E3S Web of Conferences **286**, 01009 (2021) https://doi.org/10.1051/e3sconf/202128601009
TE-RE-RD 2021

The Heat Transfer Performance of MWCNT, CuO, and Al_2O_3 Nanofluids in an Automotive Engine Radiator

Karaar Mahdi Al-Araji[1*], *M. A.* Almoussawi[1] and *Kareem* J. Alwana[2]

[1]Department of Power Mechanics Engineering, Engineering Technical Collage / Al-Najaf, Al-Furat Al-Awsat Technical University (ATU), 31001 Najaf, Iraq
[2]Al-Furat Al-Awsat Technical University, Najaf Technical Institute, 31001, Iraq

Abstract. The effect of enhancing heat transfer using three nanofluids, Multi-Walled Carbon Nanotubes MWCNT, Copper oxide CuO, and aluminum oxide Al2O3, have been experimentally studied on the automotive radiator with a concentration of 1% vol and different flow rates (4-8) l/min, air velocity of 3 m/s and inlet temperatures range (60-80) °C. The results showed that the use of nanofluids improved the thermal performance compared to the base fluid. Using the (MWCNT-Water) achieved 41.7% of Nusselt number where as, copper oxide (CuO) and aluminum oxide (Al2O3) have improved the Nussult number by 31.7 % and 12.3 % respectively. The Nusselt number showed an increase with the increase in the flow rate and the inlet temperature.

Keywords: Nanofluid, Al_2O_3, CuO, MWCNT, Automotive engine radiator, Nusselt number.

1 Introduction

The Environmental Protection Agency EPA imposes strict standards on automobile manufacturers to protect the environment from the influence of emissions of combustion engine exhausts. One of the essential things in reducing pollution and increasing engine performance is to improve the automotive cooling system. Nanofluids are new technology which consists of tiny particles (less than 100 nm) suspended in conventional cooling fluids (water and/or ethylene glycol) [1]. Many experiments on nanofluids performance as a coolant in automotive radiators in order to improve the performance and reduce the radiator's size have been carried out in the last decades. **Chaurasia et al**.[2] conducted an experimental study on a mixture of nanofluid (alumina with distilled water) at a concentration of 0.1%, 0.15%, and 0.2% with different flow rates and different temperatures. They found that a concentration of 0.2% of nanofluid has increased the heat transfer rate by 44.29%. **Topuz et al**. [3] carried out an experimental investigation on nanofluid containing aluminum oxide Al2O3 nano-particles mixed with water and ethylene glycol (50-50%), 0.5% concentration with different flow rates and fixed temperature 95 °C.

* Corresponding author: karaar.mahdi@gmail.com

Results showed an increase in cooling performance by 15% compared to the base fluid. **Ravisankar et al**.[4] applied an experimental and numerical study to reveal the performance of nanofluid (CuO with water) on a tractor radiator with a concentration of (0.025, 0.05%) and turbulent flow ($8000 \leq Re \leq 25000$). They found that the overall heat transfer coefficient has increased by 4% at a concentration of 0.05%. **Ali et al**.[5] studied experimentally the improvement in the heat transfer of automobile radiators using (MgO + water) nanofluid at different flow rates (8-16) l/min and different volume fraction. The study showed a 31% increase in the heat transfer rate at a concentration of 0.12%. **M'hamed et al**. [6] applied a nano-coolant fluid mix of MWCNT with water and EG at a 50-50% ratio on the Proton Kelisa 1000cc automobile engine. A volumetric concentration of 0.1 to 0.5% and a different flow rate with the laminar flow were suggested. Results showed an increase in the average heat transfer coefficient by 196.3% at a concentration of 0.5%. In the current study, nanofluids and their effect on automotive coolants are studied. The main aim is to enhance the average Nusselt number of the nanofluid as a coolant at the laminar flow conditions. Also, to overcome emissions of harmful gases and pumping power, to improve fuel consumption, and to reduce automotive radiators' size.

