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Review on Heat Transfer Phenomena using corrugated tubes in Heat Exchangers

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A B S T R A C T : Heat exchangers are used in different purposes in various industrial, commercial & domestic applications. Some common examples include sensible cooling & heating in chemical processing, condensation and steam generation in power plants, agricultural and pharmaceutical products, waste heat recovery etc. Increase in Heat exchangers performance can lead to more economical design of heat exchanger which can help to make energy, material & cost savings related to heat exchange process. Making corrugation on pipe smooth surface is one such technique. Literature shows numerous work being carried out in this area, where parameters under study are inside diameter of pipe, corrugation depth, corrugation pitch, temperature and phase of liquid. The combination of varying inside diameter of tube, ratio of corrugation depth to inside diameter and ratio of corrugation pitch to inside diameter shows effective results pertaining to enhancement of heat transfer. Results showed that corrugated tubes can enhance heat transfer coefficient on both the outer and inner heat transfer surface area without a significant increase in pressure drop. It also results in Increase in fluid mixing, unsteadiness, turbulence flow or by limiting the growth of fluid boundary layers close to the heat transfer surface is done by corrugation on the surface of pipe.

Keywords: Heat exchanger, heat augmentation, corrugated pipe

1. Introduction

Heat exchangers are used in different purposes ranging from conversions, utilization & recovery of thermal energy in various industrial, commercial & domestic applications. Some common examples include condensation and steam generation in power plants, sensible cooling & heating in chemical processing, agricultural and pharmaceutical products, fluid heating in manufacturing & waste heat recovery etc. Increase in Heat exchangers performance can lead to more economical design of heat exchanger which can help to make energy, material & cost savings related to heat exchange process. Heat transfer augmentation is a technique needed to increase the thermal performance of heat exchangers effecting energy, material & cost savings. These techniques are also referred as “heat transfer enhancement techniques” or “heat transfer intensification techniques”. Convective heat transfer is improved by reducing the thermal resistance in the heat exchanger is what augmentation techniques do. This heat transfer augmentation technique lead to increase in heat transfer coefficient but at the cost of increase in pressure drop. So, analysis of heat transfer rate and pressure drop are the major parameter which are to be taken care of during design of heat exchanger using any of this techniques. Heat transfer augmentation method refer to the improvement of thermo-hydraulic performance of heat exchangers. Existing enhancement techniques can be broadly classified into three different categories: (a) Passive Method (b) Active Method and (c) Compound Method.

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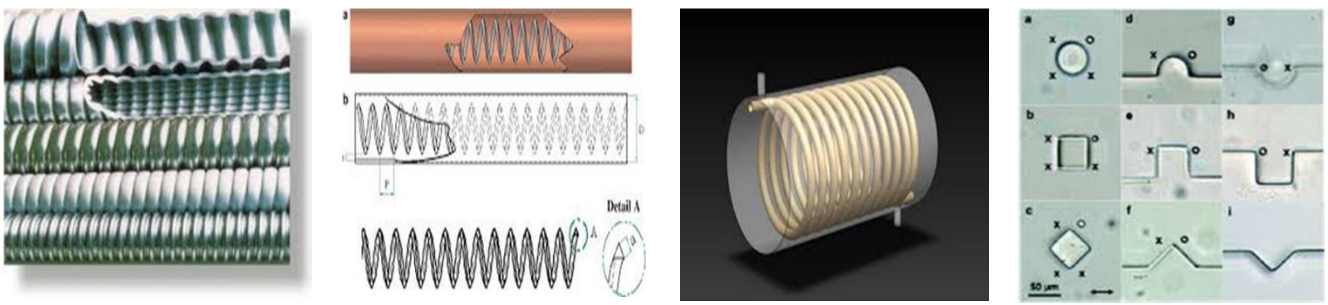
Passive Method: These methods generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. This inserts results into increase in the pressure drop but on other hand they promote higher heat transfer coefficient by disturbing the existing flow behavior. In case of extended surfaces, effective heat transfer area on the side of the extended surface is increased. Passive method hold the advantage over the active method as they do not require any direct input of external power. Heat transfer augmentation by these methods can be achieved by using treated surfaces, rough surfaces, extended surfaces, displacement enhancement devices, swirl flow devices, coiled tubes, additives for liquids, flow disruptions, channel curvature, re-entrant obstructions, and secondary flows.

Active Methods: These methods are more complex in nature from the use and design point of view as the method requires some external power input to cause the desired flow modification and improvement in the rate of heat transfer. It finds limited application because of the need of external power in many practical applications. In comparison to passive methods, these method have not shown much potential as it is difficult to provide external power input in many cases. Various active techniques are as follow mechanical aids, surface vibration, fluid vibrations, electrostatic field, injection, suction, and jet impingement.

