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A REVIEW ON "HEAT TRANSFER CHARACTERISTICS IN TRIPLE CONCENTRIC TUBE HEAT EXCHANGER WITH CORRUGATIONS"

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Abstract. Triple tube heat exchangers are the mostly used heat exchangers for thermal energy conversion with a wide range of applications such as dairy, food, pharmaceutical industries, beverage, and the like. The demand for more efficient cooling by more compact heat exchangers leads to tremendous research on this subject. In this paper, a detailed review of experimental and numerical research upon different mechanisms of heat transfer enhancement in triple concentric tube heat exchangers is performed and the relevant influences and operating conditions are thoroughly reviewed. The effects of different geometrical parameters on heat transfer and different fluids are discussed in detail.

Keywords: Triple tube heat exchangers, thermal energy conversion, geometrical parameters etc.

1. INTRODUCTION

Energy conservation ensuring its optimum utilization is one of the prime concerns of the present times. This is sure to augment the advancement of the society in all respects making energy available for purposes starting from daily chores of household to the running of huge complicated machinery pertaining to continued functioning of the society and its various branches. Thermal energy constitutes a major part of energy necessary for the day today life of the human race and needs to be utilized to the optimum level with the minimum of losses. This can be ensured if one of the aspects concerning heat exchange can be made more effective and optimized. Keeping above in mind researchers are motivated to carry out fundamental research concerning transfer of heat in and between various systems. Improvements in the designing parameters leading to an improved performance of various heat exchangers related with space heating, air conditioning, waste-heat recovery, etc. have been their prime concern. Various food processing methods such as pasteurization, draying, etc., also depend a lot on the process of heat exchange for their efficient execution.

A heat exchanger is a heat transfer device that is used for transfer of internal thermal energy between two or more fluids available at different temperatures. Different types of heat exchangers, such as parallel or counter flow type, tube shape or plate type and direct or indirect type heat exchanger are in operation these days. It is, however, important to note that specification and application of a product determine the type of heat exchanger to be used.

The heat transfer, in general, depends on the inherent characteristics of the fluid like its heat capacity, viscosity, etc. It also depends on the materials as well as the flow pattern adopted by fluid concerned.
The efficiency of heat exchangers also enhances by applying the heat transfer enhancement methods (HTEM). These techniques have been studied by several scholars in the past two decades, and are divided into passive and active methods. The active approaches require external energy while the passive methods employ the special modifications which intensify the flow mixing and interrupt thermal boundary layers for heat transfer increment.

Among the various passive methods, utilizing artificial roughness such as the ribbed surfaces and corrugation is greatly studied and used by researchers because of the simplicity and high efficiency.

Continuous improvements in design and development of heat exchanger have been carried out by various researchers. The limitations concerning effectiveness and compactness of double tube heat exchanger have been overcome by design and development of triple tube heat exchangers for the application in dairy, nutrition, beverage and pharmacological industries.

