THE TLBO ALGORITHM-BASED OPTIMAL HEAT TRANSFER PARAMETERS PREDICTION OF Al_2O_3 WATER NANOFLUIDS IN VARIABLE PITCH CORRUGATED TUBE HEAT EXCHANGER

by

Vikas V. UGLE [a*], ***Lenin NAGARAJAN*** [a],
Arulprakasajothi MAHALINGAM [b],
and Heera THEKKINEYDETH RAJAN [c]

[a] Department of Mechanical Engineering,
Vel Tech Rangarajan Dr Sagunthala R & D Institute of Science and Technology,
Chennai, India
[b] Department of Mechanical Engineering, KCG College of Technology, Chennai, India
[c] Deprtmant of Chemistry, AMET, Deemed to be University, Chennai, Tamil Nadu

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This study investigated an Al_2O_3 nanofluid water-based tube heat exchanger fitted with a corrugated copper tube under laminar flow conditions. This study is carried out to observe the heat transfer rate within the heat exchanger. The effect of nanoparticle concentrations, the flow rate of the working fluid, and the corrugated tube pitch on the heat exchanger efficiency were analysed. The results show that when Al_2O_3 water nanofluids are sandwiched between corrugated copper tubes, the heat transfer rate is significantly enhanced compared to the smooth tubes. Nanofluids of Al_2O_3 were prepared with concentrations of 0.25%, 0.5%, and 1% in deionised water. Corrugated tubes with 25 mm, 20 mm, and 18 mm pitches were fabricated for this investigation. The deionised water and Al_2O_3 nanofluid-flow rates were maintained at 0.1 m^3 per hours, 0.15 m^3 per hours, and 0.2 m^3 per hours, respectively. Results showed that Al_2O_3 nanofluids improved the heat transfer rate related to water-based fluids. The highest heat transfer occurred in the 18 mm pitch corrugated copper tube in which 1% nanofluid volume concentration was used as the heat transfer medium. It is observed that the heat exchanger containing corrugated copper tubes with pitch 17.88 mm having 0.98 vol.% of Al_2O_3 nanofluids, flowing at 0.198 m^3 per hour, enhances the heat transfer rate between the working fluids.

Key words: *corrugated tube, pitch, flow rate, Al_2O_3, nanofluid, heat transfer rate*

Introduction

The constant demand for energy saving for domestic applications and industries has made heat transfer augmentation an absolute necessity. Over the past few years, research on improving heat transfer through heat exchangers has risen exponentially. In addition reducing energy use, this heat transfer enhancement is motivated by a desire to reduce costs. Most of the studies were carried out on heat transfer optimisation increase the efficiency of heat exchangers

* Corresponding author, e-mail: uglevikas@gmail.com

[1, 2]. In a typical heat exchanger, the contact area between the hot and cold fluids is a factor that determines the rate of heat transfer [3, 4].

Fluid properties like the fluid viscosity, coefficient of specific heat, and thermal conductivities can positively or negatively influence the heat transfer coefficient. Including nanoparticles in a base fluid like water can alter thermophysical and transport properties [5]. Numerous experiments confirmed that nanofluids increase heat transfer coefficients in heat exchangers [6]. Nanofluids containing metal oxide nanoparticles were found to have increased thermal conductivity effectiveness of the resulting fluid mixture. Research work by Das *et al.* [7] used Al_2O_3 and CuO nanofluids dissolved in water to augment the heat transfer in typical heat exchangers. They inferred that the thermal conductivity of nanofluid is typically more significant than the conventional heat transfer fluid. They also developed a model considering the fluid properties. A study showed that nanoparticles' Brownian motion induced local convection, which increased thermal conductivity [8].