Compound Methods: A compound augmentation method is the one where more than one of the above mentioned method is used in combination with the purpose of further improving the thermo-hydraulic performance of a heat exchanger. Figure 1 shows various heat augmentation techniques.



(a) Corrugated Tubes (b)Twisted tape insert in a tube (c) Coiled heat exchanger (d) Flow obstruction in a channel

Fig. 1 Various Heat Augmentation Technique [1]

2. Literature Review

Heat transfer enhancement technique can produce superior heat exchanger performance. One such technique is the use of corrugated tube instead of smooth tube. Corrugated tubes can enhance heat transfer coefficient on both the outer and inner heat transfer surface area without a significant increase in pressure drop. Increase in fluid mixing, unsteadiness, turbulence flow or by limiting the growth of fluid boundary layers close to the heat transfer surface is done by corrugation on the surface of pipe. In order to reduce the size of industrial shell and tube heat exchangers corrugated tubes are chosen. However, use of corrugated tubes to replace conventional smooth tubes has only been reported over past two decades. It is still a new method for improving the heat transfer performance of heat transfer equipment. So far, the heat transfer and flow characteristics of corrugated tube have been reviewed as described in the following subsection and in Table 1.

Zimparov [2], investigated for heat transfer enhancement using combination of three-start spirally corrugated tubes with twisted tape. The test section comprises of three start spirally corrugated tubes combined with five twisted tape inserts with different relative pitches. The Reynolds number in the range from 3000 to 60000 were varied during experiments. The height to diameter ratio (e/di) and relative pitch (p/di) parameters were 0.0407, 0.0569 and 15.3, 12.2, 7.7, 5.8, 4.7 respectively. Zimparov [3], showed that friction factors and heat transfer coefficients obtained from these tubes were higher than those of smooth tube under same conditions. Zimparouv [4,5] developed a mathematical model in a turbulent flow regime to calculate friction factor and heat transfer coefficient for a spirally corrugated pipe combined with twisted tape inserts. The results obtained were compared with experimental data. The results showed good agreement between the predicted and experimental data.

Rainieri and Pagliarini [6] conducted experiments to investigate thermal performance of corrugated tubes. Different corrugation such as helical and transverse were made on the smooth surface of the pipe with different pitches. Reynolds number ranging from 90 to 800 were varied in experiments and working fluid employed was ethylene glycol. On comparison between three types of tubes such as smooth tube, helical corrugated tubes and transverse corrugated tube, the results showed that helical transverse corrugated tubes were having the highest heat transfer enhancement than helical corrugated and smooth tubes.

Table 1 Maximum velocity of air in the room at different length distance [1]

Sources	di (mm)	e/di	p/di	β (deg)	Phase
Zimparov [2]	13.68-13.73	0.0407-0.0569	4.7-15.3	67.4-68	Single Phase
Zimparov [3]	13.39 – 13.65	0.0371-0.0441	2.4-7.7	79.3-82.2	Single Phase
Zimparov [4,5]	12.44 – 13.90	0.0224 – 0.0569	7.45-21.17	67.4-90	Single Phase
Rainieri and Pagliarini [6]	14	0.107	1.143-4.571	-	Single Phase
Laohalertdecha and Wongwises [7]	8.7	0.1724	0.584 – 0.9724	74.2-79.47	Two Phase
Laohalertdecha and Wongwises [8]	8.7	0.1724	0.584 – 0.9724	74.2-79.47	Two Phase
Barba et al. [9]	14.5	0.103	0.793	45	Single Phase
Nozu et al. [10,11]	17.2	0.0174	0.407	-	Two Phase
Laohalertdecha and Wongwises [12]	8.7	0.115 – 0.1724	0.584 – 0.9724	74.2-79.47	Two Phase
Vicente et al. [13]	18	0.0239-0.0572	0.608-1.229	68-80	Single Phase
Dong et. al. [14]	16.04 –22.82	0.0243 – 0.0398	0.438 – 0.623	78.8 – 82.1	Single Phase
Targanski and Cieslinski [15]	8.8	0.0511	0.681	77.75	Two Phase

Laohalertdecha and Wongwises [7,8] studied condensation and evaporation process in a corrugated tubes with R-134a as working fluid. The behavior of heat transfer coefficient and pressure drop due to change in pitch were prime focus of study. For all experimental conditions performed, corrugated tube are better than those of the smooth pipe for heat transfer coefficient and pressure drop. Moreover, the results also showed that the corrugation surface promotes turbulent flow. On the other hand, the effect of pitch on the pressure drop was insignificant.

Babra et al. [9] experimentally studied heat transfer process in chemical and food industry for single phase using corrugated tube. Reynolds number were varied from 100 to 800 and ethylene glycol was used as working fluid. Experimental findings showed that heat transfer enhancement using corrugated tube over smooth pipe was from 4.27 to 16.79. The friction factor also shows the increase by up to 1.83 to 2.45 times as compared to smooth tubes. They proposed correlation for Nusselt number and friction factor using this experimental data.

