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A Review on Heat Transfer Enhancement Using Twisted Tape Inserts in a Tube Heat Exchanger

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Abstract- Heat exchangers are now commonly used in a wide range of applications in chemical process and other industrial applications. Hence, improvement of the hydraulic performance of heat exchangers is very necessary for provision energy. Based on different applications, various types of methods are applied using the passive technique to enhance the rate of heat transfer such as devices of swirl flow, devices of surface tension devices, extended and coated surfaces, coarse surfaces, coiled pipes, and anything that include applying special surface geometry. This paper provides a comprehensive review of passive heat transfer devices for wide variety of industrial applications.

Keywords: Heat exchangers, surface geometry, industrial applications.

I. INTRODUCTION

Heat transfer devices have been used for the conversion and recovery of heat in many industrial and domestic applications. Some examples are boiling of liquid and condensation of steaming power plants, thermal processes involved in pharmaceutical and chemical industries, sensible heating and cooling of milk in dairy industries, heating of fluid in concentrated solar collector and cooling of electrical machines and electronic devices among others. Enhancing the performance of a heat transfer device is therefore of great interest since it can result in energy, material and cost saving.

Heat exchangers are used in different procedures spanning from conversion, consumption & recovery of thermal energy in various industrial, industrial & domestic applications.

Some general examples include steam generation & concentration in power & cogeneration plants; sensible heating & cooling in thermal processing of chemical, pharmaceutical & agricultural products; fluid heating in manufacturing & waste heat recovery etc. Increase in Heat exchanger's performance can lead to more economical design of heat exchanger which can help to make energy, material & cost savings related to a heat exchange process.

The need to increase the thermal performance of heat exchangers, thereby effecting energy, material & cost savings have led to advancement & use of many techniques as ―Heat transfer Augmentation. These methods are also known as ―Heat transfer Enhancement or ―Intensification. Augmentation techniques increase convective heat transfer by decreasing the thermal resistance of equipment.

Nowadays, heat exchangers with twisted-tape inserts have widely been applied for enhancing the convective heat transfer in various industries such as thermal power plants, chemical processing plants, air conditioning equipment, refrigerators, petrochemical, biomedical and food processing plants. In general, twisted tape insert introduces swirl into the bulk flow which consequently disrupts a thermal boundary layer on the tube surface.

The thermal performance of heat exchangers can be increased by heat transfer enhancement methods. Tape insert is one of the passive heat transfer enhancement method and used in most heat transfer application, for example, air conditioning and refrigeration systems food processes.

Enhancing the thermal performance of heat exchange affects directly on energy, material and cost savings. Consequently, improving the heat exchange can significantly improve the thermal

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efficiency in applications involving heat transfer processes as well as the economics of their design and operation [1]. DPHEs are primarily adapted to high temperature and high-pressure applications due to their small diameters. They are cheap, but the space they occupy is relatively high compared to the other types. To achieve the desired heat transfer rate in the given design and length of the heat exchanger at an economic pumping power, numerous techniques have been provided. These improvement techniques were classified as active and passive techniques [2, 3].

II. LITERATURE REVIEW

Azher et al. (2018) studied forced convection heat transfer through a horizontal pipe built-in with/without twisted tape-inserts is numerically studied under a uniform heat flux condition. Water is used as a working fluid. The governing equations are numerically solved in the domain by a finite volume method (FVM) using the Realizable κ–ε (RKE) model.

The computational results are performed for a range of the Reynolds number ($4000 \leq Re \leq 9000$), the twisted ratio ($4.0 \leq TR \leq 6.0$), and heat flux ($5000 \leq q \leq 1000$ W/m^2).

Sivakumar et al. (2018)investigate the friction factor characteristics and heat transfer characteristics of a concentric tube with triangular cut twisted tape (TCTT) insert with twist ratio Y is 5.4 and depth of triangular cut was 1.2 cm were studied for laminar flow. This investigation also to find the Nusselt number, heat transfer coefficient and Reynolds number. The heat transfer enhancement was caused with the flow of fluid between the plain twisted tapes and twisted tape with triangular cut (TCTT).

Mahipal et al. (2018) deals with the use of swirl flow devices with different combinations as passive heat transfer augmentation technique. In this article, the two different swirl flow devices used are namely twisted tape (TT) and wire coil (WC) tabulator. The present work deals with the counter flow type condition of heat exchanger.

Effect of different length combination of these two different tabulator twisted tape and wire coil on the heat transfer, friction factor and pressure drop for Reynolds number ranges from 2000-10000, has studied in double pipe heat exchanger (single pass).