The material used as nanoparticles plays a significant role in heat transfer. Post-processing techniques like milling and sonication control the base fluid's particle size and distribution. It was noted that particle size decreased by 36% and 40%, respectively, while using Al_2O_3 and CuO subjected to ball milling. The resulting sonication process improved the centrifugal dispersion by 15% [9]. It was found that when using TiO as a working fluid at an inclination angle of 45° and an operating temperature of 80 °C, the highest heat transfer was 298 W, the most increased heat flux was 2.8 kW/m^2, the highest heat transfer coefficient was 1.5 W/m^2 °C and the highest thermal efficiency was 17%, respectively [10].

The Al_2O_3-water nanofluids were examined numerically for their heat transmission and pressure drop properties in a flat coiled conical tube. The pressure drop in the nanofluid and the heat transfer were studied along with the coil pitch, cone angle, aspect ratio, and solid volume fraction. The study revealed that increasing the nanofluid's Reynolds number, aspect ratio, and substantial volume percentage enhances the pressure drop and the heat transfer coefficient. However, increasing the conical coil tube's cone angle and coil pitch has an opposing effect [11]. A nanofluid was synthesised by combining Al_2O_3 nanoparticles of size 43 nm and water using a microwave-assisted chemical precipitation technique. The nanofluid experiment showed that the thermal conductivity of Al_2O_3-water nanofluid increased by 8% compared with the base fluid rising linearly with the nanoparticle concentration [12]. Heat transfer improvement with the Al_2O_3-water nanofluid was studied in a circular tube twin pipe heat exchanger with constant wall temperature. 0.2-2.5 vol.% nanoparticle concentrations were used in the experiment. The results showed that Brownian motion, appropriate dispersion, and migration of nanoparticles increase the thermal conductivity by 7% and heat transfer rate by 11%, respectively [13].

Several literature works discussed optimising fluid properties, flow characteristics and design of heat transfer systems to increase the heat transfer in typical heat exchangers [14-16]. Numerical investigations are also carried out in heat exchangers to study the characteristics of nanofluids containing metal oxides like TiO and CuO [17, 18]. Techniques like multi-layer perceptron neural network optimised by the imperialist competition algorithm, genetic algorithm, neuro-fuzzy inference system, artificial neural network, and particle swarm optimization were employed to obtain reliable results in unison with the experimental work [19, 20].

The optimisation function measures the solution's efficacy that can be maximised or minimised, respectively. A variant of the teaching-learning-based optimization (TLBO) algorithm was developed and used to simultaneously optimise heat exchangers for multiple criteria.

Optimisation in plate fins and the shell-and-tube heat exchangers was also carried out. The effectiveness of the heat exchanger is maximised by 0.23, and the cost of the exchanger is minimised as the objective of optimisation [21]. Plate-fin heat exchangers were optimised using the multi-objective improved TLBO algorithm [22].

The present study researches nanofluids produced through hydrodynamic cavitation using ultrasonically manufactured Al_2O_3 nanoparticles. The nanofluid is thus used in the heat exchanger that contains a spiral corrugated-shaped tube. This research presents findings from examining Al_2O_3 nanofluid's convective heat transfer capability in a corrugated tube heat exchanger. The study's novelty is that the nanoparticles' volume concentration is maintained relatively large, *i.e.*, up to 1 vol.%. This facilitates enhanced heat transfer because of the increased viscosity of the working fluid, even at elevated temperatures. The study will observe the heat transfer rate in the tube heat exchanger with a corrugated copper tube using water-based Al_2O_3 nanofluid under laminar flow conditions. Water-based Al_2O_3 nanofluid was prepared with varying volume concentrations, *i.e.*, 0.25%, 0.5%, and 1%. The corrugated tube with three different pitches, *i.e.*, 25 mm, 20 mm, and 18 mm, is fabricated for this investigation. The experimental study was conducted at three flow rates: 0.1 m^3 per hour, 0.15 m^3 per hour, and 0.2 m^3 per hour with deionised (DI) water and Al_2O_3 nanofluid.

