Study on the heat transfer characteristics of Al₂O₃-CuO/Water hybrid nanofluids in a shell and rotating wavy tube heat exchanger

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The present study focuses on heat transfer and characteristics of fluid flow behaviour of a rotating wavy tube HEX using water and Al₂O₃-CuO/Water (0.3%) hybrid nanofluid as coolants. The shell and wavy tube were modelled in CATIA with a tube diameter of 9.3mm and shell diameter of 140mm. The heat transfer area of the rotating tube heat exchanger is 0.0476m². Water is utilized as the hot fluid inside the shell and Al₂O₃-CuO/Water (0.3%) Hybrid nanofluid was used in tube side. The rotating wavy tube heat exchanger was fabricated by VMC and CNC machining process and tube is maintained at the speed of 57.5 rpm. The experiment was carried out by varying tube side mass flow rate and shell mass flow rate was kept constant. Experimental study reveals that the heat transfer rate of the rotating tube was higher when compared to the fixed tube by 10.5% when pure water is used. Similarly when Al₂O₃-CuO/Water (0.3%) Hybrid nanofluid is made to flow in tube side; the heat transfer rate was considerably higher than pure water by 9.15%. This is due to wavy rotating tube helps to increase the turbulence inside tube and shell side resulting in better heat transfer and a comparable pressure drop. So, this heat exchanger is found to be an optimal design and can be used in various applications.

Keywords: Wavy tube, Rotating tube, Hybrid nanofluids, Heat transfer rate, Pressure drop.
1. Introduction

Ashkan et al., [1] studied the importance of geometrical constraint on the thermal effectiveness of heat exchanger with helically curled under the steady state. The results showed that for same values of NTU and critical Reynolds number, the effectiveness was a lesser amount of parallel flow HEX, and the dissimilarity is nearly even. Amiot kumar et al., [2] attempted to study on the design of heat exchanger of shell and helical coil type along with thermal study and counterflow type. Results showed that the efficiency decreases with a height of the coil and coil diameter. The increase in shell diameter and pitch size enhanced efficiency to a reasonable value. Azad et al., [3], studied the efficiency of the heat exchanger by using alumina nanofluid. The outcome illustrate that the utilize of nanofluid enhances the heat transfer.

Kunwer et al., [4], in this experiment made an attempt to increase the rate of heat transfer and to reduce the pressure drop by adjusting the helical baffle up to that angle which gives minimum pressure loss. For increasing the heat transfer rate simple copper tube was replaced by the grooved and finned tube and experimental investigation has been carried out with both simple copper tube and grooves and finned tube and it was noticed that grooved and finned tube with helical baffle at 25degree showed better thermal performance. H.A. Mohammed et al.,[5], study the detailed review of limitations of Nanofluids and rate of heat transfer and fluid flow characteristics in microchannel HX. B. Mathew et al., [6], reveal the thermal performance of parallel flow microchannel subjected to external heat flux was investigated. The experiment conducted on parallel flow MCHS subjected to two different angle. The results shows that the thermal efficiency of parallel flow MCHS undergoing external heat transfer is independent of operating conditions as well as hydraulic diameter. N. García-Hernando et al.,[7], did experiment on micro heat exchanger to study the thermal and hydrodynamic performance of square microchannel cross-section. The results agree well with the heat transfer studies. There was no heat transfer enhancement was observed at the micro level.

Janhavli et al., [8], in this article the heat transfer coefficients, were calculated experimentally in heat exchangers. The modifications are based on the justification of Nusselt number for finding the coefficients of heat transfer on condensation part. Morsyet al.,[9] performed experimental study on multi rotating tube condenser. The effect of the rotational speed of the condenser tube bundle and flow rate of cooling water on the overall heat transfer coefficient was studied. It was noted that the rotational speed has positive effect on the overall heat transfer coefficient. Kumar et al. [10] investigated on Al2O3-Cu/Water mixture nanofluid in a heat sink of thin channel made of copper having overall dimensions 59*59*12.6 mm. The hybrid nanofluid of a 0.1 volume % was arranged by dissolve a particular amount of Al2O3-Cu nanoparticle in deionized water using an ultrasonic vibrator and also added stable nanofluid sodium lauryl sulphate as a surfactant. The results shows that standard rise in heat transfer due to convection for hybrid nanofluid compared with deionized water was 24.35%.

