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A REVIEW ON DIFFERENT TECHNIQUES USED FOR IMPROVEMENT HEAT TRANSFER IN SQUARE DUCT

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Abstract. The improvement of heat transfer along square ducts is essential for optimum thermal management in a variety of mechanical applications. The present review investigates the impact of using baffles, ribs, and tapes to increase heat transfer efficiency in square ducts and the design parameter which also play critical role to improve heat transfer such as inclination angle, blockage ratio, pitch ratio, Etc. Ribs, tapes and baffles all of them placed in different arrangements such as in-line, staggered and systematic arrangement with various technique used like adding perforation, gaps, wavy surface. This review utilizes both of experimental and numerical methods to evaluate the performance of each technique, either alone or in a combination. Empirical examination includes different rib configurations, baffle placements, and tape types. The findings reveal that gaps and holes enhance heat transfer and design parameters like attack angle has various of optimal values depended on type of obstructive where it estimates in baffles a value to 90° while in tapes and ribs are equal to 45°.

Keywords: *Attack angle; Obstacles; Blockage ratio; Pitch ratio.*

1. INTRODUCTION

Improvement in heat transfer is an important field in varies specializations and engineering application, where enhancement produce increase efficiency and reduce energy consumption and improve performance. There are three methods are active methods, passive methods and combined methods. In active methods are used techniques that required an external source of energy to rise the heat transfer where some devices which are operating at high temperatures or are subjected to high heat and thus impact up on the operation's life and performance[1] While In passive methods are which don't have any external source power to enhance the performance and efficiency as compared to the active methods[2],[3]. Combined Methods are another type of techniques which are used to improve heat transfer by a mix of active and passive methods [4]. Several types of inserts have been applied to enhance the heat transfer and geometrical parameters of inserts specifically the angle of attack [5] length, twist direction, twist ratio, Aspect ratio, etc. which have an effect on heat transfer [6]. The kind of inserts involve tapes, ribs, baffles [7][8] and fins [9].

Ribs are used to improve heat transfer in different engineering applications and cylinder V-rib with staggered arrangement has been used. The rounded shape of cylinder V-rib leads to rises in pressure loss lower compared with flat plate because it creates smooth flow of fluid, and the rising of e/H ratio produce

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high TEF [10]. For example, tapes like tapered twisted tape [11] and rotating twisted tapes [12]. Ribs like D shaped ribs [13] and broken arc rib [14]. Various factors include gaps and holes [15]. or may be arrangement [16]and effect of surface like rough surface [17] and wavy surface [18] or porous material[19].

2. SEVERAL TYPES OF INSERTS TO IMPROVE HEAT TRANSFER

2.1. Improve Heat Transfer by Ribs Insert

2.1.1. Effect of Different Shapes of Ribs

S. Alfarawi et al.[20] studied the impact of various geometries ribs involve semicircular, rectangular and hybrid ribs upon heat transfer improvement in rectangular duct. The ribs were formed from brass put on the bottom wall, which is a rectangular brass plate designed to be removable. The findings show that the velocity, turbulence intensity and pitch to height ratio have a major influence on the improvement in heat transfer and the peak value of an improvement in the heat transfer was recorded for hybrid ribs at p/e=6.6 while the best value for semicircular and rectangular ribs was at p/e =13.3. The hybrid ribs present significantly greater values for the efficiency measures compared with rectangular and semicircular ribs cases. The Nusselt number improvement ratio was achieved ranging from 1.3 to 2.14, while friction factor ratio was achieved ranging from 1.8 to 4.2.

B. V. Ravi et al.[21] studied impact of varies ribs geometry (W-shaped, rib 45° angled, M- shaped, V-shaped) up on heat transfer and friction factor characteristic in two pass ribbed square channels. Overall thermal hydraulic performance of V-shaped ribs was 7% larger compared to 45° ribs, 28% more than W-shaped ribs, and 35% more compared to M-shaped ribs. Friction factor of V-shaped ribs increases 19%, 24%, and 28%, respectively.