Materials and methods

A straight, plain tube made using copper and hexagonally corrugated tubes of 1000 mm length, 25.4 mm inner diameter, and 26 mm outer diameter are used as the test segment. The geometric specifications of the tubes are given in tab 1. A copper corrugated tube with a thickness of 2 mm, a depth of 4 mm, and grooves with a pitch of 18 mm, 20 mm, and 25 mm have been fabricated for this investigation, as shown in fig 1. Figure 2 reveals the SEM images revealing the Al_2O_3 nanostructures' size and morphology. The surface is covered by an oxidation layer, indicating the location of the nanoparticulates. The interlocking, spherical structures show the symmetricity of the oxidation layer. Also, the thermo-physical properties of DI water and nanoparticles are tabulated in tab. 2.

Table 1. Corrugated tubes' specifications

Tube materials	Notation	Inner diameter [mm]	Outer diameter [mm]	Thickness [mm]	Pitch [mm]	Depth [mm]	Length [mm]
Stainless steel tube	SST	25.4	26	02	–	–	1000
Copper tube	CuT	25.4	26	02	–	–	1000
Corrugated copper tube 1	CuCT1	25.4	26	02	25	04	1000
Corrugated copper tube 2	CuCT2	25.4	26	02	20	04	1000
Corrugated copper tube 3	CuCT3	25.4	26	02	18	04	1000

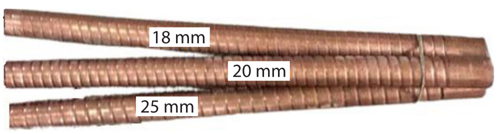

Figure 1. Fabricated copper corrugated tubes

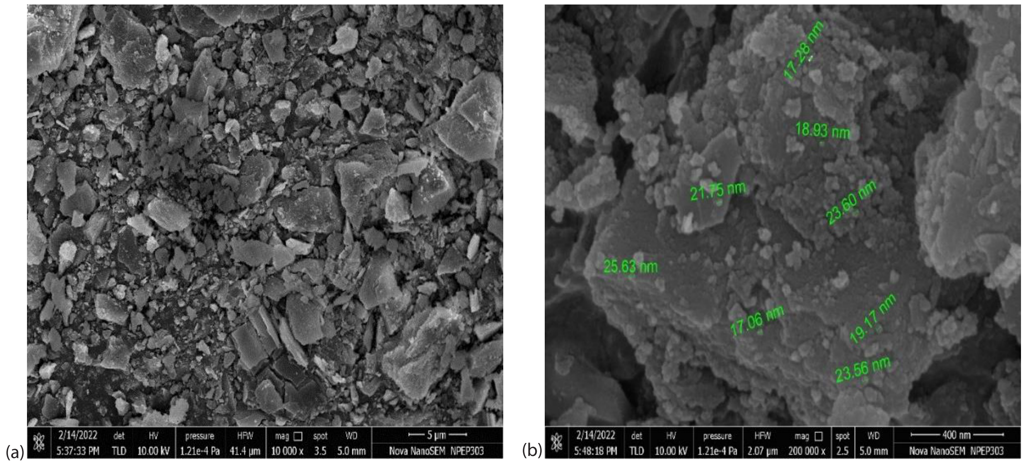

Figure 2. The SEM Images of Al_2O_3; (a) expanded to 10000× and (b) expanded to 20000×

Table 2. Thermo-physical properties of DI water and nanoparticles [23]

Physical properties	Unit	DI water	Al_2O_3
Density	[kgm^{-3}]	[997.3]	[3970]
Specific heat capacity	[$Jkg^{-1}K^{-1}$]	[4179]	[765]
Latent heat capacity	[$kJkg^{-1}$]	[2256]	[1360]
Thermal conductivity	[WmK^{-1}]	[0.605]	[40]

Experimental details

The experimental set-up for this study includes the settling chamber, the testing section, the riser, the cooling unit, the pump, and the fluid reservoir, as shown in fig. 3. The settling room helps to smooth out the fluid-flow and decrease the impact at the entrance. The test section is 1000 mm long, 26 mm outer diameter, 25.4 mm inner diameter, and 2 mm thick. A

