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Heat Transfer Enhancement in Circular Cross Section Tube Using Inserts

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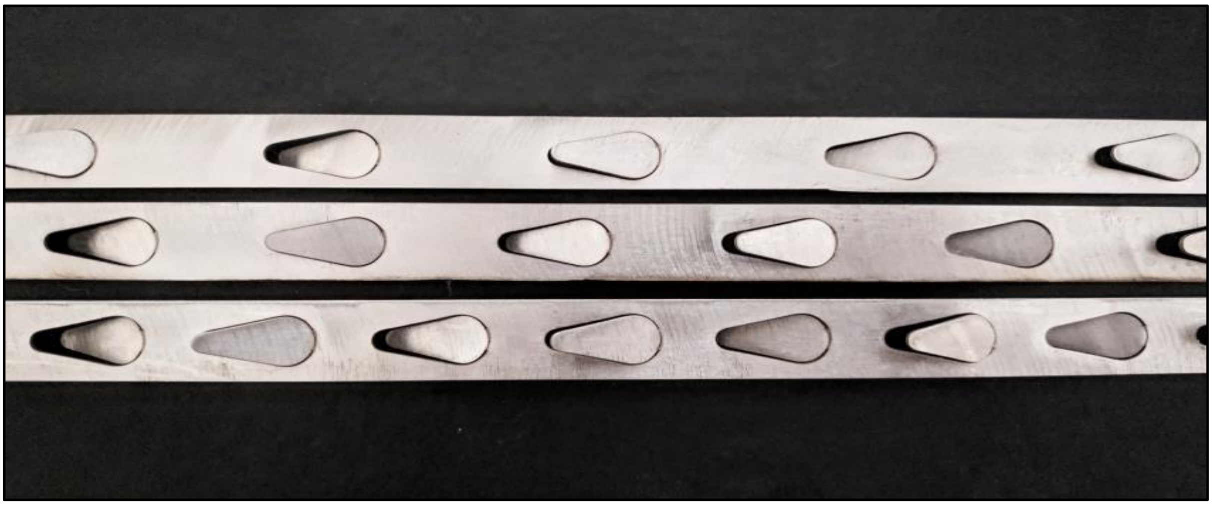
Abstract: *Convective heat transfer was empirically examined in tubes with ballooned flat perforated steel inserts under turbulent flow conditions, encompassing Reynolds numbers ranging above 15000. The primary objective of this study is to expand the existing dataset concerning inserts. The external surface of the tube received a uniform heat flux, with air serving as the chosen fluid. Correlations were derived for the mass flow rate and heat absorption, utilizing the gathered measurements within the explored range of geometrical parameters and Reynolds numbers.*