A. S. Golam[22] had a numerical and exploratory study regarding a square duct heated from lower and upper face with three variety of inserts ribs shaped (semicircle, triangular and square). The resulting effect of applying ribs lead to increase the heat transfer where square ribs, triangular and circular ribs all of them improved the heat transfer than without ribs. Square ribs give the best increase in heat transfer by (28.22-58.23) % followed by triangular and circular ribs give an increase by (20.14-45.62) (10.87-28.13) % respectively compared to without ribs, and it arranged with a staggered pattern on the top and bottom face allows for the maximum heat transfer.

S. K. Bauri and A. K. Prasad[23] have investigated that created rough surface with S-shape ribs improve heat transfer where Re in range of 6000-18000. Using rough surface led to higher increase of Nu number and friction factor. When a rise in Re number, Nu number rises advertise heat transfer coefficient while friction factor is reduced. The highest value of the overall improvement ratio was 1.48, which has been recorded at Re = 11000.

S. S. Gajghate et al.[24] studied the effect of W-ribs with three angles of rib: 45°, 50°, and 55° on heat transfer improvement, where $e/D_h=0.037$ and P/e = 4.28, 5.71, and 7.14 with Re in a range of $12x10^3$-$2x10^4$. Results show that enhancement of Nu and f for W55 was 77.29% and 651.54% at Re ≥ $15x10^3$ While for W50 it was 74.83% and 503.67%, and for W45 it was 63.26% and 390.63%. When the angle of the rib rises, heat transfer improves, and it's worth noting that an increment in pitch ratios and rib space increases the friction factor and W55 has a superior friction factor ratio when contrasted with other angles. The W55 ribbed channel provides a better thermal performance as compared to other W50 and W45 ribbed channels by 1/9 and 3/8 times.

R. Shankar[25] studied different rib shapes, effects of rib parameters, and arrangements to measure their heat transfer and friction behaviours. Results show that for several types of geometries, the best result is obtained under the following parameters: α = 45°–60°, P/e = 8 and 10, and e/Dh around 0.042.V- ribs with a homogeneous gap achieve the maximal average Nu number value of 6.46. And V-down ribs show a lower range of average friction factor. Tilted ribs that are placed at an angle of 60° provide optimal thermo-hydraulic performance. V-ribs, especially the type that has α = 60°, gaps and staggered rib arrangements, considerably enhance heat transfer but don't cause a big pressure rise.

2.1.2. Effect of Different Angles of Ribs

N. Kaewchoothong et al.[26] had looked at the implications of inclined ribs upon heat transfer coefficient in a square channel at which ribs were used in many different arrangements such as inclined, V- shaped, inverted V-shaped with square cross-section as shown in figure 1 which shows various attack angles and arrangements of the rib.

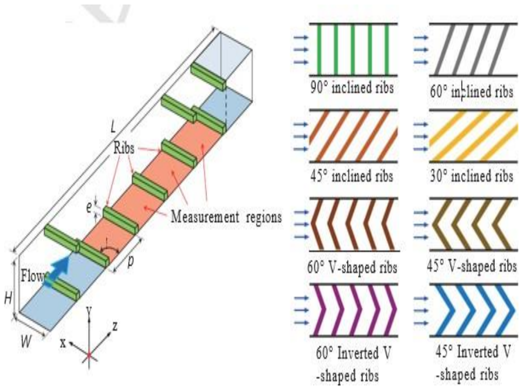

Fig. 1. Different attachment angles.

It placed on two side of the walls the angle of attack was 30°,60° and 90° while two other ribs were 45°,60°. The heat transfer coefficient distributions of tilted ribs with angle 60° and V-shaped ribs with angle 45° and 60° are very high around 19.3%, 23.5% and 32.6%, respectively, as compared with tilted ribs angled 90°. This is because of strong rotational momentum which increases the heat transfer.

