Babylonian Journal of Mechanical Engineering
Vol.2024, **pp**. 99–105
DOI: https://doi.org/10.58496/BJME/2024/012; ISSN: 3006-5410
https://mesopotamian.press/journals/index.php/BJME

Research Article

Active Techniques of Heat Transfer Enhancement: A review

Duaa Mraiza [1], Foad Faraji [2,*]

[1] *School of Engineering and Natural Sciences, Altinbas University, Istanbul-Turkey.*
[2] *School of Computing, Engineering & Digital Technologies Teesside University, UK.*

ARTICLE INFO

Article History
Received 29 Aug 2024
Revised: 20 Sep 2024
Accepted 26 Oct 2024
Published 25 Nov 2024

Keywords
Heat transfer
vibration
injection
mechanical aid

ABSTRACT

In this work, active methods for improving heat transfer are discussed, with a particular emphasis on new ideas and their applicability in various sectors of different types. Heat transfer efficiency is essential for optimising energy utilisation in industries such as chemical processing, heating, ventilation, air conditioning (HVAC), and renewable energy. Mechanical assistance, surface vibrations, electrostatic fields, and fluid injection are some approaches investigated in this research. The study also investigates the ideas behind these techniques and their practical ramifications. The results of this study indicate that active approaches, even though they often call for more power, have the potential to greatly improve thermal performance and provide new solutions for difficult technical difficulties.

1. INTRODUCTION

Heat exchangers serve several purposes, including energy conversion and industrial, home, and commercial recovery. Public examples include cooling in chemical processing, condensation in electricity, agricultural goods, pharmaceuticals, steam generation, sensible heating, cogeneration plants, waste heat recovery, and fluid heating in manufacturing.

Improving heat exchanger performance may lead to cost savings in energy, materials, and processes. Enhancing heat exchanger thermal performance has led to the invention and usage of several heat transfer augmentation strategies. These approaches improve convective heat transfer by lowering heat exchanger thermal resistance [1-3]. Using augmentation methods increases the heat transfer coefficient and pressure drop. Various strategies have been suggested in recent years to achieve high heat transfer rates while supplementing pumping power. Recently, swirl flow devices have been extensively employed to enhance convective heat transfer across sectors. Reasons for this application include minimal cost and quick setup. This research is on introducing methods to enhance heat transfer performance. The literature study covers turbulators, including coiled tubes, extended surfaces, rough surfaces, and swirl flow devices, including twisted tape, conical rings, snail entrance turbulators, vortex rings, and coiled wire.

2. HEAT TRANSFER ENHANCEMENT

Enhancing heat transfer performance is known as heat transfer enhancement (augmentation or intensification). Many experts in thermal engineering are exploring innovative strategies to improve heat transfer between surfaces and fluids. According to Bergles [4, 5], heat transfer mechanisms may be classified as active or passive. Active methods need electricity to sustain the enhancement process. Active improvement approaches include stirring or shaking the surface [6]. Hagge and Junkhan[7] described active mechanical means to improve heat transfer. In contrast, passive enhancement approaches do not need external power to maintain their properties. Passive enhancing techniques include treated surfaces,

---

*Corresponding author. F.Hamad@tees.ac.uk

rough surfaces, extended surfaces, displacement enhancement devices, swirl flow devices, coiled tubes, surface tension devices, and fluid additives.

3. ACTIVE TECHNIQUES

Heat transfer enhancement techniques are often categorised into three main types: active methods, passive methods, and compound methods. The compound approach is used for intricate designs, resulting in restricted applications.

Active methods need extra power input to enhance the rate of heat transfer. This approach has limited use in several practical applications due to the need for equipment. Compared to passive approaches, these methods exhibit limited potential due to the challenges in supplying external power input in several instances.

3.1 Mechanical Aids

Mechanical aids use physical motion or devices to augment heat transfer by disrupting the boundary layer, inducing turbulence, or enhancing fluid mixing. These adaptable technologies may be used in diverse engineering systems to enhance thermal efficiency.