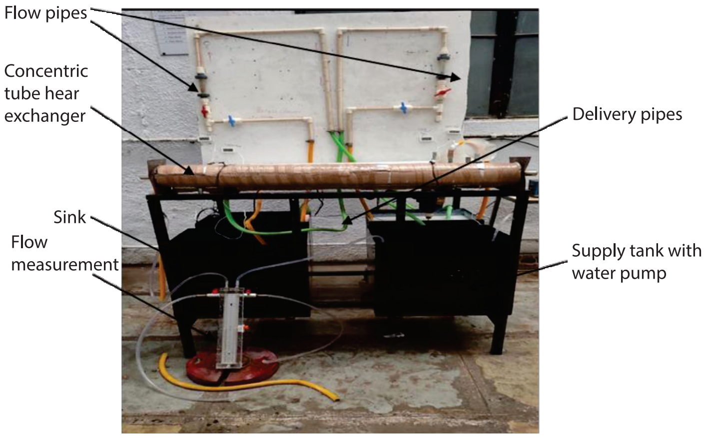

Figure 3. Lay-out of experimentation set-up

Ni-chrome heating wire with a resistance of 100 Ω is wound around ceramic beads to produce uniform heat across the test section. Thick glass wool insulation is placed over the electrical winding to minimise the heat lost to the atmosphere. A vertical pipe serves as the riser to ensure a consistent working fluid-flow throughout the testing section. Fluid is pumped through the riser and the cooling unit through which the air is cooled. A 4 l stainless steel tank with a drain valve serves as the reservoir for the working fluid. An autotransformer maintains a consistent heat flux in the test section [24].

Results and discussion

Heat transfer is experimentally examined using an Al_2O_3-water nanofluid-flowing in corrugated copper tubes under various operational conditions. The nanofluid's heat transfer rate is given [25]:

$$Q = \dot{m} Cp_{\mathrm{nf}} (T_{\mathrm{out}} - T_{\mathrm{in}}) \tag{1}$$

where $\dot{m}$ is the nanofluid mass-flow rate, Cp_{nf} – the adequate specific heat of the nanofluid, and T_{in} and T_{out} are the inlet and outlet temperatures of the nanofluid. Φ

The expression shown in eqn gives the nanofluid's effective density:

$$(\rho Cp)_{\mathrm{nf}} = (\rho Cp)\,(1 - \Phi) + (\rho Cp)_{\mathrm{s}}\,\Phi \tag{2}$$

where ρ_{nf} is the density of the nanofluid, ρ_{f} – the density of the fluid (*i.e.*, DI), ρ_{s} – the density of the nanoparticles, Cp_{f} – the density of the specific heat (*i.e.*, DI), Cp_{s} – the density of the particular warmth of the nanoparticles, and Φ – the volume concentration of the nanoparticle Xuan and Roetzel [26].

Heat transfer rate at the flow rate of 0.1 m³ per hour

When using a fluid-flow rate at 0.1 m³ per hours with nanofluid volume concentrations of 0.25%, 0.5%, and 1%, a copper corrugated tube with an 18 mm pitch achieves the maximum heat transfer rate, as shown in fig. 4. The heat transfer rate rose by 22.93%, 22.82%, and 26.27% compared to a typical stainless steel tube. When the working fluid-flows through the corrugate tube of pitch 18 mm, the overall heat transfer rate increases by 16%, 17.82%, and 20.58% more than the base copper tube [26]. Specifically, the increased thermal conductivity of the nanofluids is because of the increase in the Brownian motion of Al_2O_3 nanoparticles at elevated temperatures. Additionally, a more significant number of Al_2O_3 nanoparticles in the nanofluid shows a more substantial influence on the heat conduction in the nanofluid. This