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A. H. Theeb and M. A. Mussa.[27] had a numerical study that used hybrid efficient technique which represented by creating intersecting ribs with inclined ribs. Three ribbed patterns used, pattern1 has just inclined ribs, pattern2 has a one longitude rib placed in center of inclined ribs, pattern3 has two longitudinal ribs at the sides as shown in figure 2. Pattern3 was the most efficient and achieves highest OTP. Increases in the Nu number ratio of pattern3 and pattern2 in comparison with pattern1, are 13.19% and 7.03%, respectively.

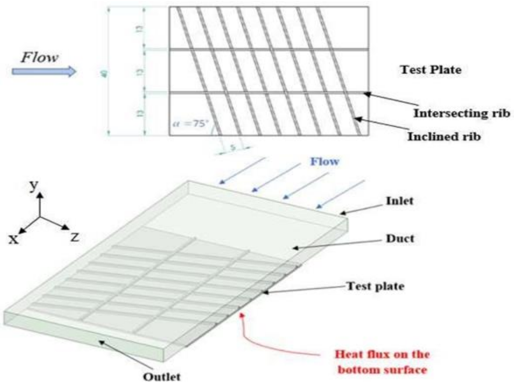

Fig. 2. Structure of rectangular duct and types of patterns.

Z. Wang et al.[28] study the ribs shape impact upon performance at a 45°degree were classified according to parallel ribs, crossed ribs and dislocation ribs performed by numerical simulation. The ribs have two types of arrangements compared with case1 (parallel)and case2 (crossed). In the case1 the ribs at 45° put on the opposite walls in parallel, while crossed ribs at 45° have a specific form such as case2.1, case2.2, case2.3 as shown in figure 3, where the red color represents a top rib and the yellow color represents the bottom rib. According to the findings, the heat transfer Improvement of parallel rib was higher than crossed ribs also friction loss, the value of average(f/f_o) parallel arrangement utilized is 25.4% higher than crossed arrangement and the case 2.2 OTP was the highest.

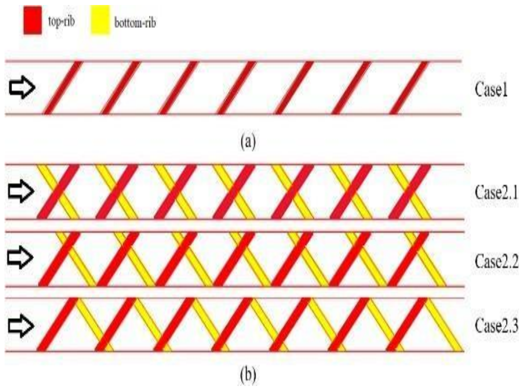

Fig. 3. Arrangement (a) parallel ribs, (b) crossed ribs and cases of ribs.

R. Fattoum et al.[29] used L-rib to improve heat transfer with varying angles (60°, 90°, 120°, 150°, 180°, and 210°) to achieve the best angle that provides maximum thermal performance. Re range of $3.8x10^3$–$18x10^3$ with the standard k-epsilon model and comparing findings with data found under the same conditions. Findings reveal that thermal performance, Nusselt number and friction factor are increased with an angle of the ribs that is greater than 90°. In particular, at an angle of 180 °, they reach

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their maximum values. The ideal angle is 180° for a Reynolds number of 18,000. In this case, Nu and f are raised by 25% and 93% as compared to their values found at 90°. Increasing the angle from 60° to 180° improves mixing (as a result of raising the turbulence intensity) which gives a rise to the heat transfer.