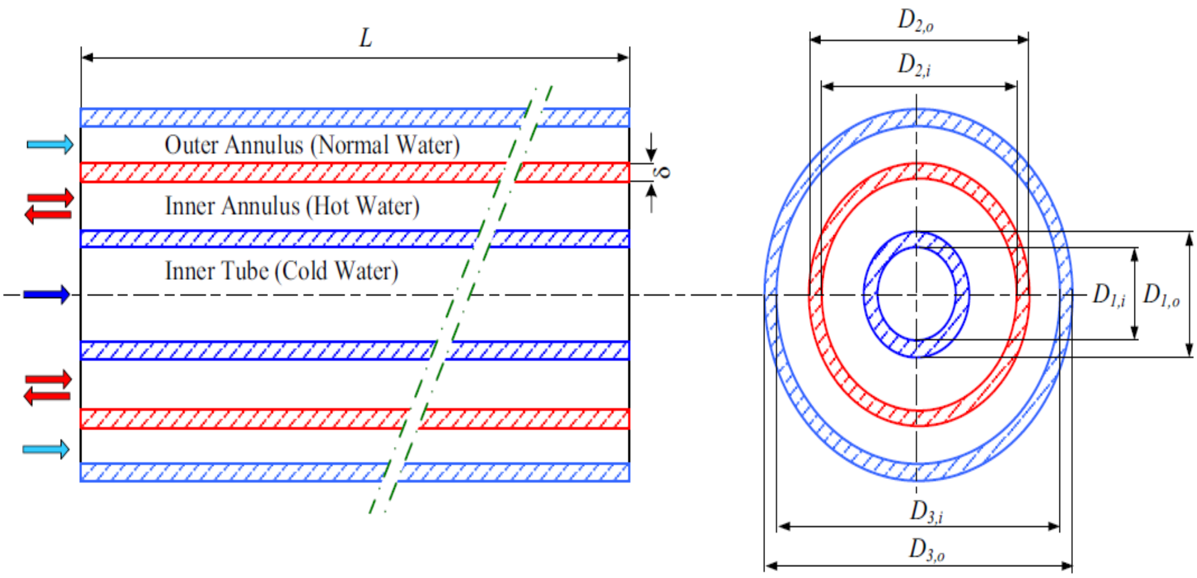

FIGURE 1. Schematic diagram of the triple concentric-tube heat exchanger.

(Courtesy: Research Paper of A. Gomaa et al. [7])

TABLE 1 Nomenclature and Subscripts

Nomenclature	**Subscripts**
D = Outer tube diameter d = Inner tube diameter p = pitch of the helix or coil l = length of the tubes n = number of turns Re =Reynolds number λ =pitch ratio (coil torsion) β= conical coil inclination angle, Rad.	i = inner circle im=intermediate circle o = outer circle

2.LITERATURE REVIEW

I. P.K. Nema and A.K. Datta et al.(2006)[10]

The present paper describes an improved simulation model for the accurate estimation of fouling thickness and milk outlet temperature. Performance of a dairy heat exchanger declines as milk fouling deposits on the heating surface. It causes an increased resistance to heat flow thereby the milk outlet temperature decreases with increasing fouling thicknesses. The paper presents an improved simulation model, which can be used to predict the fouling thickness and the milk outlet temperature very close to the experimental value. These results once again establish that fouling is controlled by temperature and shear stress on the surface of the heat exchanger. Dimensionless fouling factor in the form of the Biot number can be used in the modeling and simulation of milk fouling.

II. Quadir et al. (2014) [9]

A numerical study on heat transfer performance of a triple-tube concentric heat exchanger for different flow arrangements. He also experimentally evaluated two different flow arrangements for the triple-tube heat exchanger. It was found that for both of the arrangements, the temperature variation along the tube is significant.

III. Zheng et al.(2016)[8]

This numerically studied the heat transfer and fluid flow characteristics in an internally ribbed heat exchanger tube. Their investigation carried out on the P-type and V-type ribs. They reported respectively 57-76% and 86-94% augmentations of the Nusselt number and friction factor by employing the V-type ribs compared to the P-type ones. Also, it was found that the V-type ribs generate more intense swirl flows in comparison with the P-type ribs.

IV. Abdalla Gomaa et al. (2016) [7]

The experimental and numerical investigations of the triple concentric-tube heat exchanger are presented with particular reference to double tube heat exchanger. The purpose is to present a clear view on the thermo-fluid characteristics of this type of heat exchangers with different key design parameters leading to design optimization. Three fluids being considered are chilled water in inner tube, hot water in inner annulus, and normal tap water in outer annulus. Numerical CFD model is developed using a finite volume discretization method. The numerical model is validated and then extended to cover more extra design parameters. Four flow patterns are conducted of counter current, co-current, counter current with co-current and co-current with counter current flow. The effectiveness of triple tube heat exchanger is higher than that of the double tube heat exchanger for both parallel and counter flow by *51.4%* and *53.8%* respectively. The experiments are done for a range of Reynolds number$1720 \leq Re_{im} \leq 6260$. At a low velocity region ($Re \leq 3000$), the heat transfer per unit pumping power for double tube heat exchanger is higher than that of triple tube heat exchanger, while it is lower than that of the triple tube heat exchanger with flow velocity range ($Re \geq 3500$).

V. Giovannoni et al. (2017) [6]

This paper numerically investigated the triple-tube combustion chamber for analysis of its thermal characteristics. They concluded that employing the triple-tube heat exchanger leads to superior heat transfer rate compared to double-tube heat exchanger. The results showed that at the mass flow rate of 0.05 g/s and adiabatic condition, the percentage of combustion heat introduced to the cold mixture in the case of triple-tube heat exchanger is 18% higher in comparison with the double-tube heat exchanger.

