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Review Paper on Forced Convection Heat Transfer Augmentation by Using Flow Divider Type Inserts

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Abstract – *In the realm of industrial operations, heat exchangers serve a pivotal function. Improving their efficiency can be achieved through the utilization of heat transfer enhancement methods. These techniques find widespread application across various sectors including chemical processing, evaporator heating and cooling, thermal power generation, air conditioning, refrigeration, and automotive radiator systems, among others. Heat transfer enhancement techniques are typically categorized as active, passive, or compound. This research focuses on exploring passive techniques for enhancing heat transfer. Specifically, this study conducts a comprehensive review of recent advancements in heat transfer enhancement utilizing non-metallic inserts. The analysis encompasses a survey of various research endeavors, methodologies employed, and resultant findings in this domain. Furthermore, the investigation delves into the discussion of diverse insert types, their geometries, and the influence of such geometries on heat transfer rates.*

Key Words - Forced convection, Heat transfer augmentation, Flow Divider Insert inserts.

1. INTRODUCTION

In today's contemporary landscape, the efficient utilization of available energy while minimizing material usage and process costs has become a paramount concern post the industrial revolutions. Ensuring the effective use of energy with minimal environmental impact has emerged as a significant imperative towards sustainable development, particularly in the design of devices aimed at facilitating heat energy exchange between two or more fluids. To address this imperative, extensive research has been undertaken globally, exploring various methodologies for optimizing energy utilization. Augmentation techniques for heat exchangers, including active, passive, and compound methods, have been proposed and implemented to enhance performance.

Heat transfer, defined as the movement of energy from one region to another due to temperature disparities, is integral to numerous industries such as food and beverage processing, chemical manufacturing, automotive, and thermal sectors, directly impacting their economic viability. Improving the efficacy of heat transfer devices not only leads to energy, material, and cost savings but also contributes to environmental sustainability. The study of enhancing heat transfer performance is commonly referred to as heat transfer augmentation, with a primary focus on elevating convective heat transfer coefficients.

Passive techniques for heat transfer augmentation, which do not require external power sources, have garnered significant attention due to their cost-effectiveness and performance efficiency compared to active methods. This paper delves into a detailed examination of heat transfer augmentation utilizing passive techniques. In passive methods, convective heat transfer coefficients are enhanced by minimizing thermal resistance, thereby facilitating improved heat transfer. This can be achieved through methods such as increasing effective heat transfer area or inducing turbulence in the fluid flow within the device.

Enhancing effective heat transfer area involves modifications within the conduit, such as introducing rough or extended surfaces. Turbulence generation, on the other hand, can be accomplished using inserts or turbulators. Forced convection heat transfer, a mechanism where fluid motion is induced by an external source such as a pump or fan, plays a crucial role in facilitating efficient heat transfer. This mechanism finds widespread application in everyday scenarios including air conditioning, central heating, steam turbines, and various industrial processes, highlighting its significance in enabling efficient energy transfer.

1.1 HEAT TRANSFER AUGMENTATION

Heat transfer augmentation methods are broadly categorized into three main types: active, passive, and compound techniques. Active techniques require external power input to function, while passive techniques operate without the need for additional energy, thereby enhancing thermohydraulic performance. Compound techniques combine two or more passive and/or active methods simultaneously to achieve even greater augmentation compared to using individual techniques independently.

Passive techniques, which operate without external power, involve altering the geometry or surface of the flow channel to improve system performance. This often includes the use of inserts, ribs, or rough surfaces to promote fluid mixing and turbulence, consequently increasing the overall heat transfer rate. Passive techniques offer several advantages, including cost-effectiveness, ease of production, and simplified installation procedures.

In contrast, active techniques are more intricate in design and application due to their reliance on external energy sources to manipulate fluid flow and improve thermal efficiency. The practical implementation of active techniques is often challenging due to the difficulty in providing external energy, limiting their widespread adoption in scientific fields.

Compound techniques, which combine multiple heat transfer enhancement methods, offer promising avenues for enhancing the thermohydraulic performance of heat exchangers. Preliminary studies on compound passive augmentation techniques show encouraging results.

Forced convection, commonly employed in various applications including heat exchangers, air preheaters, and cooling systems, utilizes external mechanisms such as fans to induce fluid motion, facilitating efficient heat transfer.

1.2 METHODS OF HEAT TRANSFER

Heat transfer augmentation methods are broadly categorized into three classifications: active, passive, and compound techniques.

A. Active Method: Active methods require external power input to operate. In contrast, passive methods do not need additional energy to improve the thermohydraulic performance of the system. Additionally, combining two or more passive and active techniques is termed a compound technique, used to achieve greater augmentation compared to using a single passive or active technique independently.