M. Kaplan[30] using inclined ribs with α= 45° to improve performance in a two-pass square duct where pitch ratio is 5-10 and height ratio 0.1-0.2, Re from $2x10^4$ to $4x10^4$. The findings show that ribs with a larger value of (e/D_h) provided more intensity of stream-wise secondary flows, therefore enhancing cooling performance, but pressure loss increased too. The highest THP was 26.55%, which was obtained by using p/e = 5 and e/D_h = 0.1 at Re = 20000. The height of the rib has a more significant effect on the friction factor compared with the spacing of the rib. The maximum Nusselt number ratio of 2.74 was found by using e/D_h = 0.2 and p/e = 5.

2.1.3. Effect of Gaps

K. R. Aharwal et al.[31] had created rough surface by applying continuous ribs with attachment angle of 60° including a gap has in inclined rib arrangement in rectangular duct. The gap of inclined rib enhances friction factor and heat transfer of roughed duct where the range of rises in Nu number and friction factor is larger 1.48-2.59 and 2.26 -2.9 than smooth duct for Re number range of 3000 to 18,000.

A. Kumar and M. H. Kim[32] studied the impact of roughness width ratios upon thermal performance. Ratios varied from 1 to 6 for discrete multi-V-rib with staggered rib roughness. The results reveal that the optimal width ratio was 6, which provides peak heat transfer. The peak value in the overall thermal performance was found to be 3.67 at a Re of 16,000.

R. K. Ravi and R. P. Saini[33] used discrete multi V-shaped and staggered ribs on each side of the plate in DPSAH to improve the performance of the collector, and the roughness parameters like r/e varied from 1-2.5, relative staggered rib position equal 0.2, (Gd/Lv)=0.7, relative pitch ratio was 10, relative height equals 0.043, relative gap width equal 1 and the Re number was 2000-20000. Results show that using each side with discrete multi-V ribs and staggered ribs improves heat transfer rate and frictional losses, and the roughness parameters have a major impact on the Nu and f. The highest values of friction factor ratio and Nusselt number ratio achieved at r/e = 2.5 were to be found 2.5 and 3.4.

From the previous literature reviews [34][35][36],[37]it was concluded that the best angle for V- ribs with gaps is 60° and e/D=0.043 for SAH.

A. Kumar and M. H. Kim [38] did comparative study for various multiple V-rib roughness in rectangular ducts and multiple V-ribs involved three types of ribs as the following: discrete multiple V-ribs with staggered rib pieces, continuous multiple V-ribs and discrete multiple V-ribs and Re in range of 2000-22000. Results show that discrete multiple V-ribs with staggered rib pieces provided the best thermo-hydraulic performance. For this reason, it is recommended to provide surface roughness for rectangular ducts by using multiple V-ribs with staggered rib pieces. On the other hand, a single V-rib with a staggered rib is more effective thermo- hydraulically compared to a variety of single-ribs.

R. Maithani and J. S. Saini [17] study the heat transfer and manner of fluid flow in a rectangular duct with its rough surface incline ribs with symmetrical open spaces where Ng from 1-5, g/e=1-5,aspect ratio = 12 and Re in range of 4000-16000. The Nu number value and friction factor found in coarse duct is better than smooth duct where Nu =165.3, Nu_s =47.97,f =0.0349 respectively at optimal Ng =3 and g/e=4. Nu/Nus elevates with a rise in Ng, till Ng=3 where Peak of Nu/Nus =3.67 and f/f_s=3.66 Angle of attack equal to 60° provide the best performance.

S. S. Patel and A. Lanjewar[39] had an empirical study of an absorber plate with coarse surface set in solar air heater duct with v-rib which had symmetrical open spaces and staggered arrangement to observe the influence of it on Nu, f with number of gaps (1,2,3,4) has a big impact on Nu number and f and Re of 4000-14000. At Ng= 3 provide the largest increases in Nu number and f is 2.05 and 3.39 multiplied by the smooth plate.