Vivek Kumar et al. [11] investigated that the hydrothermal behaviour of Al2O3-MWCNT hybrid nanoliquid in mini-channel. The results shows that highest 44.02% augmentation coefficient of heat transfer was experiential for MWCNT(10:0) hybrid nanofluid. From the
above literature studies it can be concluded that very little attention has been given to study the heat transfer characteristics of a rotating wavy tube HEX using water and Al2O3-CuO/Water (0.3%) hybrid nanofluid. Hence the present study the flow and heat transfer characteristics by varying mass flow rate with constant rotating tube speed.

2. Materials and methods

2.1 Design of rotating tube HX

The modelling of the shell and rotating wavy tube heat exchanger was done in AUTO-CAD and CATIA package. Fig. 1(a) shows a 2D representation of rotating wavy tube heat exchanger. Fig.1(b) shows the 2D representation of Cover plate used to hold the gears for the rotation mechanism inside the shell. The Fig. 1 (c) shows the assembled view of rotating tube heat exchanger.

![Fig. 1(a) 2D representation of rotating wavy tube heat exchanger, (b) 2D representation of Cover plate and (c) Assembled view of rotating tube heat exchanger.](image)

2.2 Fabrication of wavy tube

The fabricated wavy tube along with gear mechanism was shown in Fig.2. The wiper die and pressure die loosely holds the tube. Sometimes tube will be filled with the filler material for preventing the shrink.
3. Experimental study

3.1 Experimental Setup

Fig. 3 reveals Photograph of the investigational arrangement. It has a shell and wavy tube manufactured out of copper. It has at inlet and outlet the temperature ports to find the temperature values. A reservoir made of stainless steel having 10 litre capacity was used in this study. A Centrifugal pump of Pedro Roquest make is able to hold 40 lpm. To regulate the flow of working fluid a rotating type gate valve was used. A flow meter having measuring range of 0.4 to 5 lpm made by R.M Enterprise was used to measure the flow. A T-type thermocouple holds the endpoint of the probe to measure the temperature. An AMBETRONICS made TC1600F MODEL data logger was connected to a data logger which has the measuring range of -50°C to 500°C. A SETRA model 3100 pressure transducer was employed to gauge pressure at shell and tube side having the range of 0 to 10 bar shall detect the values of pressure of the fluid at the inlet and outlet of heat exchanger. To picture and document the pressure, a pressure transducer was connected through a pressure data logger of AMBETRONICS replica TC-800 having range of 0 to 20 bars. The heat exchanger was supplied with a hot fluid from the heater.

Fig. 3 Photograph of typical experimental setup.
3.2 Data Reduction

Fluid properties were determined corresponding to the mean temperature of shell and tube side. With the help of these properties Reynolds number is calculated using the below equation given in Amit Kumar et al. [2]

\[ \text{Re} = \frac{\nu d}{\gamma} \]  

(1)

Using Ditttusboelter equation the Nusselt number is determined Godson et al.,[12]

\[ \text{Nu}_i = 0.027 \left( \text{Re}^{0.8} \right) \left( \text{Pr}^{33} \right) \]

(2)

The theoretical heat transfer coefficient was calculated using above determined nusselt number equation from Amit Kumar et al. [2]

\[ h = \frac{\text{Nu} \times k}{d} \]

(3)

The whole heat transfer coefficient can be received form equation of Godson et al.,[12]

\[ \frac{1}{U} = \frac{r_0}{(r_i \times h_i)} + r_0 \times \frac{\ln(r_0/r_i)}{k} + \left( \frac{1}{h_0} \right) \]

(4)

Due to rotational speed and Reynolds number of the cooling water, the overall heat transfer coefficient for the condenser is given by Morsyet al.,[9 ]

\[ A=0.933+1.283 \times 10^{-4} \text{Re} \]

\[ B=-0.002+8 \times 10^{-9} \text{Re} \]

\[ U_o=ANe^{BN}+U \]