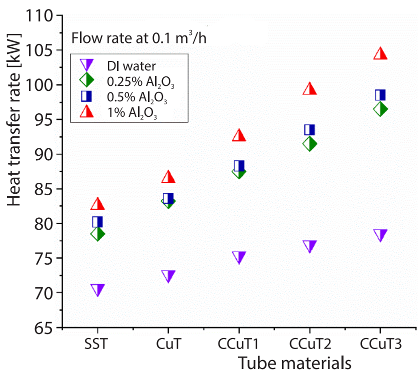

Figure 4. Heat transfer performance at the flow rate of 0.1 m³ per hour

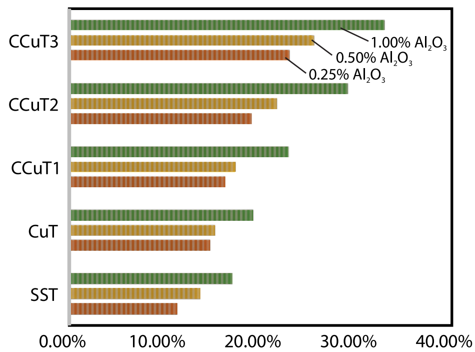

Figure 5. Improvement of heat transfer rate with Al_2O_3 at the flow rate of 0.1 m³ per hour

phenomenon causes the thermal conductivity ratio to increase proportionally with an increase in the loading of Al_2O_3 nanoparticles in the nanofluid. Compared with base DI water, the overall heat transfer coefficient increases by 22.84%, 29%, and 32.87%, respectively. This condition is observed when the pitches of the copper corrugated tube were 25 mm, 20 mm, and 18 mm, respectively, at the nanofluid volume concentration of 1%, as shown in fig. 5. Similarly, the heat transfer rate rises as the Al_2O_3 concentration increases but reduces with the pitch on the corrugated tube.

Heat transfer rate at the flow rate of 0.15 m³ per hour

The corrugated copper tube with an 18 mm pitch had the highest heat transfer rate when used with a fluid-flow rate of 0.15 m^3 per hour and nanofluid volume concentrations of 0.25%, 0.5%, and 1%, as shown in fig. 6. Increases in heat transfer efficiency of 24.67%, 26.67%, and 30.74% are achieved relative to stainless steel smooth tubes. The total heat transfer rate increases by 16.31%, 17.08%, and 20.04% when utilising a nanofluid concentration instead of a standard copper tube. A high heat transfer coefficient was noted for increased vol.% of Al_2O_3 nanoparticles. This is because their dispersion considerably affects thermal conductivity and modifies the flow rate and tube pitches accountable for improved heat transfer coefficient. The heat transfer coefficient surges by 28.95%, 34.84%, and 42.11% at its maximum when compared to base DI water, as shown in fig. 7. This was observed in the copper corrugated tubes having varying pitches at a nanofluid volumetric concentration of 1%. Similarly, the heat transfer rate increases with an increase in the Al_2O_3 concentration. However, it slowed down when there was an increase in the pitch of the corrugated tube. The Al_2O_3 nanoparticles improve fluid-flow, leading to a high shear rate at the wall and a more significant heat transfer coefficient because of the shear thinning phenomenon in nanofluids. The heat transfer coefficient increased because of Al_2O_3 nanoparticles, which can be attributed to an early shift from laminar to turbulent flow.