I. Singh et al.[40] have empirical study for improvement in thermal performance of Solar air heater (SAH) by applying two various shapes of ribs arrangement, involve multiple broken transverse ribs and square wave ribs. For two shapes, the study noted Re that increase lead to the Nu increase, while friction factor lower and Re in range of 3000-18000. Gaps increase local Nu number at gap position, so multiple broken transverse ribs get a Nu number greater and friction factor is lower than square wavy ribs. Multiple broken, and square wave ribs have the largest heat transfer improvement estimated to be 3.24 and 2.50 times respectively while THPP was to be found 2.1 and 1.62 respectively at Re=15000. The friction factor for multiple broken transverse ribs was smaller in comparison to square wave ribs, where its maximum value was 3.85 and 3.92 times respectively for multiple broken and square wave ribs.

P. K. Jain and A. Lanjewar[41] summarized V-rib roughness geometries which used to improve heat transfer in a SAH and examine performance of modern V-rib that has symmetrical gaps and staggered rib geometry and relative pitch as 0.65, α=60°,Ng=3, pitch ratios values 10,12,14 and 16 and Re in range of 3000 to 14000. Findings show that staggered rib geometry has a major impact on Nu and f. Relative pitch effects strongly on Nu and f. Nu and f reach maximum value at a relative pitch ratio of 12 and then decreases. Compared with smooth duct, the improvement of Nu and f for V-rib with symmetrical gap and staggered rib are 2.3 and 3.13, V-rib with symmetrical gap is 2.03 and 3.03 times that of smooth plate, and mutigap V-down rib combined with staggered rib is 2.27 and 3.35 times that of smooth plate respectively.

D. Wang et al.[42] valued the impact of S-shaped ribs with gaps on the thermal efficiency, heat transfer, and made gaps with limited width used to lower the flow resistance of air. The roughness of the surface rises thermal efficiency and pressure drop, where efficiency elevated by 13% to 48% and the pressure drop in range of 15.8-30 pa. Heat transfer was improved by using a rough surface where the highest enhancement for Nu number = 5.42 and friction factor= 5.87 at Re=19258.

J. Singh and A. Lanjewar[43] studied impact of g/e on thermal performance by employing arc ribs that has gaps and staggered rib. Arc rib with design parameter and more gaps break the boundary layer reformation (increase heat transfer rate). The g/e ratio has an impact on the value of Nu and f where the highest values of Nu and f are 100%, 107%, 115%,86% and 207%, 219%, 200%,178% for relative gap width is 2–5, which means that at g/e = 4, the maximum value of Nu is 115%. THPP is noted to be 1.5 because of using symmetrical arc rib roughness with gaps and staggered rib geometry. While using an arc

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rib with multiple gaps, geometry gives the optimal value of THPP, noted to be 1.4, and the best increment in Nu is found to be 101%.

2.1.4. Effect of Perforated Ribs

M. Eren and S. Caliskan[44] conducted an experimental study in rectangular duct that contains ribs with holes under uniform heat flux. The aim of study influences thermal performance. The research results indicate that perforated ribs lead to higher heat transfer coefficients than those smooth plate surfaces, where 34.1% boost in heat transfer at Re=36362. The friction factor resulting as employing perforated ribs was found larger versus that formed by smooth duct.

A. Rasool and A. Qayoum[45] have a numerical study to examine the impact of holed ribs put on the bottom wall on properties of flow in a two-pass channel. The research cares about the expected influence of the various inclination angles 0°- 30° and the hole shape (cylindrical hole, square hole, tilted cylindrical)on the heat transfer and friction factor. The results confirm that perforated ribs improve local heat transfer distribution. Also it generates longitudinal vortices work to rise turbulent kinetic energy where Inclination angle may provide 18.3 to 25.4% boost in heat transfer performance than the solid ribs. Normalized average Nu number of square perforated ribs 37.1-57.3% higher than solid ribs, it gives best thermal-hydraulic performance. Also, holes result in a high increase in pressure drop than without. Angled perforation offers higher friction factors compared to ribs with non-angled perforations.