VI. Mahmoud Abdelmagied et al.(2019)[5]

In this paper the thermo fluid characteristics of a new design of curved tube called a triple spiral tube heat exchanger (TSTHE) was achieved with a brave comparative with a double spiral tube heat exchanger (DSTHE) as particular reference. A three-dimensional computational fluid dynamic model was developed using Ansys 14.5 software package. The Realize k–ε model had been applied with enhanced wall treatment to simulate the thermo-fluid characteristics. The influence of different key design parameter such as; inlet hot fluid temperatures, flow arrangements, concentration of Alumina ($Al2O3$) nanoparticles, and Dean number were the main point of interest. The effect of Alumina-water nanofluid was considered in three different concentrations of 0.5%, 1% and 2% by volume. The results carried out at Dean number ranged from 1100 to 10,500 in the turbulent region corresponding to Reynolds number from 6400 to 57,400. The heat transfer per unit pumping power and effectiveness of DSTHE were higher than that DSTHE by 166 % and 136.3 % respectively in counter flow pattern. The increase of $Al2O3$-water nanofluid volume concentration leads to increase the convective heat transfer coefficient by 20.8 % at the same Dean number, on the expense of increasing the inner annulus friction factor by 14.17 %

VII. Mehdi Bahiraei et al. (2019) [4]

The paper attempts to numerically examine the hydrothermal characteristics and energy performance of a hybrid nanofluid containing graphene nanoplatelet–platinum composite powder in a triple-tube heat exchanger equipped with inserted ribs. The nanofluid flows in the inner annulus side, whereas the cold water and normal water flow in the tube side and outer annulus side, respectively. The ribs are installed on the outer surface of the inner tube. The overall heat transfer coefficient, effectiveness and heat transfer rate of the heat exchanger are enhanced by increasing the nanoparticle concentration and rib height and by decreasing the rib pitch. A more uniform temperature distribution is perceived at higher rib heights . The pressure drop is more intense in the cases of smaller rib pitch and higher rib height because the particles pass longer routes in these conditions. Based on the heat transfer enhancement, the case with greater rib height and smaller rib pitch at the highest concentration is suggested, because demonstrates the greatest thermal performance for the heat exchanger. carried out a numerical analysis on the performance of water–alumina nanofluid inside a spiral heat exchanger. The results showed that by increase of concentration from 0 to 5%, the convective heat transfer coefficient enhances about 26.3%.

VIII. Taraprasad Mohapatra and S. Sahoo et al.(2019)[3]

In this paper, a three fluid heat exchanger is analytically modeled in order to predict the effects of different design parameters on its thermal performances. The optimum values of these parameters relating to maximum heat transfer and minimum pressure drop are assessed using Taguchi based optimization technique. The present heat exchanger is an improvement of double tube heat exchanger, where a helical coil is inserted in the annular space occupied in between two straight tubes. The hot water is flowing through the helical coil as the heating fluid and continuously transferring thermal energy to normal water and air, which are flowing, in outer annulus and innermost straight tube.

The results of the analytical approach are compared and validated against literature and good conformity between them is observed. Three different nondimensional design parameters i.e., curvature ratio, non-dimensional coil pitch and coil side Reynolds number are selected and their effect on heat transfer and pressure drop characteristics i.e., coil side Nusselt number, effectiveness and friction factor respectively are assessed. It is found that, for tube size 0.0045 m, coil pitch 0.013 m, coil diameter 0.04253 m and hot water flow rate 5 liters per minute, present heat exchanger will perform optimum. It is also resulted that, volumetric flow rate of hot water is the most effective parameter affecting heat transfer with a contribution ratio of 66.82% and tube size is the most effective parameters affecting pressure drop with a contribution ratio of 71.07%.

IX. Mahmoud Mohammed Abdelmagied et al.(2020)[2]

The performance characteristics of a triple conically tube heat exchanger (TCTHE) are experimentally and numerically conducted. The new design developed by addition a new fluid path to a double conically tube heat exchanger (DCTHE). The research aims to evaluate the TSTHE thermal characteristics at various operating and designing key parameters involve water Reynolds number, water inlet temperatures variation, flow arrangements, inclination angles, and pitch ratios (coil torsions). A numerical model in 3D Cartesian was developed using Ansys 14.5 software package to give a clear insight on TCTHE thermal performance on a level of details not always available in experiments. A finite volume discretization method was applied to solve the governing equations. The experiments were carried out at Dean number from 450 to 6200 corresponding to Reynolds number from 2750 to 35,050. The results revealed that the effectiveness of TCTHE presents higher value compared to that of DCTHE by 50% and 57% for both experimental and numerical results. Decreasing the water inlet temperature from 80 °C to 50 °C enhances the Nusselt number, Nu by 23.2%. The counter flow pattern records a higher Nu compared to parallel flow pattern by 21.5%. Also, decreasing the coil torsion λ from 0.0111 to 0.035 enhances Nu by 34.4%, on expense of increasing the friction factor by 9.4%. Another outcome, the higher thermo-hydraulic performance index occurred at lower coil torsion of 0.035 and at 90° inclination angles β (vertical orientations).