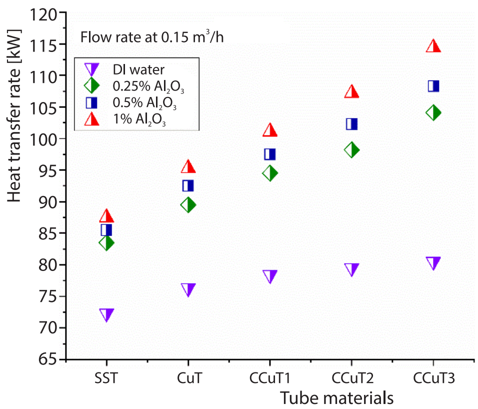

Figure 6. Heat transfer performance at the flow rate of 0.15 m³ per hour

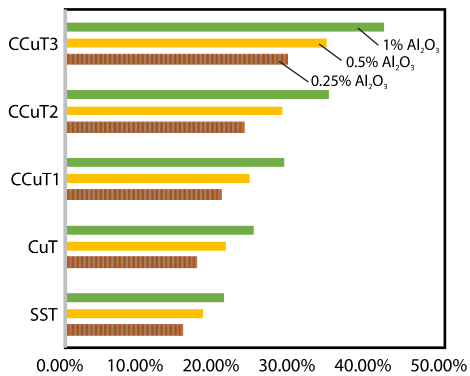

Figure 7. Enhancement of heat transfer because of Al_2O_3 at the flow rate of 0.15 m³ per hour

Heat transfer rate at the flow rate of 0.2 m³ per hour

The maximum heat transfer rate was achieved by a corrugated copper tube with an 18 mm pitch when it was used in conjunction with a fluid-flow rate of 0.20 m^3 per hour and a nanofluid volume concentration of 0.25%, 0.5%, and 1%, respectively. When the nanofluid concentration was varied in the corrugated copper tube (18 mm pitch), the overall heat transfer rate increased by 17.08%, 17.99%, and 20.00%, respectively. Compared to stainless steel smooth tubes, these tubes achieve increases in heat transfer efficiency of 23.77%, 24.58%, and 26.76%, respectively, as shown in fig. 8. Figure 9 shows that the overall heat transfer coefficient raised by 29.38%, 34.69%, and 40.29% at its highest when studying the influence of nanofluid volumetric concentration of 1% on the modified pitches of a copper corrugated tube. Likewise, the heat transmission rate is enhanced because of the increase in the Al_2O_3 concentration but reduced with the rise in the corrugated tube's pitch variation. Since the Al_2O_3 nanoparticles demonstrate a more significant influence of heat conduction in a nanofluid, their presence causes the thermal conductivity to improve proportionally with an increase in the loading of Al_2O_3 nanoparticles in the nanofluid. Hydrodynamic cavitation was used to disperse Al_2O_3 nanoparticles in water further to improve nanofluids' thermal conductivity. This enhances the nanoparticle's Brownian motion, which rises with the temperature of Al_2O_3 nanofluids. To increase thermal conductivity, liquid molecules make a nanolayered structure over the surface of Al_2O_3 nanoparticles. This allows heat to be transferred from the nanoparticles to the liquid around them, creating a homogenous suspension [13, 27].

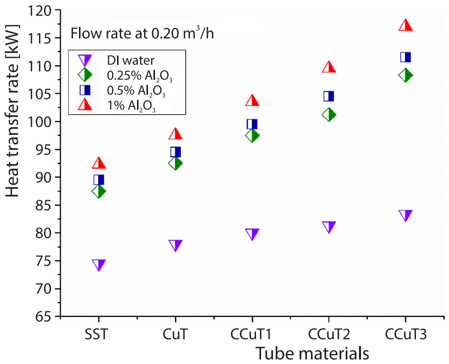

Figure 8. Heat transfer performance at the flow rate of 0.2 m^3 per hour

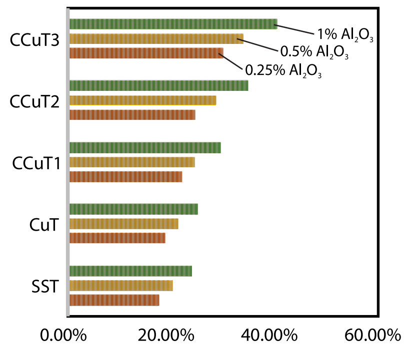

Figure 9. Improvement of heat transfer rate with Al_2O_3 at the flow rate of 0.2 m^3 per hours

Teaching-learning-based algorithm

Changing the regular parameters and the algorithm-specific variables further reduces the effort required. Rao *et al.* [28] devised a unique approach in TLBO without any specific algorithm operators. Thus, an algorithm based on teaching and learning is called a *teaching-learning algorithm*. The TLBO algorithm has no algorithm-specific variables, making it easier to implement and use than other population-based optimisation methods. As a result of TLBO, the convergence rate is improved since the best solution from each generation is used to modify the current solution. The TLBO uses the mean value as the influencing parameter to get better results. In TLBO, the *Learner Phase* and *Teacher Phase* are distinct phases [28].