(5)

The rate of heat transfer was derived from equation from Amit Kumar et al.,[2]

\[ Q = mc \left( T_{out}-T_{in} \right) \]

The effectiveness of heat exchanger \( \varepsilon = \frac{Q_{actual}}{Q_{max}} \)

(6)

The Experimental pressure drop can be calculated from

\[ \Delta p = p_{in} - p_{out} \]

(7)

4. Results and discussion

4.1 Effectiveness characteristics

The effectiveness variation of the shell and rotating wavy tube HX for changing Reynolds number is exposed in fig.4 it is pragmatic that Reynolds number rises, the effectiveness increase and originate to be superior to fixed tube. The effectiveness is increased by 9.5% when water is used as the base fluid in Fixed and Rotating tube similarly when hybrid nanofluid (Al₂O₃ + CuO / Water) is replaced by water in Fixed and Rotating tube the effectiveness is increased by 2.2%. The effectiveness is found to be 10.8% if pure water is replaced by hybrid nanofluid (Al₂O₃ + CuO / Water) rotating tube. This is due to
wavy rotating tube helps to increase the turbulence inside tube and shell side resulting in better heat transfer and a comparable pressure drop.

![Graph showing variation of effectiveness with Reynolds number.]

**Fig. 4** Variation of Effectiveness with the Reynolds number.

4.2 Heat transfer rate characteristics

Fig. 5 represents the variation of heat transfer rate because of increase in cold fluid Reynolds number of the fixed and rotating tube. It is legibly shown that the rate of heat transfer rotating cold surface increases by 10.5% when compared with the fixed tube by using water as coolant. In case of hybrid nanofluid in the rotating tube, heat transfer rate increased by 9.15% of the stationary tube. By replacing the use of water by hybrid nanofluid in rotating surface enhances heat transfer rate by 14.23%. The centrifugal force obtained by rotation of cold surface results in thinner film over the heat transfer surface which increases heat transfer rate.

4.3 Overall heat transfer coefficient and LMTD characteristics

The whole heat transfer coefficient concerning Reynolds number for hybrid nanofluids and water is presented in Fig. 6. It can be accurately noted that overall heat transfer coefficient of hybrid nanofluids is noted to be larger than that of water, due to the higher thermo-physical characters. The raise in overall heat transfer coefficient is established to be 10.5% when water was used as the base fluid in the fixed and rotating tube. Similarly, when hybrid nanofluid (Al₂O₃ + CuO / Water) is used instead of water, the overall heat transfer coefficient enlarged by 9.1%. Whereas while considering hybrid nanofluid over pure water in rotating tube, the overall heat transfer coefficient enhanced by 14.2%. The change of logarithmic mean temperature difference (LMTD) of hybrid nanofluids and water against Reynolds number is given in Fig. 7. The LMTD increases by 2.4% when water is used in the Fixed and rotating tube. Similarly when hybrid nanofluid has used the LMTD increases by
12.1% in the fixed and rotating tube. When hybrid nanofluid ($\text{Al}_2\text{O}_3 + \text{CuO} / \text{Water}$) is used in rotating tube, the LMTD increases by 12.7%.

**Fig. 5** Change of standard Heat transfer rate with Reynolds number.

**Fig. 6** Change of overall heat transfer coefficient against Reynolds number.
Fig. 7. Change of LMTD concerning Reynolds number.

4.4 Pressure drop characteristics

The drop in pressure of hybrid nanofluids and water for different Reynolds number is exposed in Fig 8. The rise in pressure drop requires high pumping power to cross pressure gradient. The percentage raise in drop in pressure when equated to pure water to that of nanofluids in the fixed and rotating tube is noted to be 6.3% for Re=1882. The pressure drop raised by 9.51% when hybrid nanofluid (Al₂O₃ + CuO / Water) was used in a fixed and rotating tube instead of pure water. Pressure drop considerably increased by 9.52% in rotating tube when hybrid nanofluid was used as the base fluid. This is due to wavy rotating tube helps to increase the turbulence inside tube and shell side resulting in comparable pressure drop also increased viscosity of the hybrid nanofluids.