2 Materials and Methods

2.1 Preparation of Nanofluid

The nanoparticles used in the current study are multi-walled carbon nanotubes MWCNT, Copper Oxide CuO and Aluminum Oxide Al_2O_3, the characteristics of nano-particles are shown in Table 1. The nanoparticles were suspended at a volume fraction of 1% with pure water (pH 6.6). An ultrasonic for 3 hours with a frequency of 37 kHz and 100 Watts was used to produce the nanofluid. The particles' stability was monitored for 15 days and no sedimentation of nanoparticles was found during this period when a surfactant (gum Arabic GA) was added to increase the nanofluid stability [7]. The prepared samples are shown in Fig.1

Table 1. The characteristics of nanoparticles

Details	**MWCNT**	**CuO**	**Al_2O_3**
Appearance	Black powder	Dark brown powder	White powder
Purity	99%	99%	99.99%
Size (nm)	D: 30-60 nm L: 5-20 um	D: 30-50 nm	D: 20-30 nm
Thermal conductivity (W/m.K)	3000	76.5	46
Density (kg/m^3)	2100	6400	3890
Specific heat (j/kg.K)	769	531	778

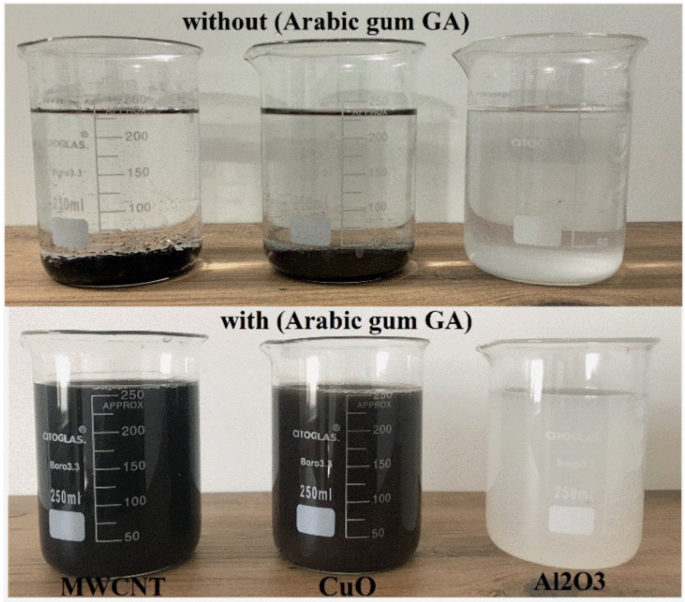

Fig 1. A Photograph showing the effect of Arabic gum on nanofluids stability

2. 2 Experimental Work

Fig. 2 shows the rig test carried out to study the three nanofluids' thermal performance. It contains a coolant tank with 30 liters with a heater capacity of 3000 watts. The liquid's temperature is controlled by a thermostat placed on the heater with a range (40 - 80) °C. The centrifugal pump speed and the amount of flow are controlled by a frequency converter (AC driver), flow meter instrument, a pressure gauge to measure the inlet and outlet coolant pressure of radiators, insulated pipelines with diameter 0.5", two thermocouples (k-type) to measure the inlet and outlet temperature of the fluid, six thermocouples (k-type) attach to the surface of the tube are distributed as shown in Fig 3 to record the temperature of the tube surface. Automotive engine radiators with 60 vertical finned flat tubes, their specifications and dimensions are listed in Table 2. An axial fan with airflow speed 3 m/s was fixed to the radiator to simulate the radiator cooling engine. The study was conducted at different temperatures range 60, 70, 80 °C for three types of nanofluids at a concentration of 1%. The ambient temperature was 25 °C, and the flow rate of (4-8) liters per minute.

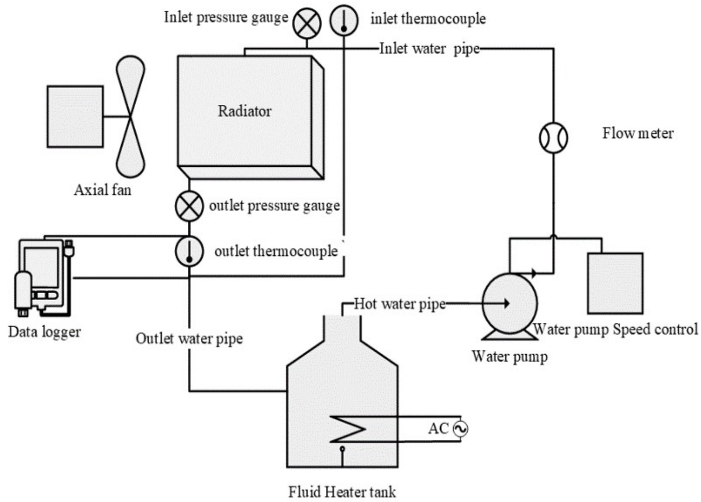

Fig 2. Schematic drawing of the experimental test rig.