Nozu et al. [10,11] conducted experiments in the annulus of a double – tube coil consisting of three U – bends and four straight lengths. The working fluid used in experiments were R-113, R-114 and a zeotropic refrigerant mixture during condensation process. The test section comprises of a corrugated copper tube having inner diameter of 17.2 mm. The mass flow rate was varied in the range of 80 to 240 kg/sm^2. The results showed that U bend showed higher heat transfer coefficient as compared to straight tubes and local heat transfer coefficient decreased along the tube length.

Laohalertdecha and Wongwises [12] conducted experiments for condensation process and R-134a was used as working fluid. The test section was a horizontal counter flow tube in tube heat exchanger having test length of 2000 mm. Inside tube of tube in tube were changed during experiments, one was smooth pipe and another was corrugated pipe having inner diameter of 8.7 mm. the outer tube was made from smooth copper tube with inner diameter of 21.2 mm. Corrugation depths were 1, 1.25 and 1.5 mm, whereas pitches used were 5.08, 6.35 and

8.46 mm respectively. The results showed that the Nusselt number and two phase friction factor were significantly higher for corrugated tubes as compared to smooth pipe.

Vicente et al. [13] presented measurements of mixed convection heat transfer and isothermal pressure drop in corrugated tubes for laminar, transition and turbulent flow regions. The working fluid used were water and ethylene glycol. The results indicated that the corrugated tubes have higher heat transfer enhancement as compared to smooth tube over specified conditions. Pressure drop significantly increased from 25% to 300% when flow starts from laminar region and when subsequently reaches turbulent region.

Dong et al. [14] experimentally determined the turbulent friction and heat transfer characteristics for four spirally corrugated tubes with various geometrical parameters. The working fluid used were water and oil. Reynolds number was varied from 6000 and 93000 for water and from 3200 to 19000 for oil. Compared to smooth pipe, their results showed that the heat transfer coefficient enhancement varied from 30% to 120%, while the friction factor increased from 60% to 160%.

Targanski and Cieslinski [15] conducted experiments during evaporation inside a smooth stainless steel pipe, smooth copper pipe and two enhanced pipes. The working fluid used to study the heat transfer coefficient and pressure drop are pure R-407C and R-407C/oil mixtures. The parameters which were controlled are average saturation temperature, mass flow, inlet vapor quality and exit vapor quality, whose values were 0°C, 250 to 500 $kg/m^2.s$, 0 and 0.7 respectively. It was observed that the heat transfer coefficient and pressure drop for the enhanced tubes were distinctly higher than those of the smooth tube. The maximum enhancement factor and penalty factor for corrugated tube were 1.25 and 1.8, respectively.

Subhashis Ray et. al.[16], the possibility of using wire loop structures on the active plate of a parallel plate channel for efficient heat transfer augmentation was explored. For this purpose, experiments and numerical simulation were carried out for periodically fully developed turbulent flow in typical repeating modules using the reliable k – ε model. Reynolds number was varied from 2000 to 20000. The effect of three different loop densities on fluid flow and heat transfer characteristics were investigated when wire loops were place perpendicular to the main flow direction. Studies were carried out for fixed loop density of 2270 loop/m2 on the effect of loop orientation on various parameters. The maximum attainable loop density was found to strongly depend on the loop orientation owing mainly to the geometric as well as manufacturing constraints. Loops oriented diagonally to the main flow direction offer the best performance was observed.

Mohsen Sheikholeslami et. al. [17] , insertion of swirl flow devices enhance the convective heat transfer by making swirl into the bulk flow and disrupting the boundary layer at the tube surface due to repeated changes in the surface geometry. In this it was observed that: the heat transfer coefficients of the coiled tubes with larger pitches are less than those of the ones with smaller pitches; and the effect of pitch on Nusselt number is more visible in high temperatures. Delta winglets generate the vortexes which increases the heat transfer without much increase in friction factor in solar air heater or heat exchangers. Curved trapezoidal winglet delta winglet had the best thermo – hydraulic performance in fully turbulent flow region. Wire coil gives better overall performance if the pressure drop penalty is considered. The use of coiled square wire tabulators leads to a considerable increases in heat transfer and friction loss over those of a smooth wall tube. The helical ribs have a significant effect on the heat transfer and pressure drop augmentations. The use of coiled square wire turbulators leads to a considerable increase in heat transfer and friction loss over those of a smooth wall tube.