1. INTRODUCTION

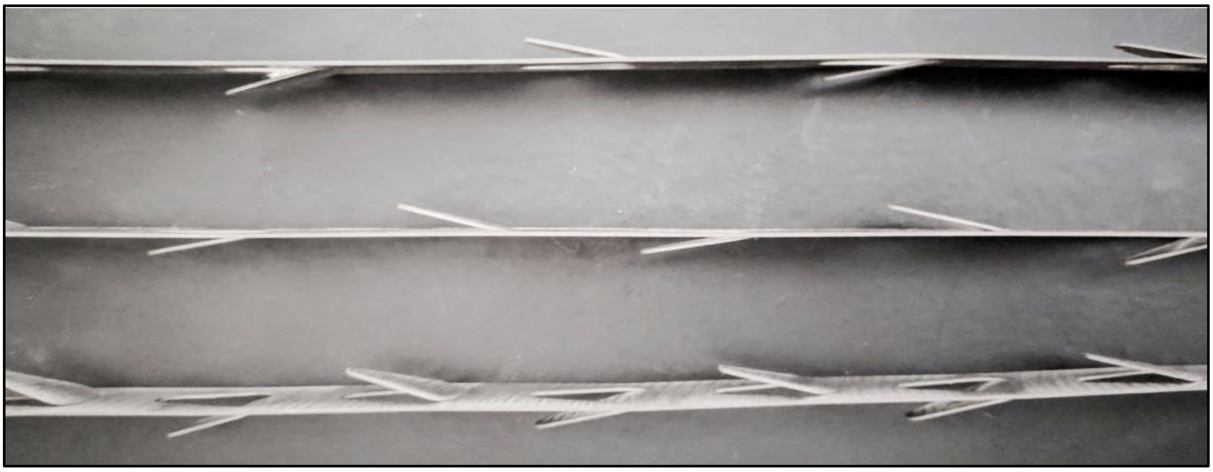
In recent years, research aimed at improving heat transfer has been of great importance. Reducing the energy demand of energy-intensive systems and maximizing energy use are common research topics. Saving energy is a huge and expensive problem for industry, and this is one reason why they often install devices called heat exchangers to save as much heat as possible from flue gases. Heat exchangers also have many other well-known uses. Engines in cars, ships, and airplanes use heat exchangers to work more efficiently, and if there is a refrigerator or air conditioner at home, heat exchangers are also used. For this reason, more numerical and experimental studies are carried out. efficient heat exchangers for heat recovery and storage systems. Heat exchangers used in industrial systems such as cooling and heating can require significant amounts of energy, so reducing the energy consumption of heat exchangers is critical. The heat transfers and fluid flow community has done a lot of work to improve heat transfer in heat exchangers to promote energy conservation. In general, two techniques are used to improve heat transfer in heat exchangers: passive and active. Active techniques require the use of an external energy source to increase heat transfer, while passive techniques achieve heat transfer enhancement through passive means (such as the use of inserts or extended surfaces), thus eliminating the need for an external energy source. Passive technologies are also cheaper than active technologies because the internal parts are relatively easy to manufacture, which reduces installation costs. Therefore, it is recommended to use passive technologies to improve heat transfer in heat exchangers. Passive techniques use not only special inserts or extended surfaces but also nanofluids, where solid nanoparticles with high thermal conductivity are dispersed in a base liquid. In an experimental study, Akcayoglu [1] investigated ducts with two rows of half-triangular blades with two different configurations. The double anti-twist strips used by Bhuiya et al. [2] in their study showed an improvement in thermal efficiency when the twist ratio of mild steel was increased. Promvonge et al. [3] used inclined vortex rings in their study and found a heat capacity factor of 1.4 at their lowest Reynolds number. Kumar et al. [4] observed a maximum thermal efficiency increase of 1.47 times compared to a normal tube when investigating circular ring perforation with different perforation indices. Zong et al. [5] used a hollow cross-disk insert for their numerical studies of the HE; as a result, they found that the flow nature was three-dimensional with turbulent flow. Hameed et al. [6] studied rectangular boxes and obtained that, for maximum outlet temperature, four inserts are to be placed in the fluid domain. Nagarajan Fluids 2021, 6, 247. https://doi.org/10.3390/fluids6070247 https://www.mdpi.com/journal/fluids Fluids 2021, 6, 247 2 of 11 and Sivashanmugam [7] used a right-left helical spacer insert fitted in a circular tube in which they varied the twist ratio of the helix. They achieved an improvement in heat transfer by increasing the value of Re and decreasing the value of the twist ratio. Gururatana et al. [8] showed that the highest TPF found was 1.45 when the extras were set to 450. Aliabadi et al. [9] investigated the arrangement of delta wings. They deployed 14 vortex generators with forward and longitudinal delta wings. The results showed that delta fins cut on both sides improve heat transfer. The literature review notes that surface disturbances in the round tube heat exchanger core play an important role in increasing efficiency. Eiamsa-ard and Promvonge [10] investigated double-sided delta fin strip inserts, and they concluded that delta fins improve both heat transfer and HE efficiency. In other studies, Eiamsa-ard and Promvonge [11] analysed the efficiency of HE in alternately counterclockwise and clockwise twisted ribbons and used short-length twisted ribbons [12], which generated strong vorticity at the inlet and improved efficiency. Similarly, considering double-delta-wing twist tape [13], twist tape connections [14], and rectangular twist tapes used by Nakhchi and Esfahan [15], Rahim et al. [16] investigated and achieved reduced pressure drop and greater fluid mixing due to increased vortex formation and improved heat transfer characteristics. Singh et al. [17] experimentally investigated hollow circular plates with rectangular fins and found superior thermal efficiency in heat transfer to a simple plain tube (a flat circular tube without any insert). Similarly, researchers using circular ring turbulators [18] and spiral ribbon rings [19] found an improvement in the heat transfer rate due to the formation of vortices in the former and vortices on top of vortices in the latter. . . Gautam et al. [20] investigated using a perforated triple-wing vortex generator and found enhancements in heat transmission and thermal performance over a simple plain tube HE.

