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Enhancing Heat Transfer Efficiency In Heat Exchangers Using Conical Tape Inserts

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Abstract
Researchers have extensively explored diverse methods to enhance heat transfer rates in conjunction with reducing the size and cost of heat exchanger systems. In pursuit of these objectives, passive heat transfer techniques have played a pivotal role, with the deployment of inserts being a prominent tool to augment turbulence within the flow. Prior research has conducted comprehensive investigations, both experimentally and numerically, into a variety of insert designs, encompassing twisted tape, wire coils, swirl flow generators, ribs, louvered strips, conical rings, and alterations in tube geometry, including the transition from plain tubes to conical configurations. These methodologies have aimed at improving several critical parameters within heat exchangers. Through an in-depth analysis of past approaches geared towards optimizing turbulence and overall performance, conical tape inserts have emerged as a methodologically robust solution. Researchers have observed that conical tape inserts have garnered substantial attention and widespread adoption for enhancing the overall efficiency of heat exchangers, particularly in conjunction with Nanofluids. Furthermore, studies have demonstrated that conical tape inserts are especially well-suited for enhancing heat transfer, whether in laminar or turbulent flow conditions, and when coupled with Nanofluids.

Key words*: Heat Exchangers, conical tape inserts , Nanofluids*

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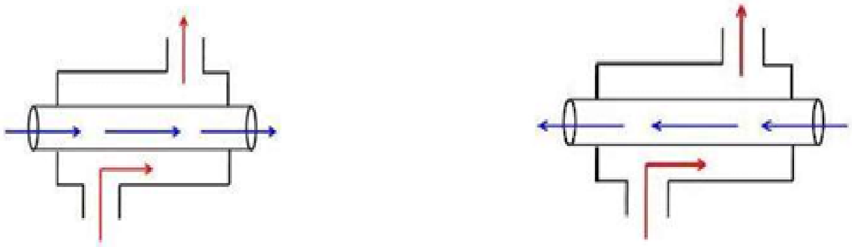
I. Introduction

The double-pipe heat exchanger is among the most basic types of heat exchangers. It earns its name from the fact that one fluid flows within an inner pipe while the other fluid circulates between the inner pipe and an outer pipe that surrounds it. This arrangement is known as a concentric tube construction. In a double-pipe heat exchanger, the flow of fluids can be categorized parallel and counter flow. Parallel flow refers to a situation where both fluid streams move in the same direction as show in figure 1a, whereas counter flow indicates that the fluid streams travel in opposite directions as shown in figure 1b. As the conditions within the pipes undergo changes such as inlet temperatures, flow rates, fluid properties, or fluid composition the amount of heat being transferred also fluctuates. This transient behaviour ultimately leads to a state where the temperature distribution becomes stable. When heat transfer begins, it has an impact on the temperatures of the fluids involved. Until these temperatures reach a steady state, their behaviour is time-dependent. Enhancing the overall heat transfer coefficient and other related parameters, including friction factor, dimensionless numbers, and the efficiency of the double-pipe heat exchanger, results in an improved overall performance for this type of heat exchanger. This, in turn, reduces the required effort, time consumption, and enhances productivity.



a. Parallel flow heat exchanger **b. Counter flow heat exchanger**

Fig. 1 heat exchangers based on direction of fluid flow

Various Applications of Heat Exchangers

Heat exchangers are used in many different technological processes. The following roster lists some types of heat exchangers and their main purpose.

- **Chiller:** A heat exchanger employs a refrigerant to lower the temperature of a liquid by means of a vapor compression or absorption refrigeration process.
- **Condenser:** It facilitates the condensation of steam or a vapor mixture, either in the presence of non-condensing gases or through their interaction.
- **Cooler:** It lowers the temperature of a liquid or gas, typically by employing water as the cooling medium.
- **Heater:** It conveys thermal energy to a liquid or gas through contact with a heated surface.
- **Reboiler:** It produces steam via the process of fractional distillation, and this steam formation is achieved through the utilization of a heating element, leading to subsequent steam condensation.
- **Thermo siphon reboiler:** Adequate pressure is essential to sustain the natural circulation of the boiling liquid.
- **Forced circulation reboiler:** A pump is employed to facilitate the circulation of the fluid within the reboiler.
- **Superheater:** Elevates the temperature of steam beyond its boiling point.
- **Evaporator:** A heat exchanger that causes the evaporation of a portion or the entirety of the liquid stream.