Agrawal et al. (2018) Heat transfer enhancement technique refers to different methods used to increase rate of heat transfer without affecting much overall performance of the system. These techniques are used in heat exchangers, some of the application of heat exchangers are in process industries, thermal power plant, air conditioning equipment, refrigerator, radar for space vehicles, automobiles etc. In the past decades several studies on passive techniques of heat transfer enhancement have been reported. This paper reviews mainly on twisted tape heat transfer enhancement and its design modification towards the heat transfer enhancement and saving pumping power.

Bhattacharyya et al. (2017) Numerical investigation of heat transfer characteristics in a tube fitted with inserted twisted tape swirl generator is performed. The twisted tapes are separately inserted from the tube wall. The configuration parameters include the, entrance angle (α) and pitch (H).Investigations have been done in the range of $\alpha = 180^o$, 160^o and 140^o with Reynolds number varying between 100 to 20,000.

Maradiya et al. (2017) Heat transfer devices have been used for conversion and recovery of heat in many industrial and domestic applications. Over five decades, there has been concerted effort to develop design of heat exchanger that can result in reduction in energy requirement as well as material and other cost saving. Heat transfer enhancement techniques generally reduce the thermal resistance either by increasing the effective heat transfer surface area or by generating turbulence.

Mahdi et al. (2016) reported the use of variant twisted tapes fitted in a double pipe heat exchanger to improve the fluid mixing that leads to higher heat transfer rate with respect to that of the plain-twisted tape. Heat transfer, flow friction and thermal enhancement factor characteristics in a double pipe heat exchanger fitted with plain and variant twisted tapes using water as working fluid are investigated experimentally.

Jedsadaratanachai et al. (2014) presents a numerical analysis of laminar fully developed periodic flow and heat transfer in a constant temperature-surfaced circular tube with single twisted tape inserted. The twisted tape is introduced and inserted in the middle of the tested tube. The effects of twisted ratios (y/W = 1, 2, 3, 4, 5and 6) are presented for Reynolds number (Re) values ranging from Re = 100 to 2000.

Pawan et al. (2013) investigate the level of heat transfer enhancement that can be achieved by forced convection in which water is flow inside horizontal pipe. The use of semi-circular cut inserts generate turbulence and superimposed vortex motion (swirl flow) causing a thinner boundary layer and consequently resulting in higher heat transfer coefficient with relatively low flow resistance. The study is focused on Reynolds number in turbulent flow.

Liu et al. (2013) reviewed experimental and numerical works taken by researchers on this technique since 2004 such as twisted tape, wire coil, swirl flow generator etc. to enhance the thermal efficiency in heat exchangers and useful to designers implementing passive augmentation techniques in heat exchange.

The authors found that variously developed twisted tape inserts are popular researched and used to strengthen the heat transfer efficiency for heat exchangers. The other techniques used for specific work environments are studied in this paper. Twisted tape inserts perform better in laminar flow than turbulent flow. However, the other several passive techniques such as ribs, conical nozzle, and conical ring, etc. are generally more efficient in the turbulent flow than in the laminar flow.

Mogaji et al.(2013)presents experimental results of heat transfer coefficient and pressure drop during two-phase flow of R134a in a horizontal tube containing twisted-tape inserts. The test section is a 2 m long copper tube of 15.9 mm inner diameter. The experiments were performed for tapes with twist ratios of 9 and 14 and a tube without insert. The mass velocity ranged from 75 to 200 kg m^2/s and the vapor quality from 5 to 95%, for adiabatic condition and for constant heat flux of 10kW/m^2.

Mazen et al. (2012) presented the advances in plate heat exchangers both in theory and application. It dresses the direction of various technical research and developments in the field of energy handling and conservation. The selected areas of heat transfer performance and pressure drop characteristics, general models and calculations change of phase; boiling and condensation, fouling and corrosion, and welded type plate heat exchangers and finally other related areas are highlighted.

Bas et al. (2012) Flow friction and heat transfer behavior in a twisted tape swirl generator inserted tube are investigated experimentally. The twisted tapes are inserted separately from the tube wall.

The effects of twist ratios (y/D = 2, 2.5, 3, 3.5 and 4) and clearance ratios (c/D = 0.0178 and 0.0357) are discussed in the range of Reynolds number from 5132 to 24,989, and the typical one (c/D = 0) is also tested for comparison. Uniform heat flux is applied to the external surface of the tube wall. The air is selected as a working fluid.

The obtained experimental results from the plain tube are validated by using well known equations given in literature.