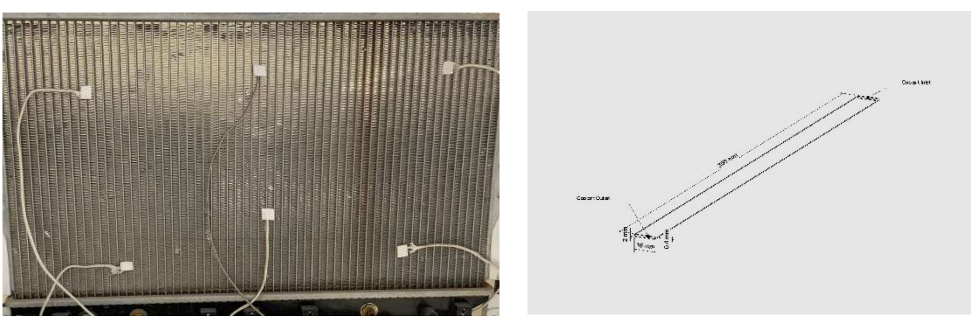

Fig 3. Thermocouple distribute on radiators and the dimension of the tube

Table 2. Dimension of the radiator in this study

Description	Specification
Tube length	350 mm
Tube height	16 mm
Tube width	8 mm
Thickness of tube	0.4 mm
Height of fins	16 mm
Width of fins	8 mm
Thickness of fins	0.09 mm
Material	Aluminum

2.3 Nanofluid Physical Properties

The following equation was used to evaluate the volumetric concentration of the nanoparticles and the amount of liquid. [8]. Nanofluid concentration is φ = 1 vol%, and the inlet temperature range of the coolants is 60-80 °C. where φ is the volume concentration

$$\varphi = \left[\frac{\frac{W_p}{\rho_p}}{\frac{W_p}{\rho_p} + \frac{W_{bf}}{\rho_{bf}}}\right] \times 100 \quad (1)$$

The following equations evaluate the effective thermal properties such as density, specific heat, viscosity, and thermal conductivity at various temperatures. Where (r) Density, kg/m^3, (Cp) Specific heat J/kg., (*bf*) base fluid, (*nf*) nanofluid, (*p*) particles.

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_p \quad (2)$$

$$Cp_{nf} = (1-\varphi)Cp_{bf} + \varphi Cp_p \quad (3)$$

By (Maxwell) model of the effective thermal conductivity for (Al_2O_3, CuO) nanofluids have approximate.

$$K_{nf} = \frac{K_p + 2K_{bf} - 2(K_p + K_{bf})\varphi}{K_p + 2K_{bf} - (K_p - K_{bf})\varphi} * K_{bf} \quad (4)$$

The (Hamilton and crosser) model of the effective thermal conductivity for (MWCNT) nanofluids have approximate. [9] where the (k) Thermal Conductivity, W/m. K.

$$K_{nf} = \frac{K_p + (n-1)K_{bf} + (n-1)(K_p + K_{bf})\varphi}{K_p + (n-1)K_{bf} - (K_p - K_{bf})\varphi} * K_{bf} \quad (5)$$

Thus, the effective dynamic viscosity is calculated by using the (Brinkman) model, where (μ) the dynamic viscosity Pa.s

$$\mu_{nf} = \frac{\mu_{bf}}{(1-\varphi)^{2.5}} \quad (6)$$

2.3 Data Extraction

According to Newton's cooling law Eq (7), the heat transfer rate can be measured by.[10]

$$Q = h\,As\,(T_b - T_w) \quad (7)$$

$$Q = \dot{m}\,Cp\,(T_{in} - T_{out}) \quad (8)$$

$$\dot{m} = \rho\,V\,A_{in} \quad (9)$$

Where (Q) heat transfer rate, (Cp) specific heat, (T_{in}) inlet temperature and (T_{out}) outlet temperature, ($\dot{m}$) mass flow rate and (ρ) density of fluid; (V) velocity of the liquid and (A_{in}) the inlet area of the flat tube.

The heat transfer coefficient and the Nusselt number were calculated using the following equation:[6]

$$h = \frac{\dot{m}\, Cp\, (T_{in} - T_{out})}{A_s(T_b - T_{w)}} \qquad (10)$$

$$Nu = \frac{h * D_h}{K} \qquad (11)$$

$$D_h = \frac{4 \times [\pi d^2 (D - d) * d]}{\pi\, d + 2 * (D - d)} \qquad (12)$$

Where (D_h) is hydraulic diameter, (k) the fluid thermal conductivity. (A_s) the flat tube surface area, (T_b) is the bulk temperature which is supposed to be the average temperature of the inlet, and (T_w) is the wall temperature.

