental set up

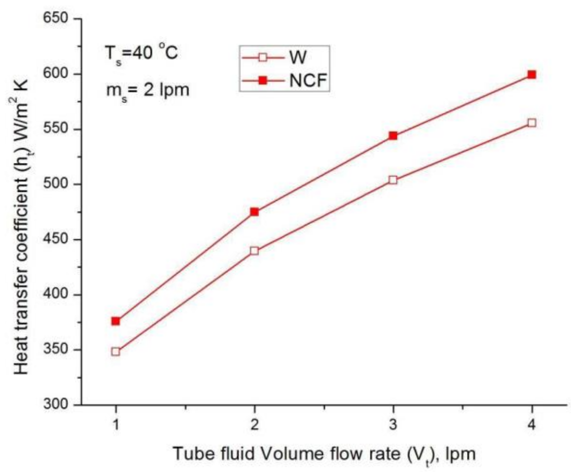



Fig. 13. Heat transfer coefficient for different tube fluid volume flow rates

The current research focuses on the development of a novel type of nanocomposite fluid ($TiO_2$-Ag/distilled water) and the performance enhancement of shell and tube heat exchangers utilizing the nanocomposite fluid as a coolant (water). The following are the research findings:

1. The sol-gel process is used to create $TiO_2$-Ag nanocomposite particles. To establish that the synthesized particle is a nanocomposite, standard characterization methods such as FESEM, HRTEM, EDAX, XRD, and FT-IR are used.
2. The FESEM picture confirms that the nanocomposite particles are spherical in form and range in size from 75 to 220 nm. The HRTEM picture verifies the spherical form and also demonstrates the presence of silver (Ag) nanoparticles on the Titanium dioxide surface ($TiO_2$). The existence of Titanium, Silver, and Oxygen elements in the nanocomposite is confirmed by EDAX analysis, and the quantity of silver (Ag) in the nanocomposite is around 9.5 weight percent, while the amount of $TiO_2$ is approximately 90.5 weight percent. The XRD peaks confirmed the production of TiO2–Ag nanocomposite particles by demonstrating the development of strong Bragg reflections indexed

to the relevant lattice planes. Average crystallite size of nanocomposite particle, using Scherer method, is estimated as 65 nm which is in good concord with the results obtained from the other characterization studies like FESEM, HRTEM. The chemical structure of the nanocomposite particle is identified by FT-IR spectroscopy analysis.

3. The nanocomposite fluid ($TiO_2$-Ag/distilled water) is made in two steps using $TiO_2$–Ag concentrations of 0.1, 0.2, 0.3, and 0.4 vol. percent in distilled water.
4. The thermal conductivity of the nanocomposite fluid is determined for all volume fractions and fluid temperatures (35, 40, 50, and 60°C) using the KD2 Pro instrument. The thermal conductivity of the nanocomposite fluid is greater than that of the traditional fluid, water, at any volume fraction and temperature. Additionally, when volume concentration and temperature increase, the thermal conductivity of the nanocomposite fluid increases. At 60 degrees Celsius, the thermal conductivity of the base fluid distilled water is 0.621W/mK. At 60°C, the 0.4 vol. percent nanocomposite fluid has a maximum thermal conductivity of 0.904W/mK. Thermal conductivity of $TiO_2$-Ag/distilled water rises by 10.62, 11.60, 8.75, and 22.10 percent for 0.1, 0.2, 0.3, and 0.4 vol. percent, respectively.
5. Thermal conductivity measurements indicate that disintegration of nanocomposite particles occurred at higher temperatures for 0.3 and 0.4 vol. percent $TiO_2$-Ag/water due to the accelerated collision of $TiO_2$ and Ag nanocomposite particles, resulting in the formation of two distinct color fluids with light grey fluid (Ag/water) at the bottom, and white milky fluid ($TiO_2$) at the top. Thus, 0.2 vol. percent, which has a greater thermal conductivity than 0.1 vol. percent, was chosen for the research of Shell and tube heat exchanger performance.
6. At various temperatures, the viscosity of the 0.2 vol. percent nanocomposite fluid is tested. With increasing temperature, the viscosity of $TiO_2$–Ag/water nanocomposite fluid reduces. At 35°C, the viscosity is 0.001444 $Ns/m^2$, whereas at 60°C, it is 0.000788 $Ns/m^2$.
7. Additionally, the nanocomposite fluid is found to be stable, having a zeta potential of -24.1mV.

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