Fig. 8 Change in Pressure drop against Reynolds number.

5. Conclusions

In the present study was carried out to find the heat transfer and flow characteristics in the rotating tube heat exchanger by using hybrid nanofluid (Al₂O₃ + CuO / Water) and water. The results are summarised below.
The effectiveness of rotating tube HX increased by 7.3% and 2.4% compared to the fixed tube when water and hybrid nanofluid were used as cooling fluid. Similarly the Overall heat transfer coefficient enhanced by 7.8% and 9.7% respectively. Pressure drop was higher for rotating tube by 21% compared to the fixed tube when water was used as the cooling fluid. Pressure drop is further increased by 23.8% while flowing hybrid nanofluid (Al$_2$O$_3$ + CuO / Water). Hence the rotating tube heat exchanger shows better performance than fixed tube when hybrid nanofluid (Al$_2$O$_3$ + CuO / Water) is used instead of pure water. Thus, it is used in dairy industry for pasteurizing process.

References

[1] Ashkan Alimoradi, (2017) “Study of thermal effectiveness and its relation with NTU in shelland helically coiled tube heat exchangers”, Case Studies in Thermal Engineering, Vol.9, pp. 100–107.
[2] Amitkumar. S. Puttewar, Andhare A.M,(2004)“Design and thermal evaluation of shell and helical coil heat exchanger”, International Journal Research in Engineering and Technology,pp.no.8-26 : 2321-7308.
[3] Abazar Vahdat Azad, Nadar Vahdat Azad, (2016) “Application of nanofluids for the optimal design of shell and heat exchangers using genetic algorithm”, Case Studies in Thermal Engineering 8, Vol 2, pp.no 198-206.
[4] Kunwer Sandeep Singh, Lalit Kumar Bajirao Chauhan,Venda Prasad Maurya,“Heat Transfer Rate in Shell and Tube Heat Exchanger Using Grooved and Finned Tube”, International Journal of Engineering Research and Technology. Volume 8. pp.no. 104–112.
[5] Mohammed. H.A, Gunnasegaran. P, Shuaib. N.H, (2011) “Influence of various base nanofluids and substrate materials on heat transfer in trapezoidal microchannel heat sinks”, International Communications in Heat and Mass Transfer, Vol. 38, pp. 194–201.
[6] Mathew. B, Hegab H., (2008) “Experimental investigation of thermal model of parallel flow microchannel heat exchangers subjected to external heat flux”, International Journal of Heat and Mass Transfer, vol 6. pp.no. 104–112.
[7] García-Hernando. N, Acosta-Iborra A., Ruiz-Rivas U., Izquierdo .M, (2002) “Experimental investigation of fluid flow and heat transfer in a single-phase liquid flow micro-heat exchanger”, International Journal of Heat and Mass Transfer, vol 1. pp.no. 104–112.
[8] Jan Havlik, Tomas Dlouhy, (2017) “Experimental determination of the heat transfer coefficient in shell-and-tube condensers using Wilson plot method”,EPJ Web of Conferences 143, 02035, pp.no. 104–112.
[9] Morsy, F.M. Wassef , V.H. Morcos & H.A.M. El Biblawy , (1987), Overall heat transfer coefficient for a multi-tube rotating condenser, chemical engineering communications, pages 41-49.
[10] Ponnusamy Selvakumar and Sivan Suresh, (2012), Use of Al2O3–Cu/Water Hybrid Nanofluid in an Electronic Heat Sink, IEEE transactions on components, packaging and manufacturing technology, Vol. 2, pp.10.
[11] Vivek Kumar, Jahar Sarkar, (2020), Experimental hydrothermal behavior of hybrid nanofluid for various particle ratios and comparison with other fluids in mini channel heat sink, International Communications in Heat and Mass Transfer, Vol.110, pp.104397.
[12] Godson. L, Deepak K., Enoch C, Jefferson. B, Raja. B, (2014) “Heat transfer characteristics of silver/water nanofluids in a shell and tube heat exchanger”, Archives of civil and mechanical engineering 14 pp.no 489-496.