3 Result and Discussion

3.1 Base Fluid (water)

Before starting experimental work on nanofluids in the radiator, it is necessary to conduct experiments on the same base fluid (pure water) and verify that the receiver operates under the same operating conditions of temperature and flow rate to compare results. It's also necessary to compare the Nusselt number measured from the experimental data with the predictions and other correlations for accuracy and reliability. There are three correlations; the first is suggested by (Dittus-Boelter) Eq.13 [11], the second developed by the researcher (Dehghandokht et al.) Eq.14 [12] and the last one was presented by (Sieder -Tate) Eq.15 [13]. Where the (Re) Reynolds number, (Pr) Prandtl number, (L) tube length.

$$\mathrm{Nu} = 0.0236 * \mathrm{Re}^{0.8} * \mathrm{Pr}^{0.3} \qquad (13)$$

$$\mathrm{Nu} = 0.951 * \mathrm{Re}^{0.173} * \mathrm{Pr}^{\left(\frac{1}{3}\right)} \qquad (14)$$

$$\mathrm{Nu} = 1.86 * \left(\frac{\mathrm{Re} * \mathrm{Pr}}{\mathrm{L}/\mathrm{D_h}}\right)^{0.3} * \left(\frac{\mu}{\mu_s}\right)^{0.14} \qquad (15)$$

Fig 4. shows the experimental result for the base fluid (distilled water), which showed a good agreement with the (Sider-Tate) correlation at the fluid inlet temperature of 80 ° C. However, increasing the Reynolds number has led to an increase in the Nusselt number, where the error rate according to equation (15) was 6.7 %, while the error rate for the other correlation was 35% for Eq.13 and 39.8% for Eq.15.

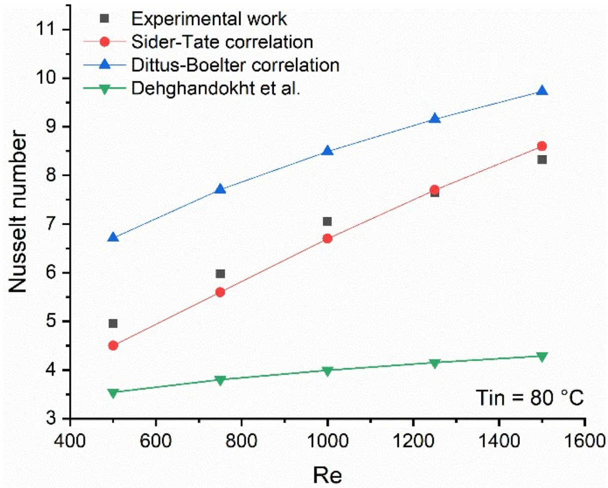

Fig 4. Comparison of the Nusselt number found from the experimental work with that resulted from different correlation

3.2 Nanofluid

Fig 5 shows the outlet temperatures of nanofluids compared to the base fluid at an inlet temperature of 80 ° C with different flow rates. The outlet temperature has decreased when using nanofluids; the highest enhance in the outlet temperature was achieved when MWCNT nanofluid has been used with an increase of 3.2% compared to the base fluid, copper oxide CuO and aluminum oxide Al_2O_3 showed lower values.

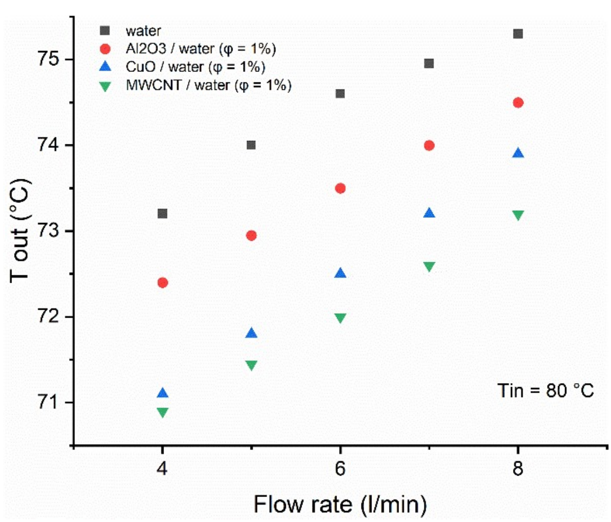

Fig 5. Comparison of the outlet temperature of the different nanofluids with the base fluid