Essentially, techniques aimed at enhancing heat transfer rates can be categorized into the following distinct approaches:

Numerous design innovations have been developed to optimize heat exchange techniques with the goal of reducing heat exchanger size and costs while enhancing performance. Extensive research has been conducted on a wide array of enhancement techniques, which can be broadly classified into three major categories.

Firstly, there is the Active Enhancement Technique, which entails the introduction of external power to improve heat transfer methods. Examples include Mechanical Aids, surface vibration, fluid vibration, electrostatic fields, injection suction, Jet impingement, and others.

Secondly, the Passive Enhancement Technique involves enhancing heat transfer without requiring external power input. This technique often focuses on convective modes that increase the effective surface area and residence time of thermal fluids. Various inserts, such as baffles, twisted tapes, ribs, wire coils, plates, helical screw inserts, insert meshing, and convergent-divergent conical rings, are used to augment heat transfer.

Lastly, the Compound Enhancement Technique combines two or more techniques, drawn from both active and passive categories, to enhance heat energy transfer rates in a manner that surpasses the individual methods. This approach has been explored in various studies.

The enhancement of thermal energy transformation in heat exchangers significantly impacts their performance and involves several heat transfer modes. For instance, it involves reducing thermal resistance in a double-pipe heat exchanger through increased convective mode. Augmenting thermal energy transformation techniques often leads to higher convective coefficients but may come at the cost of increased pressure drop. Therefore, recent research has explored different strategies to achieve a high rate of heat exchange while minimizing the rise in energy consumption.

Notably, swirl flow modes have gained traction for enhancing heat exchange in various industries. The primary objective of this paper is to provide an overview of using conical inserts in double pipe heat exchanger with nano fluids used to improve thermal energy transfer between different fluids. It encompasses a comprehensive survey of several turbulators and devices that induce swirl flow, including twisted tapes, conical rings, entry snail turbulators, vortex rings, and coiled wires.

Smith Eiamsaard et. al, [1]said that in double pipe heat exchanger which improves the heat transfer rate by 129% by improving reynold's number by using helical tapes inserts, helical tapes improve turbulency in fluid flow due to this heat transfer rate increases. Heat transfer rates can be improved by improving Nusselt number also, Nusselt number can be improved by up to 143% [2] using twisted tapes due to improvement in reynold's number.

Heat transfer characteristics of an alumina/water nanofluid in a shell and tube heat exchanger using a coil insert were published by M. Raja et al., [3] They released information on how the concentration of the Alumina/water nanofluid and Peclet number affected the properties of pumping power and heat transfer. The concentrations of 0.5%, 1%, and 1.5% were created and mixed with water, the base fluid. In comparison to those of distilled water, the overall heat transfer coefficient improved by 12.6%, 20%, and 25% for Alumina/water nanofluid at percentages of volume concentrations of 0.5, 1 and 1.5, respectively, at a Peclet of 3000. When comparing the wire coil insert pumping power to that of the distilled water pumping power, there was a noticeable increase of almost 13%.

The experimental examination on heat transmission and friction factor properties of circular tubes fitted with full-length square jagged twisted tape inserts with varying twist ratios was conducted by A.V. Gawandare et al. [4]. There are 5000–16000 Reynolds numbers in the range. They display the outcome as a change in twisted ratios between the Reynolds number and the Nusselt number. They came to the conclusion that the Nusselt number increase in plain twisted tape inserts with a twist ratio of 5.2 was 44%, and that the same was true for twist ratios of 4.2 and 3.2, where the increases were 82% and 154%, respectively. In square jagged twisted tape, the friction factor was determined to be 12%, 27%, and 51%, respectively, for twist ratios of 5.2. Additionally, they found that a 51% increase in friction factor might result in a 154% increase in heat transmission, and that a decrease in pumping power could cause the heat transfer rate to rise.