Teacher's Phase

To improve students' knowledge to the highest level possible, an excellent teacher helps them to learn all they can. A superb teacher cannot move students above the class mean in real-time, but they may be able to influence them to some extent in the future. It depends on the level of competence of the entire class. Based on the influencing values, this is estimated as the mean value. The best instructors will be selected as part of the teacher selection process. The heat transfer rate of the instructor determines the most effective instructor. As a result, the instructor's expertise will more likely benefit the whole group of students. Equation (3) can be used to improve the performance of each learner [14]:

$$Xt_n = Xt_o + \text{random}\,[X_{bt} - (tf^* m)] \tag{3}$$

Learner's phase

The second stage of the multi-objective TLBO algorithm requires students (learners) to engage with one another to increase their knowledge. Random communication between students allows them to expand their knowledge. A student being taught may learn new concepts from another student with more ability than them. This phase begins with students interacting with another randomly chosen string, for which randomly selected students are preferred. A relationship between the following eqs. (4) and (5) has been established. The heat transfer rate values of the two pupils will be compared in this section of the paper. The student's heat transfer rate value exceeds the heat transfer rate value of the selected student. If the student's heat transfer rate value is more significant:

$$Xl_{ns} = X_{ls} + \text{rand}(X_{ls} - X_{ss}) \tag{4}$$

$$Xl_{ns} = X_{ls} + \text{rand}(X_{ss} - X_{ls}) \tag{5}$$

During the subsequent iteration, the output of the learner phase will be utilised as the input for the teacher phase. After a sufficient number of generations or iterations, the instructors' and learners' grades will be repeated until the requisite number of generations or iterations has been reached. This investigation selected corrugated tube pitches, fluid-flow rate and Al_2O_3 nanofluid concentration as design variables. Three factors and three levels were determined and tabulated in tab. 3. There are 100 iterations, and the optimal number of students for multi-objective TLBO is 10. After 40 iterations, the plot below shows, fig. 10, that the solution is convergent and yields optimal parameters.

Table 3. Design variables and their levels

Design variables	Unit	L_1	L_2	L_3
Pitch	[mm]	18	20	20
Flow rate	[m^3 per hour]	0.1	0.15	0.2
Nanoconcentration	[%]	0.25	0.5	1

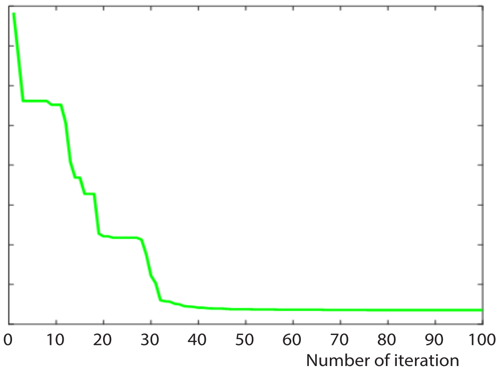

Figure 10. The multi-objective TLBO plot

After the necessary number of generations have passed, the input parameter and output parameter combinations that have been optimised for the heat transfer rate are summarised in tabs. 4 and 5. Corrugated tube pitch of 17.88 mm, fluid-flow rate of 0.198 m^3 per hour, and Al_2O_3 nanofluids concentration of 0.98 % were found to be the optimal heat transfer parameters, with corresponding response parameters of the heat transfer rate of 116.45 kW.