2. GEOMETRY OF INSERT

Ballon shaped flat perforated inserts have been used as turbulators. The perforations made are ballooned triangles and possess four different patterns of perforation The physical model of the test segment consists of a circular channel with a 45-mm internal radius and 1500-mm length. The ballon shape is in three wings and aligned at 120 degrees to each other with a height of 30 mm throughout the length, which is perforated in a triangular ballon shape in each of its. A non-perforated case has also been studied. In the present analysis, the air is considered as a working fluid with the temperature as 300 K and a constant wall heat flux density applied throughout the wall of the test section.



(a)



(b)

FIGURE 1. (a): Side view of Inserts; (b) Top view of Inserts

TABLE 1. Boundary condition and physical properties of air

Boundary Conditions	**Values**
Air Temperature at inlet (*C*)	100, 97, 95, 94, 94, 92
Inlet Velocity ($m\ s^{-1}$)	6,7, 8, 9, 10, 11
Ambient Pressure (*bar*)	1.017
Density (kg/m^3)	1.225
Specific heat ($Jkg^{-1}\ K^{-1}$)	1006.53
Thermal conductivity ($Wm^{-1}K^{-1}$)	0.0242

3. EXPERIMENTAL SETUP

It consists of centrifugal blower, entrance length, test section, and instrumentations to measure temperature, air flow rate and pressure drop. A centrifugal type of air blower driven by an AC motor of 0.3 hp is used to induce the required flow rate. A flexible joint is installed between the exit of blower and the transition section to avoid transferring motor vibration to the test section. An entrance section with a circular cross section of 45 mm diameter, 2.5 mm thickness and a length of 1360 mm is used in the present setup. The air flow rate is controlled using a regulator. The test section is composed of test tube, inserted ballooned inserts, the heating element, insulation layer and end section. The test tube is made of Galvanized Iron with length of 1500 mm, 45 and 50 mm inner and outer diameters, respectively. The air inlet temperature is measured using a thermocouple located far right from the test section to avoid the effect of heating section. Six thermocouples of 0.5 mm diameter are installed in the test section and used to measure the temperature along the tube surface. The thermocouples are cemented on the drilled holes at six places such that its distributed evenly. The ballooned inserts are inserted in the tube with an angle of 120 degrees between them. The test section is covered by 13 mm thick layer of wool glass thermal insulation. The outlet velocity of air is measured using digital pitot tube Anemometer across the tube section which is true of insulation. Data acquisition system is used to record the thermocouples readings.

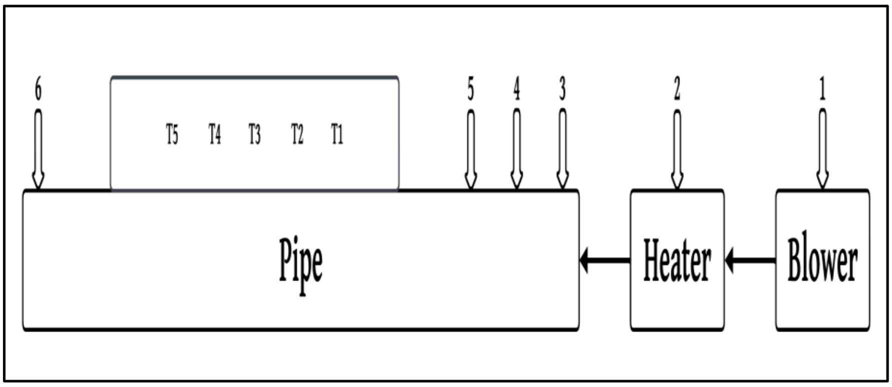


FIGURE 2. Schematic diagram of experimental setup. *1*-blower; *2*-heater; *3*-inlet thermocouple; *4*-inlet pressure; *5*-insulation; *T1-T5* Thermocouples; *6*-outlet thermocouple