P. Promvonge [5] conducted research on the impact of inserts with conical rings for turbulators. they conducted studies on the friction factor and heat transfer rate using conical rings that are placed over test tubes and utilised as turbulators. Conical rings with three distinct diameter ratios between the ring and tube diameter were introduced for the testing. Three distinct configurations of the rings were used for each ratio: a converging conical ring, a diverging conical ring, and a converging diverging conical ring. At ambient conditions, it was utilised as cold air for Reynolds numbers between 6000 and 26,000. The conical ring inserts were found to have a greater heat transfer rate than the plain surface tube. Furthermore, the DR array outperforms the others in terms of heat transport. As the test's Reynolds number and diameter ratios decrease, the effectiveness of heat transfer enhancement rises. It was determined that the friction factor is significantly increased by the usage of the conical ring.

Triangular fins as shown in fig 2 also improve the Nusselt number and friction factor in heat exchanger [6], which causes the improvement in flow characteristics such as turbulency.

Fig. 2 Triangular Fins [6]

M. Sakr et. al., [8] This study demonstrates that conical rings perform better as platforms in laminar flow than turbulent flow. Additional passive heat transfer augmentation approaches, including ribs, conical nozzles, and conical rings, are discussed in this study.

Zhang et al., [7] said heat transfer rate can be improved in heat exchanger up to 123% by inserting the helical rotor blade due to the improvement in swirl flow and turbulency by helical rotor.

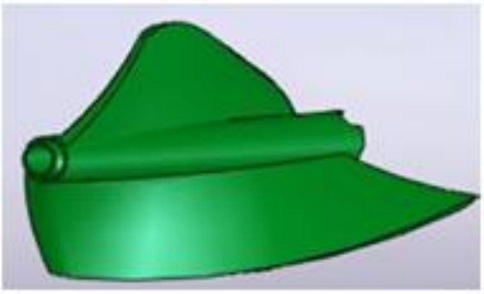


Fig.3 Rotor blades [7]

Sujoy Kumar Saha et al., [9]: Experimental friction factor and Nusselt number data for laminar flow viscous oil through a circular duct equipped with helical screw tape inserts and integral helical rib roughness were provided in this article.

A.S. M. Sayen et al., [10] presents the results of an experimental investigation into the features of heat transfer and air flow friction in a circular tube equipped with two counter-rotating, conical ring inserts with varying twist ratios for turbulent conditions. Double counter conical ring inserts significantly increased heat transmission by increasing the high pressure drop.

TT inserts with modified tubes with three-dimensional (3D) internal expanded surfaces were used in another research, as the one by Liao and Xin [11]. Water, ethylene glycol, and ISO VG46 oil were used in the study, which was carried out under various flow conditions (80 < Red < 50,000, where d is measured from the bottom of the extended surface). Both the pressure drop and the heat transfer were enhanced by the two additions. The average Stanton number (St= Nu/Re*Pr) grew by 580% for ISO VG46 oil, while f climbed by 650%.

Ibrahim et al.'s [12] examined the impact of conical rings at orientations on the frictional factor and augmentation of heat transmission. All of the conical rings were shown to increase the Nusselt number, in line with the findings of the Proving study. The augmentation decreases with increasing pitch ratio and CR diameter but increases with Reynolds number. However, it was also discovered that the frictional factor decreased with CR diameter and pitch ratio. The DR orientation exhibited the greatest average Nu of all the orientations examined, according to the scientists, at a pitch ratio of 2.

Similar numerical research on the impact of various PCRs on heat transmission and frictional pressure drop was conducted by Nakhchi et al. [13]. It was observed that there was a 35.48% increase in the Nusselt number when the number of perforation holes was increased from 4 to 10. This occurs as a result of holes encouraging recirculating flows close to the tube wall. Heat transfer would then be improved and the thermal boundary layer would be disrupted by this flow. Nevertheless, the frictional component decreases as the number of holes increases.

