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Heat Transfer Enhancement in Tubular Heat Exchanger with Jet Impingement: A Review

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ABSTRACT

Heat exchanger (HE) is a thermal device used to transfer heat from higher fluid temperatures to lower fluid temperatures. There is an increasing need to increase the efficiency of HEs, develop a wide range of investigations to increase heat transfer rate (HTR), and reduce the size and cost of industrial apparatus in accordance. The current work's goal is to review articles that discuss the main types of tubular heat HEs, factors that affect HTR, and jet impingement in tubular HEs, which are considered among the equipment used in various industries. Researchers have proposed several models of tubular HEs. Many industrial processes, cooling technology, refrigeration equipment, sustainable energy applications, and other fields use tubular HEs. Jet impingement cooling is assumed to be a very efficient method for increasing HT rate, and it has many uses in both the scientific and industrial spheres. This paper's goal is to present an overview of various techniques for improving HT in relation to jet impingement cooling and to define the area of potential future research. This study focuses on a variety of experimental and numerical studies to examine the HT and hydrodynamic behaviour of jet impingement over a range of Reynolds numbers, target surface shapes, distances from the jet plate or nozzle to the target plate, extended jet holes, and the use of nanofluids. Both single jet and multiple jet impingements cooling are included in the current work. The summary of jet impingement for various applications keeps the spotlight on new methods for enhancing HT.

1.Introduction

Heat exchangers are often used in engineering and industrial applications nowadays. It is considered that engineers struggle to develop a design for a functional HE. The reason for this is that, in addition to the necessity for an accurate evaluation of the long-term performance and the associated financial expenses, a thorough analysis of HT, pressure drop, and efficacy is also necessary, all of which necessitate laborious effort. Utilizing techniques for improving heat transmission will also result in an increase in pressure drop, which raises pumping power.

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The necessity for an ideal enclosure containing the HTR and pressure drop is therefore clearly stated to be adversely affected by some of these HT augmentation approaches. Therefore, selecting the techniques carefully is important. It is also thought that technology like computer, electric power system, car engine, and many more examples must necessarily have a high and adequate HT rate.

Tubular HEs are among the easiest and effective HEs. Tubular HE is often employed in the all type of mechanical, cloth, pharmaceutical, petroleum industries. Tubular HE is often employed. Since this form of HE has a tiny diameter, many thorough studies have also held firmly to the notion that it is used in high-pressure applications. Additionally, they are crucial in situations when a broad range of temperatures is required. Additionally, it is widely known that tubular HE significantly aids in the operations of pasteurization, reheating, preheating, digester heating, and effluent heating. Due to their affordable design and maintenance costs, tubular HEs are also used by several small companies. In order to avoid misunderstandings while selecting the most suitable techniques of interest, we concluded that the earlier studies done on this type of HE should be grouped. One of the major goals of this review article is to address the lack of published review papers on tubular HEs, to the author's knowledge.

Figure 1 show that, there are two tubes one inner tube which is cold fluid and other outer tube which is hot fluid. Cold and hot fluids mostly flow in counter and parallel flow combinations through concentric pipes in tubular HEs. The flow of hot and cold fluids is identical. While latter scenario refers to situations where fluids move the other way.

We have established that the beginnings of tubular HE publications were in the late 1940[2,3]. Investigations generally support the idea that this form of HE is moving in the direction of significant advancement. Numerous studies that fall into different categories have been conducted over the years. Some studies concentrated solely on the properties of working fluids and how they can be altered, whereas others looked into active techniques, passive methods, compound approaches, geometry change and other heat enhancement methods. Each approach, which has undergone continuous development, will be examined in-depth in the parts that follow.

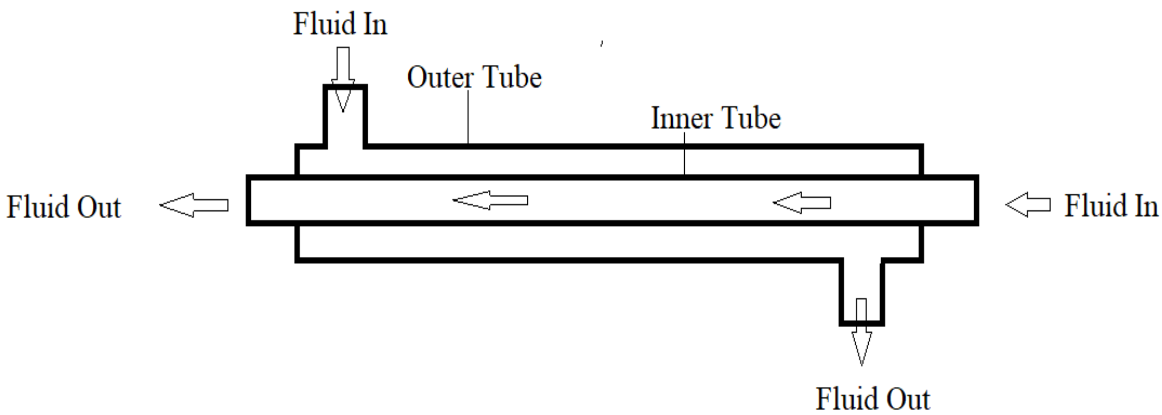

Fig. 1. Tubular heat exchanger [1]