X. Arun Kumar Tiwari et al. (2021) [1]

A novel curve tube design called Triple Tube Heat Exchanger was investigated to identify the thermo fluidic characteristics by *Arun Kumar Tiwari et al.* . This research analysis comprises of both computational fluid dynamics and experimental results. A three-dimensional computational fluid dynamics model was developed using Ansys R19.1 (fluent) research package, and the k-epsilon model is used to realize the thermo fluidic characteristic. The influence of different thermal parameters such as overall heat transfer and effectiveness were the main points of research interest by using WO3/water nanofluid with different novel inserts like twisted tape, rib, and porous plate. The thermodynamic effect of nanofluid was considered under the concentration range of 0.5%–3.0%. The computational fluid dynamics method is used to simulate the process, and experimental data is used to validate it. The result shows that the maximum overall heat transfer rate and effectiveness were 1767.91 W/m2K, 1702.71 W/m2K, and 1.86, 1.79, respectively, at 1% optimized volume concentration with WO3/water nanofluid by using rib type insert during experimental and computational fluid dynamics methods, respectively. The maximum thermal performance factor by using nanofluid in the rib type insert was observed at 0.75. The study shows an enhancement of 11.84%, 12.38%, and 14.56%, 14.30% in overall heat transfer and effectiveness by using a rib-type insert for both experimental and computational fluid dynamics methods, respectively, in comparison to without using inserts.

TABLE 2: The summarized research work results and different process parameters**.**

S. No	Title, Authors Name and Year	Type of investigation	Work -ing fluid	Dimensions and Operating conditions	Variable parameters	Main conclusion
1.	Improved milk fouling simulation in a helical triple tube heat exchanger P.K. Nema , A.K. Datta [10]	Numerical	Milk and steam	-	Dimensionless fouling factor in the form of the Biot number can be used in the modeling and simulation of milk fouling.	Improved simulation model, which can be used to predict the fouling thickness and the milk outlet temperature as a function of time and over the entire length of the heat exchanger very close to the experimental value.
2.	Numerical investigation of the performance of a triple concentric pipe heat exchanger, Quadir et al. [9]	Numerical	Water	T_h = 53 °C T_{c1} = 10 °C T_{c2} = 28 °C V_h = Vn = Vc = 35 l/m	Flow arrangement N–H–C and C–H–N	Two modes of fluid flow were suggested during the TTHE, namely N–H–C and C–H–N. The results showed that the most

						effective mode N–H–C compared to the C–H–N.
3.	Effects of rib arrangements on the flow pattern and heat transfer in an internally ribbed heat exchanger tube Nianben Zheng, Peng Liu, Feng Shan, Zhichun Liu, Wei Liu[8]	Analytical	water and air	L= 0.4m inner diameter of test section (D) =0.017 m	-Rib arrangements P-type and V-type ribs	For the range of Reynolds numbers investigated, the average Nusselt number and friction factor in the V-type ribbed tubes are about 57-76% and 86-94% higher than those in the P type ribbed tube, respectively.
4.	Experimental and numerical investigations of a triple concentric-tube heat exchanger Abdalla Gomaa, M.A. Halim, Ashraf Mimi Elsaid [7]	Experimental + Numerical	Water	$0.05 \le V_h \le 0.13$ m/s $v_c = 0.7$ m/s $v_n = 0.05$ m/s $50 \le T_h \le 70$ °C $T_c = 10$ °C $T_n = 18$ °C	- Flow pattern -Annulus spacing -Fluid temperature	Experimental results depicted that the effectiveness of the TTHE is higher in the case of parallel and counter flow pattern than the DTHE by approximately 51.4% and 53.8%, respectively.
5.	Numerical prediction of thermal performances in a concentric triple tube heat exchanger, Giovannoni et al. [6]	Numerical	Cold fuel-air mixture and hot fluid-combustion products	$0.05 \le V \le 0.15$ g/s	-	The triple tube combustion chamber permits a kindly level of renewal and the implication of a flame holder resulting in a further advantage in terms of heat transferred to the cold mixture.
6.	Thermal performance characteristics of a triple spiral tube heat exchanger, Mahmoud Abdelmagied [5]	Numerical	Alumina-water nanofluid	1.Heat exchanger length=2392.72 mm 2. Outer tube Di: 19.93mm; Do: 22.22mm 3.Intermediate tube D_i: 14.1 mm; D_o: 15.87 mm 4. Inner tube Di: 5.93mm; Do: 7.94mm p (mm) =35 N= 4 $50 \le T_h \le 80$°C Tc = 20 °C $T_n = 20$ °C	-Concentration of Alumina-water nanofluid -flow arrangement.	A notice augmentation of heat transfer enhancement occurs due to use Alumina–water nano fluid in TSTHE by 20.8 %.
7.	Application of a hybrid nanofluid containing graphene nanoplatelet–platinum composite powder in a triple-	Experimental + Numerical	GNP –P $0 \le \phi \le 0.1\%$ Vol.	$0.05 \le v_h \le 0.13$m/s $v_c = 0.7$ m/s $v_n = 0.05$ m/s	- Rib height - Rib pitch	Increasing the concentration ratio of nanomaterials, the rib height, and reduces