Table 4. Full factorial design experimental values

Std. order	Run order	Pitch [mm]	Flow rate [m^3 per hour]	Nanoconcentration [%]	Heat transfer rate [kW]
13	1	20	0.15	0.25	98.2
2	2	18	0.1	0.5	98.5
1	3	18	0.1	0.25	96.5
4	4	18	0.15	0.25	104.1
3	5	18	0.1	1	104.3
25	6	25	0.2	0.25	97.5
21	7	25	0.1	1	97.5
23	8	25	0.15	0.5	97.5
24	9	25	0.15	1	99.1
27	10	25	0.2	1	103.5
20	11	25	0.1	0.5	88.3
22	12	25	0.15	0.25	94.5
6	13	18	0.15	1	114.4
5	14	18	0.15	0.5	108.3
18	15	20	0.2	1	109.5
16	16	20	0.2	0.25	101.2
7	17	18	0.2	0.25	108.3
17	18	20	0.2	0.5	99.5
8	19	18	0.2	0.5	111.5
9	20	18	0.2	1	117
26	21	25	0.2	0.5	104.5
10	22	20	0.1	0.25	91.5
19	23	25	0.1	0.25	87.5
11	24	20	0.1	0.5	93.5
12	25	20	0.1	1	99.2
14	26	20	0.15	0.5	102.3
15	27	20	0.15	1	107.2

Table 5. Optimized results of heat transfer rate by multi-objective TLBO

Pitch [mm]	Flow rate [m^3 per hour]	Nanoconcentration [%]	Heat transfer rate [kW]
17.88	0.198	0.98	116.45

Conclusions

This study aims to determine the heat transfer rate in a tube heat exchanger using a corrugated copper tube utilising an Al_2O_3 nanofluid based on the water under laminar flow. A nanofluid of Al_2O_3 in water was investigated with concentrations of 0.25 %.vol., 0.5 %.vol., and 1 %.vol. The corrugated tube has been fabricated with three pitches of 25 mm, 20 mm, and 18 mm, and experimental research was done at three flow rates of 0.1 m^3 per hour, 0.15 m^3 per hour, and 0.2 m^3 per hour using deionised water and Al_2O_3 nanofluid. the conclusions are as follows.

- The heat transfer coefficient increases by 32.87%, 42.11%, and 40.29% at maximum compared to base DI water. This was achieved in a corrugated tube pitch of 18 mm and an Al_2O_3 nanofluid concentration of 1 vol.% for flow rates of 0.1 m^3 per hour, 0.15 m^3 per hour, and 0.2 m^3 per hour, respectively.
- Compared to the smooth copper tube, the heat transfer coefficients of 20.58%, 20.04%, and 20% were achieved at a corrugated tube pitch of 18 mm and an Al_2O_3 nanofluid concentration of 1 vol.% for flow rates of 0.1 m^3 per hour, 0.15 m^3 per hour, and 0.2 m^3 per hour, respectively.
- At 18 mm corrugated tube pitch and one vol.% Al_2O_3 nanofluid concentration for the three different flow rates, the heat transfer coefficient increased by 26.27%, 30.74%, and 26.76%, respectively. This was in comparison the base smooth stainless steel tube.
- It was observed that as the corrugation pitch increases, heat transfer decreases. However, the heat transfer rate increased with the percentage of nanofluids concentration and flow rate.
- Corrugated tube pitch of 17.88 mm, fluid-flow rate of 0.198 m^3 per hour, and Al_2O_3 nanofluids concentration of 0.98 vol.% were found to be the optimal heat transfer parameters, with a response heat transfer rate of 116.45 kW through multy-objective TLBO.

It is concluded that the heat exchanger containing corrugated copper tubes with pitch 17.88 mm having 0.98 vol.% of Al_2O_3 nanofluids, flowing at 0.198 m^3 per hour, enhances the heat transfer rate between the working fluids. This configuration can be effectively used to improve the heat transfer rate in typical concentric tube heat exchangers.

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