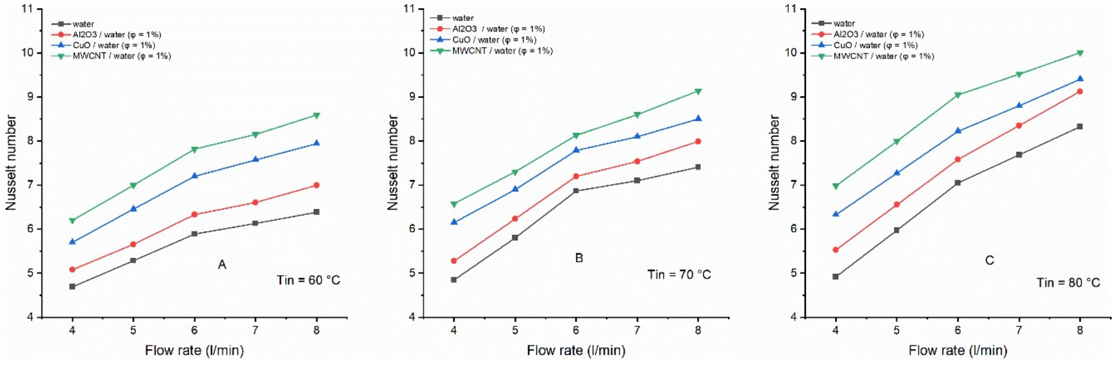

Fig 6. The effect of flow rate on Nusselt number at different inlet temperatures of nanofluids, A)60°C, B)70 °C, C) 80 °C

Fig 6. shows the enhancement of the nanofluids of (MWCNT, CuO, Al_2O_3) at different temperatures and flow rates. Also, increasing the flow velocity leads to an increase in the Nusselt number, Dattatraya et al.[10] found that Nusselt number increased by 12% when using a nanofluid at 80 ° C inlet temperature by increasing the flow rate from 7.63 to 8.82 l/min, this is the result of increasing the convection heat transfer rate, this also occur when increasing the nanofluid inlet temperature as a result of the decrease of specific heat of nanofluid which in turn lead to increase the rate of heat transfer[14].

Fig 7. shows the thermal performance enhancement represented by the ratio of the Nusselt number for the nanofluid to the Nusselt number for the base fluid of automotive radiator at an inlet temperature of 80 °C and a different flow rate. The highest improvement 41.8% was found in the flow rate of 4 l/min in the MWCNT nanofluid, while for the CuO nanofluid was 31.7 % and for the Al2O3 nanofluid was 12.3 %. The amount of heat transfer is more effective when the flow rate low with constant air velocity ambient temperature.

The main cause of enhancement of heat transfer rate can be attributed to the improve in the nanofluid's thermal properties (especially the thermal conductivity and specific heat) compared to the base fluid heat as showen in table 3. As well as, many research studies attributed this thermal improvement to Brownian motion, which causes random movement of particles in the fluid. Heris et al.[15] found that the thermal improvement rate was increased by 40% when using water-Al_2O_3 with a turbulent flow rather than laminar flow.

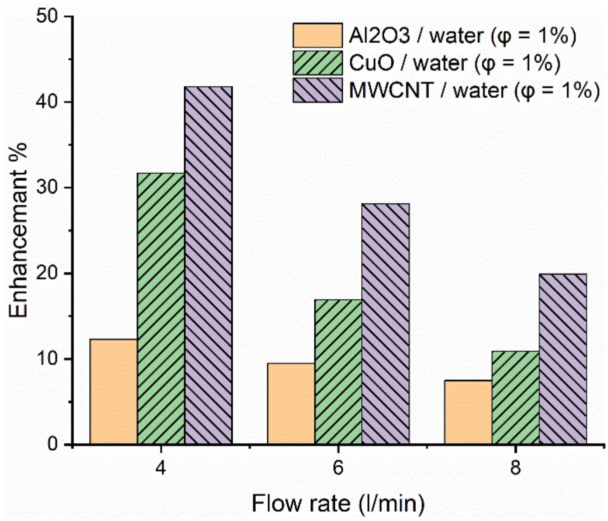

Fig 7. Variation of thermal enhancement in automotive radiators for different nanofluids at a volume concentration of 1%.

Table 3. The specific heat and thermal conductivity of nanofluids at a volume concentration of 1%.