4. MATHEMATICAL EXPRESSION

The expressions used in this investigation are given as:

Reynolds number: $Re = (\rho v D)/\ \mu$ (1)

Mass flow rate: $\dot{m} = \rho A v$ (3)

Friction Factor $f = \Delta P/(\rho v^2/D) * (L/2)$ (4)

5. RESULTS

The obtained results can be delineated into two overarching categories for comprehensive analysis. Firstly, the initial set of observations elucidates the dynamics of heat absorption from the flowing fluid in the absence of any augmentations, such as inserts. Examination of the graphical representation discerns a distinct trend wherein the unaltered setup yields a maximum heat absorption, as measured by the thermocouple (T6), of 65 degrees Celsius. Notably, as the mass flow rate (measured in kg/s) escalates continuously, the heat absorption exhibits a diminishing trend, ultimately reaching a nadir of 53 degrees Celsius. Conversely, the incorporation of inserts within the tube, arranged at an angle of 120 degrees relative to each other, engenders an amplification in heat absorption. Herein, the peak absorption attains 71 degrees Celsius, subsequently tapering to a minimum of 58 degrees Celsius at an equivalent mass flow rate observed in the initial configuration. The discerned results underscore a pronounced enhancement in heat absorption from the flowing fluid, nearing an approximate improvement of 10 percent, as compared to the baseline scenario.

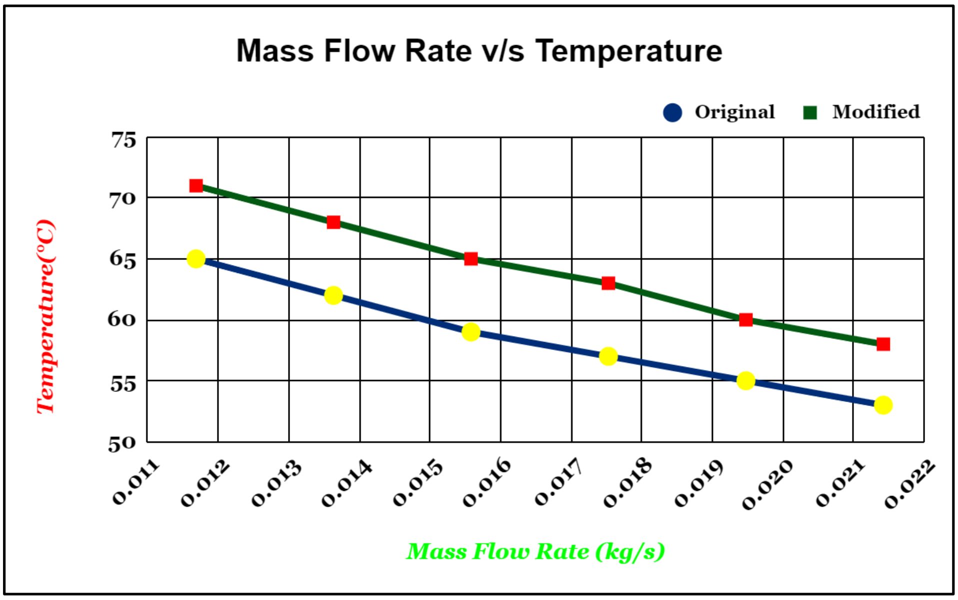


FIGURE 3. Variation of Temperature with Mass Flow Rate

6. CONCLUSIONS

Heat transfer experiment was conducted to find the *Re*, ΔP and measure the $\dot{m}$ *in* a circular tube of Internal diameter as 45 mm with 3 inserts of length 1500 mm at an angle of 120° where the heated liquid flowing is air.