Although the technique is inherent in special heat exchangers known as Scraped Surface Heat Exchangers (SSHEs), as shown in Figure (1), it is rarely investigated in the literature. The SSHEs are devices primarily employed in the food, chemical, and pharmaceutical industries for heat transfer, crystallisation, chilling, and evaporation [8]. Schematically illustrated in Figure 1, the construction of an SSHE is straightforward and comprises three primary components: a shell, a rotating shaft, and scrapping blades known as scrapers [9]. The scrapers have the ability to continually remove the working fluid from the inner surface of the shell while also blending it with the working fluid that circulates in the annular area that exists between the shell and the shaft. Not only does this result in a clean heat transfer surface, but it also leads to a considerable improvement in heat transmission. In most cases, the SSHEs are used for working viscous and tenacious fluids; nevertheless, the devices that are being evaluated may also be utilised for gases [10]. Hernandez-Parra et al. [11] conducted a numerical investigation of the heat transfer and fluid movement of sorbets that were contained inside an SSHE unit. In the suggested model, the key characteristics considered were the thermophysical properties of the working fluid that were dependent on temperature. A comparison was made between the numerical findings that were obtained and the experimental data that were accessible in the established body of literature. The experimental study was carried out by Martinez et al. [12], who also presented a novel approach to the measurement of the wall temperature in an SSHE. The two-dimensional transient model was developed by the authors in order to facilitate the evaluation of the disparity between the temperature of the thermocouple and the temperature of the wall on the side that was removed. In order to account for the large influence that thermocouple data had on the heat transfer coefficient, a corrective model was brought forward. Chen et al. [13] investigated an SSHE that used silt as the working fluid. The authors presented a three-dimensional numerical model of the SSHE and provided evidence to support their claim by comparing it to the experimental findings published in the literature. In addition to this, Bayareh et al. [14] have created and validated a three-dimensional numerical model of thermal-flow processes. The authors researched how the shape of the blades affected the thermal efficiency and heat transfer performance of a single-shaft heat exchanger (SSHE). An innovative blade design that eliminates the possibility of fluid deposition was developed. The primary factors that influence the heat transfer rate in an SSHE were numerically examined by Dekhordi et al. [15]. These factors include the rotational speed of the blades, the length and material of the stator, the number of blades and their configuration, the viscosity of the working fluid, the heat flux at the stator wall, and the inlet flow rate. They concluded that the rotational speed in question was the most influential component.

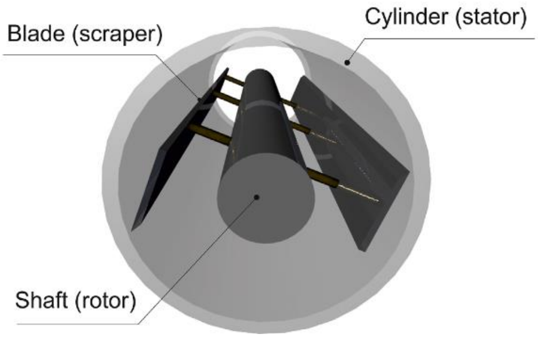

Fig. 1. SSHE heat exchanger

3.2 Surface Vibration

They have been mostly used in single-phase flows. A low or high frequency is used to induce surface vibrations, leading to enhanced convective heat transfer coefficients. It is well-established that certain industrial applications experience vibrational phenomena, such as pulsating flow and ultrasound-induced vibrations. A review of the literature, including reputable articles in archival journals, reveals that while vibrations can negatively impact the durability and lifespan of devices due to the onset of fatigue stress on surfaces, numerous analyses have been conducted to assess the influence of vibration on enhanced heat transfer. Vibrations possess the ability to significantly augment heat transfer and destabilise tube flow, thereby facilitating the rapid growth of thermal boundary layers, which results in improved heat transfer.