Fluid	Volume fraction (%)	Specific heat (J/kg.K)	Thermal conductivity (W/m.K)
Water	0%	4200	0.667
Al_2O_3	1%	4162.81	0.684
CuO	1%	4160.34	0.688
MWCNT	1%	4154.96	0.707

4 Conclusions

In this research, the effect of using MWCNT, CuO, and Al_2O_3 nanofluids has been investigated in automotive radiators. A significant improvement in Nusselt number compared to the base fluid was achieved when using the mentioned nanofluids. The highest improvement was 41.8% for MWCNT mixed with distilled water at a concentration of 1%. The experimental results showed that the Nusselt number for base fluid and nanofluid has increased with the increase in the flow rate due to the increases in fluid turbulence inside the tube, resulting in more heat to transfer by convection. The increase in the inlet temperature has also resulted in the Nusselt number increase due to the change in the thermal properties. This is attributed to the increases in thermal conductivity and the the decrease in viscosity and specific heat of the fluids. Nanofluid can be a promising for coolants' radiators' future; this provides profitable methods for engineers to promote effective and compacted radiators to reduce the size and weight, thus; reducing the fuel consumption.

References.

1. U. S. Choi, *Am. Soc. Mech. Eng. Fluids Eng. Div. FED*, vol. 231, pp. 99–105, 1995.
2. P. Chaurasia, A. Kumar, A. Yadav, P. K. Rai, V. Kumar, and L. Prasad, *SN Appl. Sci.*, vol. 1, no. 3, 2019, doi: 10.1007/s42452-019-0260-7.
3. A. Topuz, T. Engin, B. Erdoğan, S. Mert, and A. Yeter, *Heat Mass Transf. und Stoffuebertragung*, 2020, doi: 10.1007/s00231-020-02916-8.
4. R. Ravisankar, V. S. K. Venkatachalapathy, and N. Alagumurthy, *Heat Transf. - Asian Res.*, vol. 46, no. 1, pp. 61–74, 2017, doi: 10.1002/htj.21198.
5. H. M. Ali, H. Ali, H. Liaquat, H. T. Bin Maqsood, and M. A. Nadir, *Energy*, vol. 84, pp. 317–324, 2015, doi: 10.1016/j.energy.2015.02.103.
6. B. M'hamed, N. A. Che Sidik, M. F. A. Akhbar, R. Mamat, and G. Najafi, *Int. Commun. Heat Mass Transf.*, vol. 76, pp. 156–161, 2016, doi: 10.1016/j.icheatmasstransfer.2016.05.024.
7. A. O. Borode, N. A. Ahmed, and P. A. Olubambi, *Phys. Fluids*, vol. 31, no. 7, 2019, doi: 10.1063/1.5105380.
8. S. S. Chougule and S. K. Sahu, *J. Nanotechnol. Eng. Med.*, vol. 5, no. 1, pp. 1–6, 2014, doi: 10.1115/1.4026971.
9. P. Estellé, S. Halelfadl, and T. Maré, *J. Therm. Eng.*, vol. 1, no. 2, pp. 381–390, 2015, doi: 10.18186/jte.92293.
10. D. G. Subhedar, B. M. Ramani, and A. Gupta, *Case Stud. Therm. Eng.*, vol. 11, pp. 26–34, 2018, doi: 10.1016/j.csite.2017.11.009.
11. F. W. Dittus and L. M. K. Boelter, *Int. Commun. Heat Mass Transf.*, vol. 12, no. 1, pp. 3–22, 1985, doi: 10.1016/0735-1933(85)90003-X.
12. M. Dehghandokht, M. G. Khan, A. Fartaj, and S. Sanaye, *Appl. Therm. Eng.*, vol. 31, no. 10, pp. 1588–1599, 2011, doi: 10.1016/j.applthermaleng.2011.01.035.
13. E. N. Sieder and G. E. Tate, *Ind. Eng. Chem.*, vol. 28, no. 12, pp. 1429–1435, 1936, doi: 10.1021/ie50324a027.
14. S. Z. Heris, M. Shokrgozar, S. Poorpharhang, M. Shanbedi, and S. H. Noie, *J. Dispers. Sci. Technol.*, vol. 35, no. 5, pp. 677–684, 2014, doi: 10.1080/01932691.2013.805301.
15. S. Z. Heris, S. G. Etemad, and M. N. Esfahany, *Int. Commun. Heat Mass Transf.*, vol. 33, no. 4, pp. 529–535, 2006, doi: 10.1016/j.icheatmasstransfer.2006.01.005.