The effect of mass flow rate is significant on the rate of heat absorption. The presence of even a single insert enhances the process of heat absorption. When the inserts are coupled together, we can see a 10% increase in the heat absorption when the mass flow rate is kept constant. The *Re* was above 15000 even when the experiment is at a stage with least velocity and varied to a greater extent. The heat absorption at the initial stage is much higher when the difference in the temperature of the flowing liquid and the internal surface temperature of the pipe is higher and it gradually slows down after an hour. Acknowledgements This work was performed in Mechanical Engineering Department at Christ (Deemed to be University). Author Contributions: S.A.: Investigation, S.A.; Methodology, S.A.; writing-review and editing, S.A.; Validation, T.R.; Supervision, T.R Both authors have read and agreed to the published version of the manuscript.

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Nomenclature

A	Area of the circular pipe(m^2)
Cp	Specific heat of air ($J\ kg^{-1}\ K^{-1}$)
D	Test segment Internal diameter (m)
f	Friction factor for rough tube
k	Thermal conductivity of air ($W\ m^{-1}\ k^{-1}$)
L	Test section length (m)
$\dot{m}$	Air flow rate ($kg\ s^{-1}$)
Re	Reynolds Number
ρ	Density of air ($Kg\ m^{-3}$)
v	Velocity of the fluid ($m\ s^{-1}$)
μ	Viscosity of air ($m^2\ s^{-1}$)
ΔP	Pressure difference (between inlet and outlet of the test segment) (*bar*)

REFERENCES

[1]. A. Akcayoglu, “Flow past confined delta-wing type vortex generators,” Experimental Thermal and Fluid Science, vol. 35, no. 1, pp. 112–120, Jan. 2011, doi: https://doi.org/10.1016/j.expthermflusci.2010.08.012.

[2]. M.M.K. Bhuiya, A.S.M. Sayem, M. Saif Islam, U. Chowdhury, and M. Shahabuddin, “Performance assessment in a heat exchanger tube fitted with double counter twisted tape inserts,” International Communications in Heat and Mass Transfer, vol. 50, pp. 25–33, Jan. 2014, doi: https://doi.org/10.1016/j.icheatmasstransfer.2013.11.005.

[3]. P. Promvonge, N. Koolnapadol, M. Pimsarn, and C. Thianpong, “Thermal performance enhancement in a heat exchanger tube fitted with inclined vortex rings,” Applied Thermal Engineering, vol. 62, no. 1, pp. 285–292, Jan. 2014, doi: https://doi.org/10.1016/j.applthermaleng.2013.09.031.

[4]. A. Kumar, Sunil Chamoli, and M. Sharma, “Experimental investigation on thermal performance and fluid flow characteristics in heat exchanger tube with solid hollow circular disk inserts,” vol. 100, pp. 227–236, May 2016, doi: https://doi.org/10.1016/j.applthermaleng.2016.01.081.

[5]. Y. Zong, D. Bai, M. Zhou, and L. Zhao, “Numerical studies on heat transfer enhancement by hollow-cross disk for cracking coils,” Chemical Engineering and Processing - Process Intensification, vol. 135, pp. 82–92, Jan. 2019, doi: https://doi.org/10.1016/j.cep.2018.11.007.

[6]. V. M. Hameed and M. A. Hussein, “Effect of new type of enhancement on inside and outside surface of the tube side in single pass heat exchanger,” Applied Thermal Engineering, vol. 122, pp. 484–491, Jul. 2017, doi: https://doi.org/10.1016/j.applthermaleng.2017.04.119.

[7]. M

[8]. S. Gururatana and S. Skullong, “Experimental investigation of heat transfer in a tube heat exchanger with airfoil-shaped insert,” Case Studies in Thermal Engineering, vol. 14, p. 100462, Sep. 2019, doi: https://doi.org/10.1016/j.csite.2019.100462.

[9]. M. Khoshvaght-Aliabadi, O. Sartipzadeh, and A. Alizadeh, “An experimental study on vortex-generator insert with different arrangements of delta-winglets,” Energy, vol. 82, pp. 629–639, Mar. 2015, doi: https://doi.org/10.1016/j.energy.2015.01.072.

[10]. Smith Eiamsa-ard and Pongjet Promvonge, “Influence of Double-sided Delta-wing Tape Insert with Alternate-axes on Flow and Heat Transfer Characteristics in a Heat Exchanger Tube,” Chinese Journal of Chemical Engineering, vol. 19, no. 3, pp. 410–423, Jun. 2011, doi: https://doi.org/10.1016/s1004-9541(11)60001-3.