In a study by Qingang Xiong and colleagues [20], they conducted CFD simulations on a double pipe heat exchanger using conical and fusiform tubular inserts. They found that the double pipe heat exchanger with circular inner pipes and 12 mm fusiform turbulators yielded the best thermal performance. Specifically, at a Reynolds number (Re) of 4000, the configuration with 9 mm fusiform inserts and a rectangular inner pipe with a 0.72 aspect ratio achieved the highest coefficient of performance, approximately 27.74. This configuration also increased the overall heat transfer coefficient by 4.58% compared to a plain rectangular tube and by 4.68% compared to a circular tube without turbulators.

In another study by Mahalingam Arulprakasajothi and colleagues [21], they investigated the performance of conical strip inserts in a tube heat exchanger using a water-based titanium oxide nanofluid. They concluded that the strip geometry and the nanofluid concentration significantly influenced the thermal performance of the circular tube heat exchanger. The highest heat transfer was achieved with staggered conical strips with a twist ratio of 3 and a 0.5% volume concentration of nanofluid. The study also derived correlations using regression analysis.

Seyed H and their team [22] reported on the influence of a curved conical turbulator on heat transfer enhancement in a helical double-pipe heat exchanger. Their results indicated that the maximum effectiveness was observed when the inner diameter of the turbulator and the radius of the turbulator's holes were 19 mm and 3.6 mm, respectively. Furthermore, the swirl flows generated by the turbulator significantly enhanced heat transfer. Increasing the inner radius of the turbulator by 26.7% resulted in an 80% increase in effectiveness, while a 133.34% increase in the radius of the turbulator's holes led to a 50% growth in effectiveness.

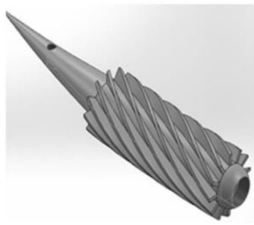


Fig.4 swirl generator [22]

Nano fluids

Although nanotechnology is relatively new, functioning gadgets and their structures are not new in the world. The discovery that a molecule has a nanometer width through experimental evidence on the diffusion theory in 1905 is regarded as a significant turning point in the scientific development of nanotechnology. On December 29, 1959, Professor R.P. Feynman made a visionary statement. At the bottom, there is ample room. A carbon nano tube is a substance with a diameter measured in nanometers and formed like a tube. It is composed of carbon. Allotropes of carbon with a cylindrical nanostructure are called carbon nanotubes. The peculiar qualities of the cylindrical carbon molecules make them useful for nanotechnology. Particularly because of their exceptional mechanical, electrical, and thermal conductivity, carbon nanotubes are used as additions to a variety of structural materials.

Applications of nano fluids in heat transfer applications

The heat transfer properties that are relevant to many systems for improved performance are based on the ideas of nanofluids. Numerous studies have been conducted on the parameters of heat transmission with nanofluids, particularly in the areas of convective and thermal conductivity. With these properties, applications of nanofluids in various industries, such heat-exchanging devices, seem promising. The following particular fields can make use of nanofluids in enhancing the heat transfer:

- Food processing
- Defence
- Nuclear applications
- HVAC systems
- Water chillers
- Pharmaceuticals

With a trapezoidal twisted tape insert, Prasad et al. [14] used distilled water as the base fluid and Al_2O_3 as a nanoparticle. They found that there was a significant amount of heat transfer in the annulus section that was connected to the inner pipe. As the volume 1% $Al_2O_3$of nanoparticles increased, heat transmission via the convective route improved.

Majeed et al., [15] published a result pressure drop in heat exchanger using SiO_2 nano fluids, pressure drop is occurred due to mixing of nano SiO_2 nan o fluids in heat exchanger with 25 to 50mm particle size. Simultaneously Nusselt number is increased due to the mixing of SiO_2 nano fluids in heat exchanger due to the thermal conductivity of nano particles [16]

Albadr et al. [17] were conducted experiments on different ranges of reynold's number from 15000 to 175000 to calculate heat transfer rate and friction factor along with peclet number and concluded Nusselt number increased by 62.6% with 2% concentration ofAl_2O_3.