2. An Overview of Tubular Heat Exchangers

A case was made for the analysis and prediction of the dynamic properties of a particular tubular HE using two automatic control techniques in one of the early studies on tubular HEs by Mozley [2], who used both numerical and experimental approaches. These techniques relied on analogies from passive electrical networks and basic mathematical concepts. Additionally, he

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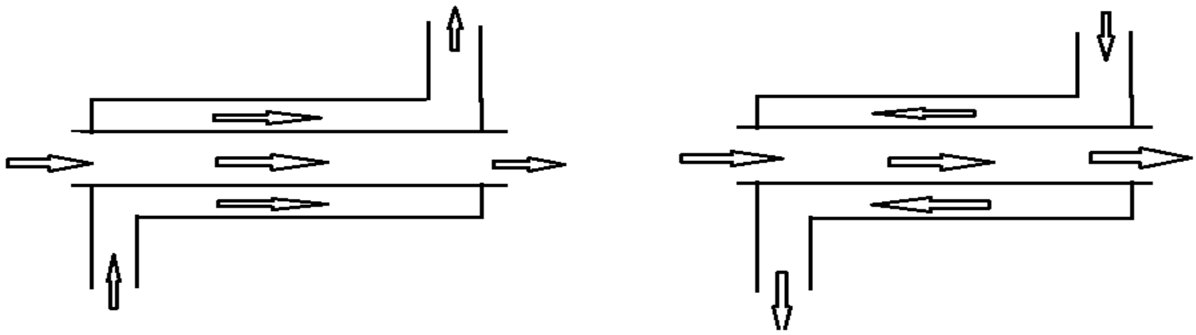
analyzed frequency responses that were based on fundamental analogy results and came to the conclusion that the numerical results were in good agreement with the outcomes of the experiment. Cohen and Johnson [3] investigated the dynamic properties of tubular HEs in the same year. This experimental and numerical effort helped to shape some people's thinking for years to come. It was claimed that the characteristics of the components of tubular HEs could be simply calculated by the frequency responses of the data in this work, which provided equations of dynamic characteristics for a straightforward system. They also noticed how well these statistics matched the outcomes of the experiments. Figure 2 shows that both hot and cold fluid moves in parallel direction and counter flow direction.



(a) (b)

Fig. 2. (a) Parallelflow and (b) Counterflow

Later, Lachi*et al.,* [4] investigated the time constant of a shell and tube HE and a tubular HE. This investigation's specific goal was to categories the properties of these HEs during transient conditions, especially when sudden variations in intake velocities are taken into account. This investigation has been conducted using a model with the two parameters: time delay and time constant. Furthermore, it should be mentioned that the analytical term was obtained by using the energy balance equation. Additionally, it was mentioned that an experimental approach was performed to validate the numerical data, and the largest observed variation was found to be less than 10%. Additionally, Aicher and Kim [5] conducted an overview of the research to examine the impact of counter flow in the nozzle portion of a tubular HE installed on the shell side wall. It's become clear that the counter flow in the nozzle part had a substantial influence on pressure drop and heat transfer. Furthermore, it was determined that if the HE was small enough and the ratio of free cross section areas was low enough, the impact would be more visible. Additionally, they offered actual linkages for predicting the HT rate in turbulent flow. Mare*et al.,* [6] experimental and numerical investigation of mixed HT with backflow in concentric DPHEs. Water flowed in a laminar regime as the investigation's working fluid. The PIV approach, one of the most widely used flow visualization techniques, was also used to display the associated velocity vectors [7]. According to velocity distribution, an inner tube boundary condition with a constant temperature is produced by a high volume rate of flow in the annulus. Additionally, it was noted that a reverse flow appeared in both the inner tube and the annulus, with the Richardson number of unity and low flow rates being the best times to see the phenomenon. Table-1 shows that, literature review of characteristics flow in tubular heat exchanger.

Table 1
Characteristics flow in tubular Heat Exchanger

Reference	Methodology	Working Fluid		Outcomes
		Inner tube	Outer tube	
Aicher and Kim [5]	Cross flow's impact in the nozzle area	water	water	The nozzle impact on HT is higher when HEs are smaller in size.
Dezfoli and Mehrabian' [8]	Experimental data and conventional correlation predictions comparison	hot water	cold water	HT from the shell side to the tube side is 3.4 times slower than from the tube side to the counter flow, which is 1.5 times slower. The HT coefficient on the shell side is more than what was expected.
Moradi and Etemad [9]	Through a DPHE, an experimental study of a pseudoplastic fluid	non-Newtonian fluids	cold water	The Reynolds and Graetz numbers rise as heat transport does. The HT will rise along with the CMC (carboxy-methyl-cellulose) content.
Sheikholeslami *et al.,*[10]	Investigation of HT and turbulent flow	water	air	As the top container temperature and water moving rate is rise, the Nu on the water side rises while falling on the air side.
Ma *et al.,*[11]	An examination of the HT between supercritical carbon dioxide and water at temperatures near to pseudo-critical.	sCO2	water	The all and sCO2-side HT coefficients are decreased as sCO2-side pressure is increased.