[11]. S. Eiamsa-ard and P. Promvonge, “Performance assessment in a heat exchanger tube with alternate clockwise and counter-clockwise twisted-tape inserts,” International Journal of Heat and Mass Transfer, vol. 53, no. 7–8, pp. 1364–1372, Mar. 2010, doi: https://doi.org/10.1016/j.ijheatmasstransfer.2009.12.023.

[12]. S. Eiamsa-ard, C. Thianpong, P. Eiamsa-ard, and P. Promvonge, “Convective heat transfer in a circular tube with short-length twisted tape insert,” International Communications in Heat and Mass Transfer, vol. 36, no. 4, pp. 365–371, Apr. 2009, doi: https://doi.org/10.1016/j.icheatmasstransfer.2009.01.006.

[13]. S. Eiamsa-ard, C. Nuntadusit, and P. Promvonge, “Effect of Twin Delta-Winged Twisted-Tape on Thermal Performance of Heat Exchanger Tube,” Heat Transfer Engineering, vol. 34, no. 15, pp. 1278–1288, Dec. 2013, doi: https://doi.org/10.1080/01457632.2013.793112.

[14]. S. Eiamsa-ard, K. Nanan, C. Thianpong, and P. Eiamsa-ard, “Thermal Performance Evaluation of Heat Exchanger Tubes Equipped with Coupling Twisted Tapes,” Experimental Heat Transfer, vol. 26, no. 5, pp. 413–430, Oct. 2013, doi: https://doi.org/10.1080/08916152.2012.704483.

[15]. M.E. Nakhchi and Javad Abolfazli Esfahani, “Numerical investigation of rectangular-cut twisted tape insert on performance improvement of heat exchangers,” vol. 138, pp. 75–83, Apr. 2019, doi: https://doi.org/10.1016/j.ijthermalsci.2018.12.039.

[16]. M. Rahimi, S. R. Shabanian, and A. A. Alsairafi, “Experimental and CFD studies on heat transfer and friction factor characteristics of a tube equipped with modified twisted tape inserts,” Chemical Engineering and Processing: Process Intensification, vol. 48, no. 3, pp. 762–770, Mar. 2009, doi: https://doi.org/10.1016/j.cep.2008.09.007.

[17]. S. Singh, Jagmohan Singh Negi, Sangeeta Bisht, and H. Sah, “Thermal performance and frictional losses study of solid hollow circular disc with rectangular wings in circular tube,” Heat and Mass Transfer, vol. 55, no. 10, pp. 2975–2986, May 2019, doi: https://doi.org/10.1007/s00231-019-02631-z.

[18]. V. Kongkaitpaiboon, K. Nanan, and S. Eiamsa-ard, “Experimental investigation of convective heat transfer and pressure loss in a round tube fitted with circular-ring turbulators,” International Communications in Heat and Mass Transfer, vol. 37, no. 5, pp. 568–574, May 2010, doi: https://doi.org/10.1016/j.icheatmasstransfer.2009.12.016.

[19]. Smith Eiamsa-ard, Vichan Kongkaitpaiboon, and K. Nanan, “Thermohydraulics of Turbulent Flow Through Heat Exchanger Tubes Fitted with Circular-rings and Twisted Tapes,” Chinese Journal of Chemical Engineering, vol. 21, no. 6, pp. 585–593, Jun. 2013, doi: https://doi.org/10.1016/s1004-9541(13)60504-2.

[20]. A. Gautam, L. Pandey, and S. Singh, “Influence of perforated triple wing vortex generator on a turbulent flow through a circular tube,” Heat and Mass Transfer, vol. 54, no. 7, pp. 2009–2021, Feb. 2018, doi: https://doi.org/10.1007/s00231-018-2296-4.

[21]. R. L. Webb, “Performance evaluation criteria for use of enhanced heat transfer surfaces in heat exchanger design,” International Journal of Heat and Mass Transfer, vol. 24, no. 4, pp. 715–726, Apr. 1981, doi: https://doi.org/10.1016/0017-9310(81)90015-6.