A great number of studies have shown that the vibrations that are created in the flow system increase the rate of heat transfer by causing chaotic motion, which ultimately leads to fluid mixing. In the following, you will find a summary of appropriate works. The purpose of the experiments that Bash and colleagues [16] carried out was to explore the impact that forced vibration has on the movement of heat in the transverse direction of a circular tube. Both the frequency and the amplitude were found to fall within the range of 13 to 30 Hz and 0.001 to 0.002 mm, respectively, while the flow regime remained laminar. The conclusion that was reached was that the rate of heat transfer dramatically increased with higher frequency as opposed to with larger amplitude. In their study on heat transmission, Mishra et al. [17] looked at a number of different vibration applications. An investigation of the impact that vibration has on heat transfer was carried out, taking into account both Newtonian and non-Newtonian fluid situations. An investigation was conducted on the impact that vibration and nanofluid have when combined. The Reynolds number of the fluid flow, the amplitude and frequency of the vibration that was applied, and the rheological characteristics of the fluid were the important factors that determined the amount of heat that was transferred. It has been shown via research that the use of nanofluids in vibrating settings resulted in a thirtyfold increase in heat transfer when compared to the Newtonian fluid application, which did not include vibration. On a tube-type horizontal heat exchanger, Klaczak [18] used longitudinal vibration with frequencies ranging from 20 to 120 hertz. An empirical correlation for the Nusselt number has been created by him, and it is based on the Graetz number, frequency, and amplitude. The average degree of accuracy of this correlation is 4.6%. It is notably noticeable at low Reynolds numbers as the Nusselt number rises as the frequency that is applied increases. A thermally conditioned grooved cylindrical copper pipe that was filled with water was subjected to longitudinal vibrations with frequencies ranging from 3 to 9 Hz and amplitudes ranging from 2.8 to 25 mm. Chen et al. [19] exploited these vibrations. The effectiveness of heat transmission was studied at a variety of temperatures, including those of acceleration and condensation. When everything was said and done, the conclusion that was reached was that the rate of heat transfer increased with vibration. However, the rate of improvement in heat transfer was slowed down because of the excessive usage of vibrational energy for the process. The researchers Lee et al. [20] investigated the impact that vibration has on crucial heat flow and the enhancement of heat transfer for a fluid that was contained inside a vertical tube and was exposed to a variety of frequencies and amplitudes. Under the parameters that were investigated, there was a 12.6% increase in the flow of heat, which led to the conclusion that the critical heat flux is more sensitive to amplitude than it is to frequency. Kim et al. [21], who conducted research that was quite similar to this one, investigated the impact that tube vibration had on critical heat fluxes in order to discriminate between crucial heat flow and vibration-induced flux. A study conducted by Deleoei and colleagues [22] investigated the effect that ultrasonic vibration has on the lowering of pressure and the increase of heat transfer in turbulent intake flows. The ultrasonic transducer was attached to the stainless steel tube that was designated as the test part, and the tube was then submerged in a two-phase fluid that maintained a consistent temperature level. In their study, Deleoei and colleagues [23] investigated the impact that ultrasonic vibration and nanoparticles have on the reduction of pressure drop and the promotion of heat transfer in turbulent intake flow. When the Reynolds number was decreased, the effect of ultrasonic vibrations was stronger than it was otherwise.