Additionally, Ma *et al.,* [11] experimental investigation of the impacts of supercritical carbon dioxide (sCO2) in tubular HEs included a thorough examination of the effects of pressure, mass flow, and buoyancy force on the sCO2-side. On the one hand, it was shown that when gas-side pressure increased, both the overall and gas-side HTR subtly declined. On the other hand, it was clear that the water side's flow rate—as opposed to the gas side—was the crucial component of the HTR. Additionally, a genetic algorithm-based mathematical connection for forecasting HT rate was given. Additionally, it is mentioned that several experiments into the flow and fluid properties of tubular HEs have been conducted; an overview of these investigations is provided in the following table. Tubular HEs have recently been employed in solar and geothermal applications as well. Using the computational finite volume approach, Templeton *et al.,* [12] studied tubular HEs for solar energy storage. The simulation was based on recent samples from countries with cold temperatures, such as Canada. They noted that the proposed model was capable of simulating temperature fluctuations in both injection and extraction scenarios. There haven't been many studies done in this area, to my knowledge.

3. Jet Impingement

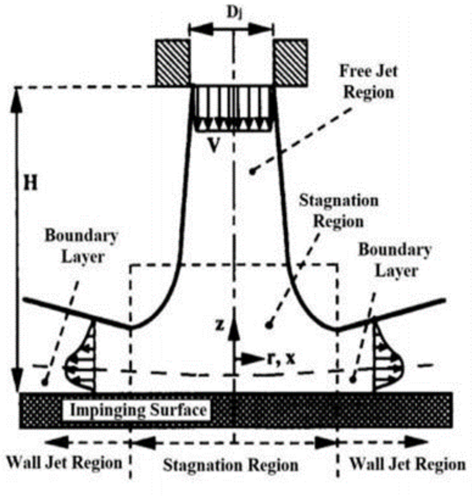
Experimental and numerical studies have been conducted in large numbers for jet impingement. A large number of reviews are available on HT by jet impingement. The reviews that came before this one only covered one jet impingement technique to improve HT. The data was examined by Jambunathan *et al.,* [13] for a single circular jet impingement. Wolf *et al.,* [14] conducted a thorough analysis of jet impingement boiling to determine its strengths and weaknesses as well as the potential for further research. Dewan *et al.,* [15] reviewed current developments in turbulent jet impinging HT computation. Naveen [16] critically examined the liquid jet impingement technique for analyzing the HT performance of discrete heat electronic modules. Krishan *et al.*, [17] discussed the improvement in HT caused by synthetic jet impingement. The effects of nano particles on jet impingement HT were reviewed by Mohammadpour and Lee [18-20] have conducted additional recent reviews on jet impingement cooling.

The objective of the current review paper is to investigate the enhancement of HT using the jet impingement method by investigating the various factors influencing HT rate. These variables include the target surface's shape, the Reynolds number, and the distance from the jet plate or nozzle to the target plate. This work also discusses the use of PCMs and nanofluids to speed up HT rates when using jet impingement techniques. The aforementioned methods of jet impingement HT are highlighted in this review paper.

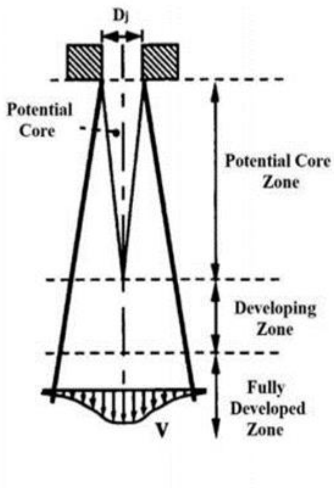
3.1 Jet Impingement Flow Characteristics and Heat Transfer

The fluid flow characteristics affect the HT phenomenon in jet impingement. Three distinct regions make up the flow structure of a single jet: the free jet, stagnation, and wall jet. The region that behaves like a free jet originates from the nozzle and is located far from the target surface. In this region, the shear-driven interaction between the exiting jet and surroundings causes the entrainment of mass, momentum, and energy. The free jet can be classified into three zones: I, the potential core, the developing zone, and the fully developed zone (Figure 3). The average jet velocity in the potential core zone is equal to the nozzle exit velocity. A point or area where the average jet velocity is roughly 95% of the nozzle exit velocity is commonly referred to as the end of the potential core. Immediately following the potential core, the jet velocity rapidly drops. Because of this, the jet plate to target plate spacing is a crucial factor that influences how quickly heat is transferred. After the potential core, there is a developing region where the large shear stresses at the jet boundary cause the axial velocity profile to decay. A fully developed profile is obtained after developing a region. The stalling region refers to the area where the jet impacts the target surface. As axial velocity decreases, static pressure increases in the stagnation region. The area that follows is referred to as the wall jet region because the bulk is radially directed outward. Numerous variables, such as nozzle geometry, velocity profile, jet exit velocity, jet and target plate spacing, and turbulence level, have an impact on the HT between the impinging jet and the target surface. Maximum HT occurs at the stagnation point, and HT rates decrease radially after that.