Zhang et al. (2012) presents a simulation of multi-longitudinal vortices in a tube induced by triple and quadruple twisted tapes insertion. The simulation is conducted in order to gain an understanding of physical behavior of the thermal and fluid flow in the tube fitted with triple and quadruple twisted tapes for the Reynolds number from 300 to 1800. The obtained results show that, a maximum increase of 171% and 182% are observed in the Nusselt number by using triple and quadruple twisted tapes.

Guo et al. (2011) proposed a centre-cleared twisted tape aiming at achieving good thermo hydraulic performance. Comparative study between this type and the short-width twisted tape was performed numerically in laminar tubular flows.

The computation results demonstrated that the flow resistance can be reduced by both methods; however, the thermal behaviors are very different from each other. For tubes with short width twisted tapes, the heat transfer and thermo hydraulic performance are weakened by cutting off the tape edge.

Contrarily, for tubes with centre-cleared twisted tapes, the heat transfer can be even enhanced in the cases with a suitable central clearance ratio. The thermal performance factor of the tube with centre-cleared twisted tape can be enhanced by 7 to 20% as compared with the tube with conventional twisted tape. All these demonstrated that the center-cleared twisted tape is a promising technique for laminar convective heat transfer enhancement.

Murugesan et al. (2011) studied the effect of V-cut twisted tape insert on heat transfer, friction factor and thermal performance factor characteristics in a circular tube were investigated for three twist ratios (y=2.0, 4.4 and 6.0) and three different combinations of depth and width ratios (DR=0.34 and WR=0.43, DR=0.34 and WR=0.34, DR=0.43 and WR=0.34).

The obtained results show that the mean Nusselt number and the mean friction factor in the tube with V-cut twisted tape (VTT) increase with decreasing twist ratios (y), width ratios (WR)and increasing depth ratios (DR). Subsequently an empirical correlation also was formulated to match with experimental results with ±6% variation for the Nusselt number and ±10% for the friction factor.

Hejazi et al. (2010) had done comprehensive experimental investigation is conducted on the augmentation of heat transfer coefficients and pressure drop during condensation of HFC-134a in a horizontal tube at the presence of different twisted tape inserts. The test section is a 1.04 m long double-tube counter-flow heat exchanger.

The refrigerant flows in the inner copper and the cooling water flows in annulus. The experiments are performed for a plain tube and four tubes with twisted tapes inserts of 6, 9, 12 and 15 twist ratios.

The pressure drop is directly measured by differential pressure transducer. It is found that the twisted tape with twist ratio of 6 gives the highest enhancement in the heat transfer coefficient and the maximum pressure drop compared to the plain tube on a nominal area basis.

Sarada et al. (2010) present work shows the results obtained from experimental investigations of the augmentation of turbulent flow heat transfer in a horizontal tube by means of varying width twisted tape inserts with air as the working fluid. In order to reduce excessive pressure drops associated with full width twisted tape inserts, with less corresponding reduction in heat transfer coefficients, reduced width twisted tapes of widths ranging from 10 mm to 22 mm, which are lower than the tube inside diameter of 27.5 mm are used.

III. CONCLUSION

Heat transfer enhancement techniques generally reduce the thermal resistance either by increasing the effective heat transfer surface area or by generating turbulence in the fluid flowing inside the device. Rough surfaces or extended surfaces are used for the purpose of increasing the effective surface area whereas inserts, winglets, tabulators etc. are used for generating the turbulence.

These changes are usually accompanied by an increase in pumping power which can results in higher cost. The effectiveness of a heat transfer enhancement technique can be evaluated by the Thermal Performance Factor (TPF) which represents the ratio of the relative effect of change in heat transfer rate to change in friction factor.

In general, some kind of inserts is placed in the flow passage to augment the heat transfer rate, and this reduces the hydraulic diameter of the flow passage. Heat transfer enhancement in a tube flow by inserts such as twisted tapes, wire coils, ribs and dimples is mainly due to flow blockage, partitioning of the flow and secondary flow. Flow blockage increases the pressure drop and leads to increased viscous effects because of a reduced free flow area.

Blockage also increases the flow velocity and in some situations leads to a significant secondary flow. Secondary flow further provides a better thermal contact between the surface and the fluid because secondary flow creates swirl and the resulting mixing of fluid improves the temperature gradient, which ultimately leads to a high heat transfer coefficient twisted tape generates a spiral flow along the tube length. A wire coil insert in a tube flow consists of a helical coiled spring which functions as a non-integral roughness.

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