Jian Guo et al. [18] To get the best heat transfer performance with the least flow resistance laminar forced convective heat transfer was studied. The variation calculus method is employed to establish the equations describing the optimized fluid velocity field and temperature field. Numerical solutions of the equations for a convective heat transfer process in a section cut of a square duct indicate the optimized flow should have a tranverse secondary swirl flow pattern considering of multiple vortexes with identical swirl direction in the junction region of any two neighboring vortexes. The calculated transverse secondary flow in the tube with four reverse vortex generator inserts approximately follows the optimized flow pattern and the tube is thus found to have the best thermo – hydraulic performance, validating the proposed convective heat transfer enhancement method. The objective function for heat transfer enhancement and the constraint function for external pump work consumption were derived, and the optimization equation for flow and temperature fields were established via the variation calculus method. Enlightened by these theoretical results, a novel convective heat transfer enhancement method for laminar flows was proposed, which relies on the excitation of transverse swirl flow**.**

Taye Stephen Mogaji et. al. [19], this study was regarding experimental analysis of heat transfer coefficient and pressure drop during two-phase flow of R134a in a horizontal tube containing twisted tape inserts. For a twist ratio of 9, the enhancement parameter given by the ratio between the heat transfer enhancement and pressure drop penalty ranged from 0.08 to 0.12 for a mass velocity of 75 kg m-2 s-1 and from 0.35 to 1.40 for a mass velocity of 150 kg m^{-2} s^{-1}. . The analysis of the enhancement parameter allowed concluding that the use of twisted tape is suitable when it is applied to the high vapor quality region of the evaporator and under mass velocities higher than 150 kg m^{-2} s^{-1}**.**

M M K Bhuiya et al. [20] The study explored the effects of the double counter twisted tapes on heat transfer and fluid friction characteristics in air flow in a heat exchanger tube. Four different twist ratios were used in experiment with double counter twisted tapes ie. y = 1.95, 3.85, 5.92 and 7.75 using air as testing fluid in a circular tube turbulent flow region where the Reynolds number was varied from 6950 to 50,050. The double counter twisted tape offered a significant enhancement of heat transfer, friction factor as well as thermal enhancement efficiency compared with the plain tube values. The Nusselt number and friction factor for the tube with double counter twisted tape inserts obtained were 60 to 240% and 91 to 286% higher than those of the plain tube values at the comparable Reynolds number respectively.

Wen-Chieh Huang et al.[21] , Heat transfer enhancement of repeated ring-type ribs in circular tubes was experimentally investigated. Air, water and ethylene glycol – water solution (33.3% EG by vol.) were used as the working fluid. The Reynold number (Re) was in the range of 3601 – 26025 and the Prandtl number (Pr) was in the range of 0.7-15.6. The rib pitch-to-tube inner diameter ratio (p/d) and rib height-to-tube inner diameter ratio (e/d) were arranged in the range of 0.29-5.8 and 0.025-0.069 respectively. The Nusselt value increases with e/d value and it decreases with an increase of the p/d value. In addition, the Nu value increases with the Re value and it is proportional to the 0.45 power or the Pr value. The mechanical energy consumption index and the Nu enhancement index were used to compare the heat transfer enhancing tubes to a smooth tube. At e/d 60.043, for achieving an effective heat transfer enhancement, the p/d value needs to be smaller than 4.35 at e/d 0.069, for avoiding a large pressure drop, the p/d value should be larger than 1.45.

Tabish Alam et. al. [22] , Various turbulence generators such that ribs, baffles and delta winglets are considered as an effective technique. This paper represents the extensive literature review of various tabulators investigated for enhancing heat transfer and friction in solar air heaters and heat exchangers. The correlations developed for heat transfer and friction factor in solar air heaters and heat exchangers by various investigators have been presented and reviewed. Transvers rib at different angle further enhances the heat transfer due to movement of vortices along the rib and formation of a secondary flow cell which results in high heat flow region near the leading end. Delta winglets generate the vortexes which increase the heat transfer without much increase in friction factor in solar air heater or heat exchangers. Thus there is tremendous scope.

3. Summary

As discussed above, papers reflect the experimental work carried out regarding evaluation of single phase heat transfer in corrugated tube and other. Work pertaining to heat transfer enhancement using corrugated tube in two phase flow are limited. However, little information is now available for some cases on two phase heat transfer enhancement by using corrugated tube. There are no suitable correlations for heat transfer coefficient, pressure drop characteristics and other important relevant parameters yet available. Typically, corrugated tubes can improve the heat transfer performance on the heat exchanger in order to reduce the size of the heat exchangers. Heat transfer enhancement is achieved not only by employing corrugation on tubes but recently few more techniques have been developed which are using wire loop structures inside a pipe, by introducing some obstruction at inlet of flow creating swirl motion, by controlling the velocity of flow, by using twisted tape inserts etc. By employing all such means to increase the heat transfer phenomena care must be taken that it must not be at the cost of pressure drop caused. Because increase in pressure drop may lead to increase in pumping energy, ultimately results in increase of energy consumed. Hence, enhancement of heat transfer must be economical and not at the cost of any other waste of energy.

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