B. Passive Method: Passive methods operate without relying on external power sources; instead, they involve altering the geometry or surface of the flow channel to enhance thermohydraulic performance. Inserts, ribs, and rough surfaces are commonly utilized to induce fluid mixing and turbulence, resulting in an overall increase in the heat transfer rate. Passive techniques offer several advantages over other heat transfer enhancement methods, including low cost, ease of production, and installation. Conversely, active techniques are more intricate in design and application due to their dependency on external energy sources to manipulate fluid flow and improve thermal efficiency. Overcoming the challenges associated with providing external energy poses limitations, thereby restricting the widespread use of active techniques in scientific fields.

C. Compound Method: Compound techniques involve combining multiple heat transfer enhancement methods, including both active and passive techniques, to improve the thermohydraulic performance of heat exchangers. These techniques can be employed simultaneously to generate augmentation that enhances the system's performance beyond the capabilities of individual techniques operating independently. Preliminary studies on compound passive augmentation techniques have shown promising results. In the context of the current global energy crisis, exacerbated by continuous consumption growth, heat transfer augmentation has the potential to enhance device performance and reduce device size.

1.3 ADVANTAGES

Advantages of heat transfer augmentation techniques such as

- Increase the heat flow transferred in the heat exchanger.
- Reduce the surface area of the heat exchanger
- Reduce the driving temperature difference across the tube wall.

1.4 APPLICATION

Forced convection is commonly used in applications such as

- Heat Exchanger
- Heating Ventilation and Air Conditioning (HVAC) Systems
- Air Preheater
- Economizer
- Automotive Radiators
- Aerospace Applications
- Drying Processes
- Power Generation

- Solar Collectors
- Cooling of electronic components by fans
- Heating of homes using forced air blowers

1.2 ADVANTAGES

Heat transfer augmentation techniques offer several advantages, including:

- Enhancement of heat flow transferred within the heat exchanger.
- Reduction of the surface area required by the heat exchanger.
- Decrease in the driving temperature difference across the tube wall.

1.3 APPLICATION

Forced convection finds widespread application in various sectors, including:

- Heat Exchangers
- Heating, Ventilation, and Air Conditioning (HVAC) Systems
- Air Preheaters
- Economizers
- Automotive Radiators
- Aerospace Applications
- Drying Processes
- Power Generation
- Solar Collectors
- Cooling of electronic components by fans
- Heating of homes using forced air blowers

2. LITERATURE SURVEY

D. R. Hase et al. [1] conducted experimental investigations into heat augmentation employing non-metallic flow divider type inserts in forced convection. Their research focused on passive techniques for enhancing heat transfer, particularly utilizing Nylon flow divider inserts. These non-metallic inserts were designed to induce turbulence, thereby increasing heat transfer rates. The experiments involved externally heating a horizontal tube fitted with various inserts, including the Nylon flow divider insert featuring a 90-degree angle between consecutive blades. The study applied constant heat flux to a plain tube and conducted experiments at different mass flow rates of air to determine Nusselt number and friction factor. Initially, experimental data from the plain tube were compared with established correlations such as Dittus-Boelter and Blasius to validate the experimental setup. Once validated, experiments were conducted with the Nylon flow divider insert, and the obtained values of Nusselt number and friction factor were compared. The study observed a significant 70% increase in Nusselt number, with an overall enhancement ratio exceeding unity and enhancement efficiency ranging from 1.5 to 2.0.

S. G. Mushan et al. [2] investigated heat augmentation using non-metallic inserts in forced convection, employing two distinct types of inserts: Bakelite differential Annular Inserts and Acrylic Twisted Tape. The experimental data for the plain tube were meticulously compared with established correlations such as Dittus-Boelter and Petukhov, revealing a satisfactory agreement. For the Differential Annular Type insert, a remarkable maximum increase in Nusselt number of 112% was observed, accompanied by an overall enhancement ratio ranging from 0.54 to 1.12. The friction factor, which is directly related to pressure drop, was found to range from 0.5 to 0.6. On the other hand, for the Nonmetallic Acrylic Twisted Tape Insert, an impressive maximum increase in Nusselt number of 187% was noted, along with an overall enhancement ratio ranging from 1.10 to 1.58. The friction factor ranged from 0.06 to 0.08.

Sandeep P. Nalavade et al. [3] undertook experimental and numerical investigations into friction factor and forced convective heat transfer characteristics for air flow in a heated pipe using innovative flow divider type turbulators. Their experiments delved into exploring the impact of pitch to diameter ratio and twist angle of turbulators on heat transfer and friction factor. The study encompassed a comprehensive Reynolds number range of 7000 to 21000, investigating various parameters to elucidate their influence on convective heat transfer and pressure loss in fluid flow behavior. To complement their experimental endeavors, Computational Fluid Dynamics (CFD) simulations were meticulously conducted to scrutinize the effect of altering the angle of twist of turbulators. The experimental setup involved applying a constant heat flux to the test section (GI pipe), meticulously recording temperature data, air flow rates, and pressure differentials across the test section.