Many researchers are interested in this topic because of the broad range of industrial and domestic applications as well as the fundamental significance of jet impingement. For achieving high rates of HT, jet impingement techniques are used. A number of factors affect how quickly heat is transferred by an impinging jet, including the Reynolds number, the target surface's shape, the distance between the jet plate and the target plate, extended jet holes, the use of nanofluids and PCMs, and jet temperature dissipation. Review of published numerical and experimental work that takes into account how some of these parameters affect HT rate. Figure 3(a) shows flow regions of impingement jet and (b) shows main flow zones of free jet.



(a)



(b)

Fig. 3. (a)Flow regions of impingement jet (b) Main flow zones of free jet [21]

3.2 Target Surface Shape and Spacing Between Jet Plate and Target Plate

There are many variations in the literature for the shape of the jet impinging target surface and the separation between the jet plate and target plate to increase HT rate. Choi *et al.,* [22] conducted an experimental and numerical study to investigate the use of angled ribs and dimples to enhance HT for internal cooling of turbine blades. The study's Reynolds Number ranged from 30,000 to 50,000. A design with a 2 or 4 channel aspect ratio was chosen to stimulate a gas turbine blades internal coolant passage. Rib pitch, rib angle, dimple diameter, and centre-to-centre distance were all 6mm, 6°, and 7.2mm, respectively. As compared to rib only and dimple only configurations, placing dimples between the ribs (rib-dimple compound case) increased the HT coefficient and increased the pressure drop within an acceptable range. Huang *et al.,* [23] investigated the enhancement of HT for a micro channel heat sink with jet impingement by adding dimples to the target surface. A numerical comparison between jet impingement with concave, convex, and mixed dimple structures and jet impingement without dimples was conducted. The findings indicated that jet impingements had the best cooling performance for convex dimples. Jet impingement without dimples, jet impingement with mixed dimples, and jet impingement with concave dimples all demonstrated the second-best cooling performance. Additionally, it was found that applying convex dimples to jet impingement could reduce flow resistance. The impingement with the highest pressure drop was those without dimples, followed by those with mixed, concave, and convex dimples. In summary, jet impingement with convex dimples can significantly enhance HT and fluid flow performance compared to other structures.

Jing *et al.,* [24] conducted a numerical study to examine the effectiveness of jet impingement cooling on flat and irregular target surfaces (concave and V shapes). The study's Reynolds number range was 10,000–50,000. On target surfaces, additional surface configurations of triangular ribs and dimples/protrusions were also present. In comparison to flat targets, non-flat target surfaces showed more complex flow patterns. Adopting dimples and protrusion led to an improvement in local and overall HT. In flat channels, larger Reynolds numbers are associated with an increase in average Nu/Nu0, and sparse arrangements are associated with the highest Nu/Nu0 values. Protrusion was found to exhibit significant advantages over dimple for non-flat targets in terms of HT performance. Additionally, for flat targets, protrusion produced a larger f/f0 than dimple, and for concave/V-shaped targets, a low f/f0was seen. Target surface shapes were found to have less of an impact on the amount of heat flux, whereas the roles of target placement and Reynolds number were found to be more important. The study has a significant effect on the thermal design of electronic devices and turbine blades. Tepe *et al.,* [25] performed a numerical study to investigate cooling performance by impinging turbine blades with extended jet holes on a target surface that was a flat plate with ribs. The Reynolds number varied from 15,000 to 45,000 throughout the study. When ribs were added to the target surface, the average Nu was lower than it would have been on a surface without ribs, but the Nu distribution was more even along the surface. In a different study, Tepe*et al.,* [26] used extended jet holes in an experimental and numerical investigation to examine the cooling effectiveness of a jet impinging on a rib-roughened surface. The parameters were rib height Hr/Dj for the experimental study, 0.42, and different values of 0, 0.25, 0.42, and 0.58 for the numerical investigation. The nozzle to target surface spacing was 1, 2, 3, 4, 5, and 6, and the Reynolds number range was from 16,250 to 32,501. Results showed that when a rib roughened target surface was used, the average Nu could be improved by 40.32% by using extended jet holes. The low rib height contributed more to the improvement in HT than any other factor. At a high Reynolds number of 32,500, the nozzle to target plate spacing was found to have the highest average and local nu, while at a low Reynolds number of 27,100 or less, the nozzle to target plate spacing had the highest average and local nu. Using extended jet holes is a workable method for jet impingement cooling, with the most workable solution at the nozzle to target surface spacing of 3.0 or less, according to PEC findings.

In order to investigate the thermal performance of impinging air jets at short nozzle to target plate distances, Lytle and Webb [27] carried out an experimental study. Throughout the study, the distance between the nozzle and the target plate was kept to less than one nozzle diameter. From the results, it was deduced that closing the gap between the target plate and the nozzle significantly increased HT. This increase in HT was made possible by accelerating the fluid and creating a high amount of turbulence by decreasing the distance between the nozzle and the target plate. Lee *et al.,* [28] conducted an experimental study to examine the impact of the distance between the jet plate and target plate on HT for an array of jets impinging on a flat target surface. The study was done for jet to target plate distances of 1.5D, 3D, 5D, and 8D, and Reynolds numbers ranging from 8,000 to 50,000. Smaller distances between the jet and the target plate and lower Reynolds numbers allowed for the local observation of Nu increases in cross flows. The intense interaction between impinging jets, along with an increase in mixing and turbulent transport, were the main contributors to this increase in local Nu. Tepe *et al.,* [29] numerical and experimental study for extended jet whole HT enhancement. Nozzle to target plate distance Gj/Dj was adjusted for values of 1, 2, 3, 4, and 5, while the distance between the jet plate and target plate Z/Dj was kept constant at 6. 16,250 to 32,500 Reynolds numbers were used during the study. According to the experimental findings, a decrease in Gj/Dj led to an increase in HT and a pressure drop. The most practical solution was found at nozzle to target plate distance Gj/Dj = 2 for all values of Reynolds number, according to an analysis of the PEC ratio.