3.3 Electrostatic Fields

An electrostatic field, similar to electric or magnetic fields, or a combination thereof from direct current (DC) or alternating current (AC) sources, is used in heat exchanger systems to induce enhanced bulk mixing, forced convection, or electromagnetic pumping, hence improving heat transfer efficiency. This approach is relevant in heat transfer processes employing dielectric fluids. Improving single-phase heat transfer processes, particularly in gas systems, has been a significant focus for scientists and engineers. There are a lot of articles on the EHD enhancement of heat transfer. Fernandez et al. [24] reported experimental findings of an electro-hydrodynamically-enhanced oil heater with an annular cross-section. The findings indicated that the application of a high direct current voltage of 30 kV across the annular gap significantly produced radial fluid motion. This led to a heat transfer rate enhancement over twenty times that of fully formed laminar flow, but the pressure drop rose just thrice. Within a heat pipe heat exchanger, Kui [25] conducted research to determine how the presence of an electric field affected the thermal transfer of air from one air to another. As a function of the Reynolds number, the voltage that was delivered, and the pattern of the voltage (static and impulsive), a correlation was shown in terms of the heat transfer coefficient, the heat transfer rate, and the temperature efficiency. The electrohydrodynamic stability was examined by Moatimid [26], which included the transmission of heat and mass between two fluids that communicate with each other in a cylindrical contact. An investigation was conducted to determine how the stability of a cylindrical interface between two liquid phases was affected by the presence of a tangential periodic electric field. Between two coaxial cylindrical surfaces, the two phases were confined, and the contact allowed for the transmission of both heat and mass. After constructing and analysing a thorough dispersion equation, conclusions were drawn. The conclusions of the analysis were confirmed by numerical analysis. The linear stability of an interface between two dielectric viscous fluids that were separated by a horizontal interface was later proven by Moatimid [27]. A periodic electric field that was directed in a direction that was perpendicular to the contact caused the system to experience strain. A method known as the multiples time scale was used in the inquiry [28]. It investigated how the critical surface charge density and electric field are affected by factors such as surface tension, low viscosity, velocity streaming, and gravity. The verification of the analytical conclusions was accomplished via the use of numerical data. An experimental investigation on the enhancement of corona wind in free convection was carried out by Owsenek and colleagues [29] in the year 1995. The investigation used a heated horizontal flat plate. High voltage was applied to a needle using a needle. Through the use of the EHD methodology, Paschkewitz and Pratt [30] investigated the impact that the properties of the fluid had on the enhancement of heat transmission. The rate of heat transfer, the pressure drop, the amount of electrical power used, and the transition between viscous-dominated and electrically-dominated flow regimes were all investigated. Working fluids consist of three different cooling oils, each of which has a drastically different set of physical characteristics. While maintaining the same low Reynolds number, it was found that the EHD exerted a significant amount of impact on liquids with a low viscosity. By comparing the theoretical conclusions with the evidence that was already available from experiments and analyses, the findings were verified.

3.4 Fluid Injection

This approach involves injecting the same or a different fluid into the primary bulk fluid via a porous heat transfer interface or upstream of the heat transfer section. This method is used for the single-phase heat transfer procedure. Saffari et al. [31] conducted an experimental assessment of the impact of air bubbles on the reduction of pressure drop in a vertical helical coil. The range of void fraction and Reynolds numbers was (0 to 0.09) and (8000–50000), respectively. The findings demonstrate that the drag reduction ratio was 25% at the lowest Reynolds number. Ezzat et al. [32] conducted a computational and experimental investigation on the impact of air bubble injection in a vertical pipe subjected to continuous heat flux. The investigations were conducted within a water flow rate range of 8 to 10 litres per minute, an airflow rate range of 1.5 to 4 litres per minute, and a heat flux range of 27,264 to 45,398 W/m², respectively. A CFD algorithm and the k-e turbulence model were used to resolve the energy, momentum, and continuity equations. Bubbles injection enhanced heat transfer and temperature distribution. Additionally, air bubbles elevate the mean Nusselt number for the minimal heat flux of 27264 W/m² by 33.3% in numerical analysis and 23% in experimental results, respectively. Ghashim [33] experimentally studied by employing two techniques: bubble injection on pressure drop in water flow in a vertical pipe. A transparent tube with a diameter of 0.025 m and a length of 2 m was utilised as the test section. The trials used air bubble flow rates of 0.5, 1, and 1.5 litres per minute, with water Reynolds numbers ranging from 13321.68 to 22202.79. It was noticed that little air bubbles had a greater impact than larger bubbles on reducing the pressure differential. Furthermore, the maximum decrease in pressure drop attained was 28% at a volume fraction of 11% and a low Reynolds number of 13321.68.

4. CONCLUSIONS

Through this review, the transformational potential of active heat transfer improvement approaches is brought to light. Each approach has its own set of advantages, ranging from enhancing the effectiveness of heat exchangers in industrial settings to resolving certain issues that arise in contemporary engineering systems. Despite the fact that active approaches need more resources, their influence on performance is rather significant. In the future, research may concentrate on making these methods compatible with environmentally friendly energy practices or investigating how they might be integrated with cutting-edge materials and intelligent systems. Through the implementation of this strategy, thermal management systems across all sectors will continue to undergo innovation.