A. H. Dhumal et al. [4] delved into investigating heat transfer enhancement for tube-in-tube heat exchangers through the utilization of twisted tape inserts. Their study primarily entailed a theoretical investigation into the convective heat transfer performance and flow characteristics of fluids in double pipe heat exchangers. The findings underscored critical observations regarding the impact of Reynolds number on heat transfer performance and flow behavior. Emphasizing the significance of selecting appropriate inserts based on specific requirements, the study shed light on the delicate balance between heat transfer enhancement and pressure drop.

Sahil Sunil Patil et al. [5] meticulously analyzed forced convection heat transfer to enhance thermal performance using pipes equipped with triangular fin inserts. Their study meticulously delved into experimentally investigating the heat transfer performance of copper tubes fitted with triangular fin inserts. The findings highlighted substantial enhancements in heat exchanger effectiveness, with critical conclusions drawn regarding the effects of mass flow rate and fin spacing on heat transfer and pressure drop. Proposing new correlations for Nusselt number and heat transfer coefficient based on their experimental data, the study provided valuable insights for practical applications.

H. V. Chavan et al. [6] ventured into exploring heat transfer enhancement utilizing twisted tape inserts, ultimately identifying the twist ratio yielding the highest heat transfer rate. Their study conclusively demonstrated that twisted tape inserts significantly amplify heat transfer rates compared to plain tubes within a specific Reynolds number range. With meticulous observations made on Nusselt number variations and friction factors for different twist ratios, the study underscored the intricate relationship between these parameters.

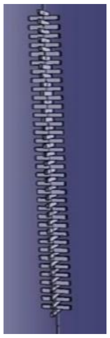
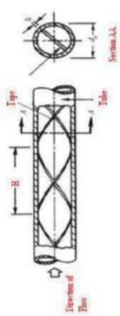
A. M. Rathod et al. [7] conducted an exhaustive experimental study focusing on heat transfer augmentation by forced convection from various ribbed surfaces. Their study meticulously investigated the heat transfer characteristics over ribs in turbulent boundary layers under varying Reynolds and Nusselt numbers. Observing a significant enhancement in turbulent heat transfer due to the presence of ribs, the study drew valuable conclusions regarding the effectiveness of different rib arrangements and materials.

N. C. Kanojiya et al. [8] meticulously reviewed enhancement techniques in heat transfer using inserts, with a particular emphasis on the utilization of nanofluids. Their comprehensive review highlighted various passive methods for enhancing heat transfer rates, with a specific focus on twisted tape inserts. The review meticulously documented observations regarding the impact of perforations in twisted tape inserts on heat transfer rate and pressure drop. The review concluded by underscoring the potential of twisted tape inserts for future applications, particularly in laminar flow scenarios.

S. Naga Sarada et al. [9] undertook an in-depth investigation into the enhancement of heat transfer using varying width twisted tape inserts. Their study experimentally explored the potential of reduced width twisted tape inserts to enhance heat transfer rates in a horizontal circular tube. Observing critical effects of modified twist ratio and Reynolds number on heat transfer and overall enhancement ratio, the study concluded by proposing correlations for practical use, shedding light.

3. REVIEW OF WORK CARRIED OUT

Name of Author	Geometric View of Insert	Observation & Comment
D. R. Hase et al. [1]	 Nylon flow divider insert	Nu increased and decreased with increase in Re. Nu is increased by 70%
S. G. Mushan et al. [2]	 Bakelite Differential Annular Insert	Nu increased and decreased with increase in Re. Nu is increased by 12%
S. G. Mushan et al. [2]	 Acrylic Twisted Tape Insert	Nu increased and decreased with increase in Re. Nu is increased by 87%

Sandeep P. Nalavade et al. [3]	 Al Insert mounted on rod	The turbulator with pitch to diameter ratio (p/d) 0.54 and 30° angle of twist (θ) performs better.
H. A. Dhumal et al. [4]	 Low carbon steel ANSI AS-177 helical twisted tapes	With increase in twist ratio, Nusselt's Number decreases but at the same time pressure drop also decreases.
Sahil Sunil Patil et al. [5]	  AL Pipe with GI Triangular Fin Insert.	The heat transfer coefficient demonstrates an upward trend with the escalation of the Reynolds number. Meanwhile, the friction factor exhibits a declining pattern with the increment of the Reynolds number, whereas in the finned tube, it gradually diminishes as the gap between two fins increases (with a spacing of 160mm).

4. CONCLUSION

- For the Nylon flow divider insert, the Nusselt number (Nu) exhibited an increase followed by a decrease with the rise in Reynolds number (Re). Notably, Nu experienced a significant increase of 70%.
- Similarly, in the Bakelite Differential Annular Insert, Nu displayed a similar trend of increasing and then decreasing with rising Re, resulting in a 12% increase.
- In the case of the Acrylic Twisted Type Tape, Nu demonstrated a similar behaviour with variations in Re, showing an impressive increase of 87%.
- It was observed that with an increase in twist ratio, Nusselt's Number (Nu) decreased, accompanied by a decrease in pressure drop.

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