4.Heat Transfer Enhancement Methods

Three broad categories may be used to classify HE improvement techniques.

4.1 Active Method

This approach solves the problem of accelerating HT using an outside force. The use of reciprocating plungers, magnetic field implementation for flow disruption, surface or flow vibration, and electromagnetic field application are some typical examples. It is said that this approach has been the subject of some research in tubular HEs. A tubular HE with a spinning inner tube was experimentally studied by El-Maghlany *et al.,* [30]. The impact of hot and cold fluids, flow configurations (parallel flow or counter flow), as well as the speed of the inner spinning tube on the number of transfer units (NTU) and efficiency of the HE led to the corresponding results. It was commonly accepted that as rotation speed grew, the rate of HT, NTU and efficacy did as well.

Meanwhile, Zhang *et al.,* [31] looked at how rotor-assembled strands may improve heat transmission in tubular HEs. Three alternative geometries were present in the strands: helical blade rotor, blade-discrete rotor, and blade rotor with ladders. It was found that the friction factor increased by 37.4–74.8 percent and the age of the Nusselt number increased by about 71.5–123.1 percent when compared to a smooth tube. Additionally, it was determined that the instance of a blade rotor with ladders satisfied the highest performance assessment standard for tubular HEs.

According to the authors' knowledge, there have been relatively few studies on the use of active techniques in tubular heat HEs, and no single numerical analysis has been done yet. However, it is important to note that research on active approaches in annuli and concentric tubes has received a lot of media attention. These HEs are not included in the category of tubular HEs since the inner tube is not taken into account.

4.2 Passive Method

This approach does not depend on an outside force to enhance HT. Surface or geometrical alterations, as well as different inserts, are crucial in the field [32-35]. The use of twisted tapes, extended surfaces [1, 36-54], and wire coils [38-40], and other types of tabulators has been often noted in recent research on the use of different passive approaches in tubular HEs. Investigations into each of these strategies will be covered in detail in the sections that follow.

4.2.1 Twisted tapes insert in tubular heat exchanger

Twisted tape inserts are one of the most effective HT improvement techniques, and they have a variety of applications since they are straightforward, inexpensive, and simple to install, and require little upkeep. Twisted tape often works as a continuous swirl generator to stir up flow. This improves fluid mixing, which eventually boosts the rate of HT. However, it has been shown in past studies that twisted tapes function better in laminar flow conditions. The investigations relating to the twisted tape insert in tubular HEs will next be covered. Naphon [55] investigated the HT and pressure drop of horizontal tubular HEs with and without twisted tape inserts that were perforated experimentally. The trials used hot and cold water running through the annulus and inner tube, respectively. The findings demonstrated that the HT and pressure drop in the HE were significantly impacted by the twisted tape insert. Finally, correlations between the rate of HT and the pressure decrease that might reasonably anticipate the outcomes were shown.

In accordance with earlier studies, Yadav [57] conducted a second experimental examination to examine the impact of half-length twisted tapes on the pressure drop and HT of a twin pipe U-bend heat exchanger. In tubular HEs, the twisted tapes within the inner tube increased HT by 40% compared to smooth tubes. The performance assessment criterion for smooth tubes, however, was 1.3–1.5 times higher than that of the aforementioned improved heat exchanger, according to the related data. It is noted here that little research has been done on the impact of twisted tape inserts in tubular HEs. Although this effect was the subject of a numerical analysis, it was reported [36].

4.2.2 Extended surfaces (fins)

The three kinds of HT are all addressed by an extended surface, also known as a fin, with conduction and convection receiving the most of the focus. Fins may not necessarily increase the rate of HT as is frequently assumed.

The annulus's ability to transport heat was negatively impacted by the use of these fins. Both experimentally and computationally, Kumar *et al.,* [39] investigation focused on tubular HEs with longitudinal fins that had three distinct geometries: parabolic, triangular, and rectangular. It was determined that longitudinal rectangular fins were more effective than the others HT base, whereas longitudinal parabolic fins produced smaller pressure drops.

They added that the hot fluid should flow at a higher mass flow rate than the cold fluid. In order to provide the ideal operating conditions, a detailed experimental and computational analysis of smoothness and rectangular-finned double pipe and multi-tube HEs was accomplished. In this HE, the inner tube carried the hot water while the annulus carried the cold. It should be emphasized that only the smooth tubular HEs were subjected to the experimental procedure. He conducted more research on the redesigned tubular HEs using numerical simulations in which three possible rectangular, triangular, and parabolic designs for the fins were taken into consideration after validating the computational results with the same experimental ones. Table 2 shows that, literature review of passive methods in heat exchanger.