Conflicts Of Interest

The author's paper explicitly states that there are no conflicts of interest to be disclosed.

Funding

The author's paper clearly indicates that the research was conducted without any funding from external sources.

Acknowledgment

The author acknowledges the institution for their commitment to fostering a research-oriented culture and providing a platform for knowledge dissemination.

References

[1] M. J. Al-Dulaimi and K. E. Amori, “Effect of receiver geometry on the optical and thermal performance of a parabolic trough collector,” Heat Transfer, vol. 51, no. 3, pp. 2437–2457, Jan. 2022, doi: 10.1002/htj.22406.

[2] M. J. Al-Dulaimi and K. E. Amori, ‘Optical and thermal performance of a parabolic trough collector for different receiver geometries’, Arab. J. Sci. Eng., vol. 47, no. 12, pp. 16117–16133, Dec. 2022.

[3] K. A. Ameen, H. Abdulrasool hasan, M. J. Al-Dulaimi, A. M. Abed, and H. F. Al-Qrimli, “Improving the performance of air conditioning unit by using a hybrid technique,” MethodsX, vol. 9. Elsevier BV, p. 101620, 2022. doi: 10.1016/j.mex.2022.101620.

[4] A. E. Bergles, Handbook of Heat Transfer, 3rd ed. New York, NY, USA: McGraw-Hill, 1998.

[5] A. E. Bergles, "The implications and challenges of enhanced heat transfer for the chemical process industries," Chemical Engineering Research and Design, vol. 79, no. 4, pp. 437–444, 2001.

[6] E. I. Nesis, A. F. Shatalov, and N. P. Karmatskii, "Dependence of the heat transfer coefficient on the vibration amplitude and frequency of a vertical thin heater," Journal of Engineering Physics and Thermophysics, vol. 67, no. 1-2, pp. 696–698, 1994.

[7] J. K. Hagge and G. H. Junkhan, "Experimental study of a method of mechanical augmentation of convective heat transfer in air," Tech. Rep. HTL3, ISU-ERI-Ames-74158, Iowa State University, Amsterdam, The Netherlands, 1975.

[8] C. S. Rao and R. W. Hartel, "Scraped surface heat exchangers," Critical Reviews in Food Science and Nutrition, vol. 46, no. 3, pp. 207–219, 2006.

[9] P. Błasiak and S. Pietrowicz, "An experimental study on the heat transfer performance in a batch scraped surface heat exchanger under a turbulent flow regime," International Journal of Heat and Mass Transfer, vol. 107, pp. 379–390, 2017.

[10] J. Hagge and G. Junkhan, "Mechanical augmentation of convective heat transfer in air," Journal of Heat Transfer, vol. 97, no. 4, pp. 516–520, 1975.

[11] O. D. Hernandez-Parra, A. Plana-Fattori, G. Alvarez, F.-T. Ndoye, H. Benkhelifa, and D. Flick, "Modeling of flow and heat transfer in a scraped surface heat exchanger during the production of sorbet," Journal of Food Engineering, vol. 221, pp. 54–69, 2018.

[12] D. Martinez, F. Illan, J. Solano, and A. Viedma, "Embedded thermocouple wall temperature measurement technique for scraped surface heat exchangers," Applied Thermal Engineering, vol. 114, pp. 793–801, 2017.

[13] J. Chen, J. Wu, X. Ji, X. Lu, and C. Wang, "Mechanism of waste-heat recovery from slurry by scraped-surface heat exchanger," Applied Energy, vol. 207, pp. 146–155, 2017.

[14] M. Bayareh, A. H. Pordanjani, A. A. Nadooshan, and K. S. Dehkordi, "Numerical study of the effects of stator boundary conditions and blade geometry on the efficiency of a scraped surface heat exchanger," Applied Thermal Engineering, vol. 113, pp. 1426–1436, 2017.

[15] K. S. Dehkordi, M. A. Fazilati, and A. Hajatzadeh, "Surface scraped heat exchanger for cooling Newtonian fluids and enhancing its heat transfer characteristics: A review and a numerical approach," Applied Thermal Engineering, vol. 87, pp. 56–65, 2015.