	tube heat exchanger equipped with inserted ribs M. Bahiraei et al. [4]		Base fluid-Water	$50 \le T_h \le 70$ °C Tc = 10 °C Tn = 18 °C		the rib pitch lead to a marked improvement in the heat transfer rates and the increased effectiveness of the TRTHE.
8.	Analytical investigation and performance optimization of a three fluid heat exchanger with helical coil insertion for simultaneous space heating and water heating, Taraprasad Mohapatra & Biranchi N. Padhi & Sudhansu S. Sahoo [3]	Analytical	water and air	Test section Length=1.8m. It consists two concentric parallel straight tubes and one helical coil Outermost (G.I. material): Di=.07m, t_o=.0025m Innermost (Cu material): di=.0268m, ti=0.001m $T_{h,1}$ = 62.5 °C, $T_{n,1}$ = 32 °C & Ta,1 = 35 °C	- coil curvature ratio, δ = 0.091, 0.152 and 0.216 coil pitch, λ = 0.083, 0.115 and 0.148	For maximum heat transfer in TFHE, the optimum value of different design parameters were obtained as dc,i = 0.0045 m, p = 0.018 m, Dc = 0.04253 m and V˙ h: = 5LPM.
9.	Investigation of the triple conically tube thermal performance characteristics Mahmoud Mohammed Abdelmagied [2]	Experimentally and numerically	Water	1.L =2760mm 2.Outer tube Di: 19.93 mm; Do: 22.22 mm 3. Intermediate tube Di: 0.044 m; Do: 0.048 m 4. Inner tube D_i:0.020 m; D_o:0.024 m	T_h= 50, 60, 70, and 80 °C Three coils with different pitch ratios of 0.035, 0.071, and 0.111 and three inclination angles of 0°, 45°, and 90°	Decreasing the water inlet temperature from 80 °C to 50°C enhances the Nusselt number, *Nu* by 23.2%. At the same condition, reducing *λ* from 0.111 to 0.035 enhances the Nu_h by 34.4%.
10.	Experimental and numerical investigation on the thermal performance of triple tube heat exchanger equipped with different inserts with WO3/water nanofluid under turbulent condition (2021) Arun Kumar Tiwari et al. [1]	Experimental and numerical investigation	WO3/water nano fluid	1. L=750 m 2. Outer tube Di: 0.064 m; Do: 0.068m 3. Intermediate tube Di: 0.044 m; Do: 0.048 m 4. Inner tube Di: 0.020 m; Do: 0.024m	m_i = 0.051 kg/s $0.017<m_{im}<$ 0.068 kg/s m_{io}= 0.051 kg/s	An enhancement of 14.30%, 10.64%, and 5.38% in the ε using rib, porous plate, and twisted tape inserts is achieved without using inserts through experimental and CFD analysis.very close to the experimental value.

3. CONCLUSION

Due to the wide application of heat exchangers in various industries, improving the heat transfer and increasing the efficiency are very important. Accordingly, a lot of researches have been performed to increase heat transfer. Triple-tube heat exchangers are introduced to solve the disadvantages of double-tube heat exchangers by passage of the extra flow and increase of heat transfer area per unit length. As per the review done it is found that there is need to carry out the investigate the heat transfer rate with structural modification of Triple- concentric tube heat exchangers. And the heat transfer phenomena can be effectively enhanced by using the geometry modification like corrugation and the further research can be gone in this direction.

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