Table2
Passive methods in Heat Exchanger

Reference	Configuration	Working Fluid		Finding
		Inner tube	Outer tube	
Naphon [55]	Typical twisted tape	water	water	Across the spectrum of Reynolds numbers, the rate of HT is higher at lower twist ratios than it is at higher ones. The rate of HT is significantly influenced by the inlet hot water temperature.
Yadav [56]	Half-length twisted tapes	hot oil	cold water	When compared to a standard heat exchanger, the pressure coefficient with half-length twisted tape inserts increased by 40%.Half-length twisted tape has the best HT performance on an equal mass flow rate basis, followed by smooth tube.The efficiency of smooth tubes for heat transmission is highest per unit pressure drop, followed by half-length twisted tape.
Braga and Saboya [37]	Finned tubes	hot water	cold water	Cut-and-twist fin changes might be helpful in low-Reynolds situations
Akpinar [39]	Helical wires	hot air	cold water	Nusselt number increased by up to 2.64 times as compared to the empty pipe. In the studies, a friction factor increase of up to 2.74 times in comparison to the smooth tube was noted.

Naphon [40]	Coil-wire insert	hot water	cold water	In laminar flow, coil-wire insert is more significant. As Reynolds number rises, the effect of the coil-wire insert on the augmentation of HT begins to diminish.
Choudhari and Taji [41]	Various materials are used to make coil wire inserts (copper, aluminum, stainless steel)	hot water	cold water	It was discovered that the friction factor increased as the pitch of the coil wire insert decreased. Hot water is provided via the inner tube of the heat exchanger, while cooling water is placed in the outside annulus to reduce heat losses.
Zohir [42]	Outer tube: cold water	hot water	cold water	Turbulators cause separation and reattachment areas to form around them.
Yildiz *et al.,* [43]	In a DPHE's inner tube, propellers with a 45-degree outward angle are employed.	hot air	cold water	Compared to the system without propellers, HT rates were around 250% better. In contrast to the pressure decrease in the empty tube, the increase varied between 500 and 1000%. For low Reynolds numbers, the impact of propellers on heat transport is reduced.
Akpinar *et al.,* [44]	Swirl components employed in a DPHE's inner pipe's entry portion	hot air	cold water	Reduced diameters and more holes both resulted in higher HT rates. In comparison to a smooth tube, the maximum heat transmission rate was 130 percent. This increase applied to a swirl element with five 3 mm-diameter holes for the zigzag pattern.
Eiamsa-ard *et al.,* [45]	Louvered strips placed on a core rod with forward and backward configurations.	hot water	cold water	When compared to when used with a forward arrangement, the louvered strip's use with a backward layout improves total enhancement ratio by 9 to 24%. With an increase in inclination angle, the Nusselt number rises. This can be explained by the louvered strips' considerable turbulence strength, which causes the flow to mix quickly, especially at greater inclined angles.
Zhang *et al.,* [46]	Utilization of vortex generators and helical fins on a DPHE's outer tube simultaneously	hot water	cold air	Helical fins and vortex generators were used together, resulting in an effective design with improved HT. When using a shorter helical pitch, the pressure loss will increase significantly.
Sheikhol-eslami *et al.,* [47]	The inner tube of a DPHE has an exterior surface with a perforated circular ring.	water	air	Due to a smaller crossing angle between the velocity and the temperature field, using perforated circular rings results in lesser HT enhancement than circular rings. Thermal performance raises as the number of perforated holes rises, but falls when Reynolds number and pitch ratio rise.

Numerous numerical investigations in the area of employing fins in tubular HEs have been carried out as a result of earlier studies. Kahalerras and Targui [48] investigated how to improve heat transmission in tubular HEs by adding porous fins to the inner tube's outer surface. The Brinkman-Forchheimer Extended Darcy was utilized as the numerical model for the porous areas, and the finite volume approach was employed to solve the differential equations relating to the boundary conditions. The accompanying results, according to the authors, may only be used if the fluids flowing through the two tubes are the same and moving at the same mass flow rates. In this investigation, the effects of geometric, physical, and thermal parameters on the HT and pressure drop of the tubular HEs were carefully investigated. These parameters include the height and spacing of the porous fins, the Darcy number, and the thermal conductivity ratio Rk. The highest average Nusselt number was achieved for the scenario when Rk = 1, for smaller porosities and greater fin heights.

Syed *et al.,* [49] examined the laminar convection in tubular HEs with changing fin-tip thickness in yet another innovative numerical analysis. The ratio of the fin-tip angle to the fin base angle, with values ranging from 0 to 1, is used to define the tip thickness. The fin forms range from triangular to rectangular in cross section. It's important to note that this parameter is being specified for the first time ever. Discontinuous Galerkin Finite Element Method (DG-FEM) is employed in their simulation. Additionally, pressure drop, Nusselt number, and j-factor are taken into account in order to determine the performance of tubular HEs. The Nusselt number and j-factor increase for a rectangular cross-section were 178 and 89 %, respectively. However, with a triangular cross-section, the Nusselt number and j-factor increase were 9.5 and 19%, respectively. Additionally, they demonstrated how the fin-tip angle and the size and number of fins were closely connected. It was determined in the end that specifying the aforementioned parameter had a considerable impact on the design of tubular HEs, resulting in improvements in cost, weight, and friction loss. Here it is noted that several more numerical studies on finned tubular HEs have been carried out [50,51].