[16] A. Bash, A. Alkumait, and H. Yaseen, "Experimental investigation of the influence of mechanical forced vibrations and heat flux on coefficient of heat transfer," Scientific Journal of University of Zakho, vol. 6, no. 3, pp. 124–129, 2018.

[17] S. K. Mishra, A. Arora, and H. Chandra, "Application of vibration on heat transfer – a review," i-Manager's Journal on Future Engineering and Technology, vol. 15, no. 1, pp. 72–81, 2019.

[18] A. Klaczak, "Report from experiments on heat transfer by forced vibrations of exchangers," Heat and Mass Transfer, vol. 32, no. 6, pp. 477–480, 1997.

[19] R. H. Chen, Y. J. Lin, and C. M. Lai, "The influence of horizontal longitudinal vibrations and the condensation section temperature on the heat transfer performance of a heat pipe," Heat Transfer Engineering, vol. 34, no. 1, pp. 45–53, 2013.

[20] Y. H. Lee, D. H. Kim, and S. H. Chang, "An experimental investigation on the critical heat flux enhancement by mechanical vibration in vertical round tube," Nuclear Engineering and Design, vol. 229, no. 1, pp. 47–58, 2004.

[21] D. H. Kim, Y. H. Lee, and S. H. Chang, "Effects of mechanical vibration on critical heat flux in vertical annulus tube," Nuclear Engineering and Design, vol. 237, no. 9, pp. 982–987, 2007.

[22] A. A. Delouei, H. Sajjadi, R. Mohebbi, and M. Izadi, "Experimental study on inlet turbulent flow under ultrasonic vibration: pressure drop and heat transfer enhancement," Ultrasonics Sonochemistry, vol. 51, pp. 151–159, 2019.

[23] A. A. Delouei, H. Sajjadi, M. Izadi, and R. Mohebbi, "The simultaneous effects of nanoparticles and ultrasonic vibration on inlet turbulent flow: an experimental study," Applied Thermal Engineering, vol. 146, pp. 268–277, 2019.

[24] J. Fernández and R. Poulter, "Radial mass flow in electrohydrodynamically-enhanced forced heat transfer in tubes," Int. J. Heat Mass Transfer, vol. 30, pp. 2125–2136, 1987.

[25] K. Lui, "The enhancing heat transfer of heat pipe by the electric field," in Proc. 7th Int. Heat Pipe Conf., USA: Begell House, 1993, pp. 563–567.

[26] . M. Moatimid, "Electrohydrodynamic stability with mass and heat transfer of two fluids with a cylindrical interface," Int. J. Eng. Sci., vol. 33, 1994.

[27] G. M. Moatimid, "Electrohydrodynamic instability of two superposed viscous miscible streaming fluids," Chaos, Solitons & Fractals, vol. 12, pp. 1239–1257, 2001.

[28] A. H. Nayfeh and B. Balachandran, Applied Nonlinear Mechanics. New York, NY, USA: Wiley, 1995.

[29] B. L. Owsenek, J. Seyed-Yagoohi, and R. H. Page, "Experimental investigation of corona wind heat transfer enhancement with a heated horizontal flat plate," J. Heat Transfer, vol. 117, pp. 309–315, 1995.

[30] J. S. Paschkewitz and D. M. Pratt, “The influence of fluid properties on electrohydrodynamic heat transfer enhancement in liquids under viscous and electrically dominated flow conditions,” Exp. Therm. Fluid Sci., vol. 21, pp. 187–197, 2000.

[31] H. Saffari, R. Moosavi, E. Gholami, and N. M. Nouri, "The effect of bubble on pressure drop reduction in helical coil," Experimental Thermal and Fluid Science, vol. 51, pp. 251–256, 2013.

[32] A. W. Ezzat, N. N. Abdullah, and S. L. Ghashim, "Effect of air bubbles on heat transfer coefficient in turbulent convection flow," Journal of Engineering, vol. 23, pp. 8–28, 2017.

[33] S. L. Ghashim, "Study effect of bubble size on drag reduction," in 10th International Conference on Advances in Science, Engineering and Technology (ICASET-18), Paris, France, June 20–21, 2018.