Jassim et. al., [18] conducted experimental evaluations on the impact of TiO_2 and Al_2O_3 nanofluids on the performance of a heat exchanger. They investigated the substitution of traditional fluids with nanofluids, which led to notable enhancements in performance. Specifically, with a 3% concentration of nanofluids, the improvements ranged from 13% to 23%.

Bahmani et. a., [19] performed a numerical investigation focused on forced convection within a double-tube heat exchanger. Their study involved the utilization of nanofluids, specifically alumina-water mixtures, while varying Reynolds numbers within the range of 10,000 to 100,000. The outcomes of their research demonstrated a direct correlation between the Reynolds number and the augmentation of the Nusselt number, as well as an increase in the convection heat transfer coefficient. Remarkably, the study reported that the maximum improvement rate for the average Nusselt number was 32.70%, and the enhancement in thermal efficiency reached up to 30%.

In this section, a comprehensive analysis of prior research reveals that the use of smaller nanoparticles led to enhancements in thermal conductivity and viscosity, with no substantial changes observed in density (as shown in Table). Next, we delve into the impact of nanoparticle shape on the properties of nanofluids.
Influences of nanoparticle size on nanofluid properties according to different studies.

Base Fluid	**Nanoparticles**	**Particle Concentration (%)**	**Size (nm)**	**Temperature Range °C**	**Observation about Nanofluids Properties**
Water	Tio2	-	25-50	15-51	Thermal conductivity of 22 nm was enhanced by 1.24% and 2.43% more than those of 50 nm and 100 nm, respectively.
water	Al_2O_3	1	20	10-50	Thermal conductivity of 20 nm was enhanced by 1.54% and 2.43% more than those of 50 nm and 100 nm, respectively. No significant variation in density
		2	50		
		3	100		
Water	SiO_2	-	30	25-65	Thermal conductivity was improved by 3.80, 4.90, and 7.80%, respectively, compared to the base fluid. The viscosities increased by 6.10, 8.30, and 9.20% compared with those of pure water.
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II. Conclusions

After reviewing numerous prior studies on double-pipe heat exchangers, it becomes evident that each one holds significant value in the quest to develop an efficient, well-designed, and cost-effective double-pipe heat exchanger. These research endeavours play a pivotal role in advancing the depth of exploration within this field. They tackle a range of important challenges related to the heat exchanger by experimenting with different nanoparticle concentrations and employing diverse fluid geometries to enhance heat transfer.

- ❖ Examining ways to enhance heat transfer is a crucial endeavor, and it can be achieved by strategically placing hot and cold fluids in either the inner or outer tubes. This allows for a comprehensive analysis of the properties concerning heat flux and provides specific fluid specifications, simplifying the study of various conditions.
- ❖ Addressing the need for heat addition or removal within a system, whether it involves a double-pipe heat exchanger with a temperature differential in the working fluid or adjustments in its applications, provides an effective solution for managing heat gain or heat loss.
- ❖ To improve the functionality and viability of the system, further theoretical and practical consideration should be given to the material and geometry modifications of double-pipe heat exchangers with conical tape inserts.
- ❖ The central focus of these studies revolves around the diffusion and dispersion rates of nanoparticles within the base fluid, as their primary objective is to enhance heat transfer using a variety of nanoparticles. Examining how nanoparticles degrade under different operational conditions is a crucial aspect to consider in the broader context.
- ❖ The breakdown rate of nanoparticles is accelerated by an increase in the friction factor and Reynolds number, thus there is no need to investigate how the size of the particles decreases over time, which would make it difficult to increase their efficiency.
- ❖ According to these investigations, conical tape inserts have been shown to enhance the efficiency and heat transfer rate in double pipe heat exchangers. $\mathrm{Si}O_2$ nanoparticles prove to be the most suitable choice for enhancing heat transfer and Nusselt numbers in comparison to the current options available.

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