It is important to note that many additional studies on finned tubular HEs have been thoroughly examined through optimization procedures, which has significantly advanced the area. In one of these studies, Sahiti *et al.,* [52] investigated how to reduce the amount of entropy produced by a pin-finned tubular heat exchanger for a range of flow lengths and pin lengths as a function of Reynolds number. Experimental analysis was done on the tubular HEs HT and pressure drop properties. Water and air were the working fluids in the tests, and they flowed via the inner tube and the annulus, respectively.

They came to the conclusion that more heat exchanger passageways with smaller pin heights would be preferred over fewer passages with greater pin heights Iqbal *et al.,* [53] carried out an analysis on the best design of longitudinal fins that resulted in greater conjugate HT after gaining a solid understanding of optimization in HEs. Existing fins had trapezoidal, parabolic, and rectangular shapes. In this numerical experiment, governing equations were solved using a genetic algorithm and the Discontinuous Galerkin Finite Element Method (DG-FEM), with the goal function being the optimization of the fin form. The equivalent diameter and hydraulic diameter were two separate metrics that were used to maximize the findings. The HT coefficient increased by 289 percent according to optimized data based on equivalent diameter, but by only 70 % for hydraulic diameter. It should be mentioned that Iqbal *et al.,* [54,57] have also conducted comparable experiments for improving finned tubular HEs.

Divya *et al.,* [58] investigate the channel's MHD peristaltic flow's temperature-dependent characteristics. One of the fundamental elements that have taken on remarkable relevance in the present because of its uses in biomedical engineering and other fields of industry is the temperature effects on fluid flow [59]. For the peristaltic movement of nanoparticles with chyme applications, Vaidya *et al.,* [60] included the magnetic impact and numerous slip variables. Vaidya *et al.,* [61] present the MHD Bingham fluid due to peristalsis with numerous chemical reactions along the aspect of application to blood flow with geometry through restricted arteries. The flow of Rabinowitsch fluid in a porous channel with varying liquid characteristics was covered by Vaidya *et al.,* [62]. They observed that the width of the conduit affected the consistency of the liquid. The governing non-linear equations' solution was obtained using the perturbation approach.

Experimental research on the enhancement of heat transfer by jet impingement on dimpled plates was conducted by Lutade *et al.,* [63]. They concentrated on the dimple shapes and evaluated the spherical and cylindrical dimple shapes. According to Lutade *et al.,* [63] the spherical dimple improves heat transmission more than the cylindrical dimple. Be aware that the cylindrical dimple's steep vertical edge might trap the flow, preventing the wasted air from leaving the chamber. As a result, there is no space for the incoming flow to hit the plate's surface, which results in a slow rate of heat transfer. The hexagonal ring turbulators were proposed by Patil *et al.,* [64] we looked at these geometries at various diameters and pitch ratios. The heat transfer enhancements ranged from 2.28 to 3.01, and the model with the largest performance index—1.34—had a diameter of 0.8 and a pitch ratio of 1. The pinned heat sink that influences fluid turbulence to improve heat transmission was studied by Kore *et al.,* [65]. High power components are used in the heat sinks that use air as their working fluid and are propelled by a tiny fan with a nominal speed mounted to the top of the heat sink to induce drawn or impinged axial air flow [66]. A concave depression with a shallower depth promotes heat transmission more than one with a deeper depth because the shallower dimple allows for easier shed of the internal vortices than the deeper one. Additionally, certain fluids may become trapped at the bottom of deep dimples, which slows down heat transmission [67].

4.3 Compound Method

This technique for improving HT combines active and passive techniques. One approach that has been the subject of several investigations into HEs is the simultaneous use of fluid vibration and wire coils. After considering the most recent studies on the theory of tubular HEs, we assert that there haven't been many studies reported on the subject. In one such unusual instance of research, Omkar *et al.,* [68] carried out a study where the outside surface of the rotating inner tube was covered with helical fins. The working fluids were water and glycerol, which circulated in the inner tube and annulus, respectively. It was discovered that the Nusselt number increased by 64% when the inner tube revolved at 100 rpm as opposed to a steady inner tube.

5. Nanofluids

Nguyen *et al.,* [69] conducted an experimental investigation to evaluate the efficiency of heat transmission of an impinging jet over various geometries of target surfaces using an Al_2O_3-Water nanofluid. The Reynolds values employed in the experiment ranged from 3800 to 88000. Nozzle to surface separations was 2 mm, 5 mm, and 10 mm. The particle volume percentage was 0%–6%, while the Prandtl number varied from 5 to 10. The experiment's findings made it abundantly evident that using nanofluids for a certain configuration of particle volume fractions and nozzle to surface distance might enhance HT. At a 2.8% volume percentage of nanofluid particles and nozzle to surface distances of 5 mm, the maximum HT coefficient was found. High particle volume fractions of 6% were shown to be ineffective for improving heat transmission in jet impingement settings. In an experiment employing a jet nanofluid system, Naphon and Wongwises [70] discovered that the average CPU temperature was 3.0% and 6.25% lower compared to a jet liquid impingement cooling system and a traditional cooling unit using liquid, respectively. The aim of the study was to evaluate the HT performance of jet nanofluids in cooling computer processing units. The coolant's flow rate was adjusted from 0.008 kg/s to 0.020 kg/s while maintaining a 2.00 mm nozzle-to-fin tip distance. TiO_2 particles dissolved in base fluid served as the working fluid. Zeitoun and Ali [7] performed an experimental research by vertically impinging nanofluid across a horizontally placed circular surface. Three distinct nanoparticle volume concentrations are 0%, 6.6%, and 10%. According to experimental results, heat transmission was enhanced when nanoparticle concentration was raised but Reynolds number remained the same.

Jaberi *et al.,* [71] conducted an experimental study to examine the thermal performance of the system by impinging a fluid jet of Al_2O_3 and water nanofluid over a circular flat disc. The Reynolds number range was 4,200 to 8,200, and the weight-based concentration of nanoparticles was maintained between 0.0198 and 0.0757%. Results revealed that, in comparison to water alone, the presence of nanoparticles improved thermal performance. The concentration of nanoparticles was increased to increase the HT coefficient, and a maximum HT coefficient of 0.0597% was reached at this concentration. The addition of nanoparticles was ineffective above this concentration level; in fact, the lowest HT coefficient was observed at a concentration of 0.0757%. The maximum HT coefficient for nanofluids was found to be 50% higher than for water at Reynolds number 4,200. Results revealed that, in comparison to water alone, the presence of nanoparticles improved thermal performance. The concentration of nanoparticles was increased to increase the HT coefficient, and a maximum HT coefficient of 0.0597% was reached at this concentration. The addition of nanoparticles was ineffective above this concentration level; in fact, the lowest HT coefficient was observed at a concentration of 0.0757%. The maximum HT coefficient for nanofluids was found to be 50% higher than for water at Reynolds number 4,200.

Zhou *et al.,* [72] employed different nanoparticle concentrations of silver-water nanofluids to examine the effectiveness of a submerged impinging jet's HT in plate and fin heat sinks. When a nanofluid was used instead of a base fluid, the HT coefficient increased by 6.23%, 9.24%, and 17.53%, respectively, for the same jet velocity and nanoparticles by weight concentrations of 0.02%, 0.08%, and 0.12%. Lv *et al.,* [73] demonstrated the improvement of HT by impinging a free single jet of a SiO_2-water nanofluid. The study employed three distinct nanoparticle volume concentrations of 1%, 2%, and 3% with a Reynolds number range of 8000 to 13,000. The convective HT coefficient for the nanofluid increased by 40% in comparison to water for the specified Reynolds number range and 3% nanoparticle volume concentration. According to Selimefendigil *et al.,* [74], corrugated surfaces had less of an impact on the enhancement of HT than flat surfaces at low Reynolds numbers. However, for high Reynolds numbers, the Nu would rise by around 6.99–8.87%. While cylindrical nanoparticles displayed a departure from the linear connection, spherical nanoparticles maintained a linear relationship between Nu and solid volume fraction. Table 3 shows that, literature review of nanofluids, flow rate and heat transfer performance.

Table 3
Nanofluids, flow rate and heat transfer performance

Reference	Methodology	Nanofluid	Flow Rate/ Reynolds number	Heat Transfer Performance
Sun *et al.,* [75]	Experimental Study	Silver-multiwall carbon nanotube/waterhybrid nanofluids	0.1–0.6m3·h−1	Increased HT coefficient by 29.45%
Sorour *et al.,* [76]	Experimental Study	SiO_2-Water	40,000	Nu having grown by up to 80%.
Kareem *et al.,* [77]	Experimental/ Numerical Study	CuO-Water	1,000-8,000	2.9%maximum Enhancement in Nu

6. Conclusion

The proposed review article addresses experimental and numerical investigations mostly related to force convective HT that occurs in tubular HEs. According to reports, this kind of heat exchanger is frequently used in engineering and industrial operations. Numerous researches, mainly including passive HT improvement techniques, have emphasized the necessity for a better HT rate and a reduced friction factor.

In some instances, it was discovered that the rate of HT increased by roughly 400% while the greatest pressure drop was reduced by 1000% when compared to a smooth tube. Geometry adjustment in twin pipe HEs is also a significant way of raising the performance assessment criterion in HEs, which calls for more research in the future.

Secondary flow significantly contributes to raising the HT rate in several of these experiments. In certain studies, the annulus of the twin pipe heat exchanger was additionally heated using techniques like coiled wires.

According to the scientists, utilizing vortex generators and low-Prandtl-number fluids in the annuli may be a wise decision. In twin pipe HEs, the active enhancement approach is not frequently employed, so it is thought that the authors should pay special attention to this method.

The comprehensive analysis of current impinging jet technologies to pinpoint the key technical research outcomes that are critical to enhancing the design and functionality of heating and cooling processes is performed. The most significant practical developments in the field of jet impingement thermal control are the main subject of this paper.

The ability of jet impingement to provide the best possible convective HT in a variety of engineering applications appears to be well established. Utilizing various stimulating jets has certain flow characteristics and thermal performance that can be precisely predicted by computational approaches or tested using advanced techniques.

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