J. Liu et al.[46] had a study with the aim to improve heat transfer in rectangular channel by creating holed ribs composed of inclined perforations with rectangular cross-sectional. Holes come in circular and square shapes at an angle varying from 0°- 45° for forming secondary flows. Overall averaged Nu number has larger in all cases with inclined angle compared to straight cases where improvement ratio is nearly 1.85 % - 4.94 %.

J. Liu et al.[47] have an empirical and numerical explorations to impact of holed ribs in a rectangular channel with AR (4:1) on heat transfer and fluid flow. The perforated ribs are installed on the bottom wall. Ribs have three varying forms (solid, round holes, square holes) where four cases,case1:solid ribs,case2:Round holes higher space, case3:square holes, case4:Round holes lower space. Perforated ribs lead to a boost in low heat transfer with a small reduction in pressure drop, this feature is more obvious when the perforated ratio is huge like in case4, the local heat transfer enhances by about 12%-24%. Overall heattransfer optimized by about 4%-8% Also overall thermal performance has been enhanced with a slight reduction in pressure drop.

Friction factor reduce by applying perforation where it values 0.02786, 0.02723, 0.02754, 0.02596 at Re=40000.

V. P. Singh et al.[48] studied experimentally the effect of continuous and perforated multi-V ribs on DPPFSH. Relative height, relative pitch, α,W/w and diameter of perforation are 0.043,10,60,2:4:6:8:10 and 1.26 mm. Findings show the hole in multi-v ribs reduces flow reattachment distance and the recirculation zone on the lower side of the ribs, so the performance was superior in all cases. The highest improvement in Nu was 481.14 and 342.0 at W/w = 6 for each perforated and continuous ribs, when Re =

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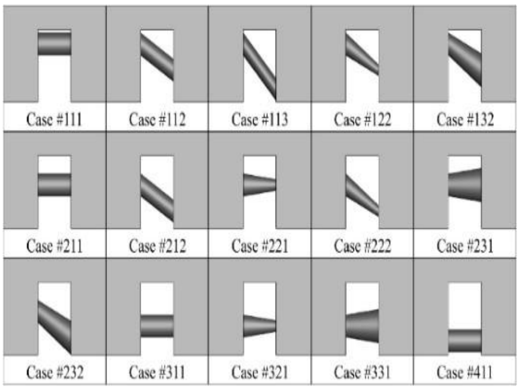
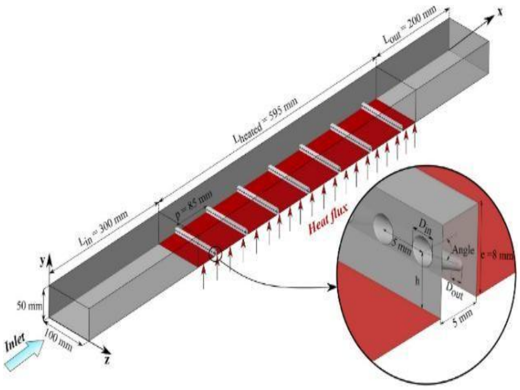
18000.Nu/Nus, f/fs for perforated and continuous multi-V ribs have the highest values of 8.35 times, 8.91 times, 5.94 times, and 5.94 times, 12.31 times, when compared with smooth duct. The maximum values of THPP were 3.65 and 1.92 for perforated and continuous.

S. Javanmard and A. Ashrafizadeh[49] research the influence of geometrical factors on the pressure drop and heat transfer properties of hollow ribs and ribs put in rectangular channel. Geometrical factors of ribs represent three variables in design, the first variable was relative hole inlet height, the second variable inclination angle of hole and the last variable was cross-sectional area of the perforation. Height values (0.2, 0.4, 0.6 and 0.8), angle values (0°, 30°and45°), area (convergent, straight, and divergent) and Re=10000-25000 As shown in figure4 and this figure shows the change in cross-section area and the dimensions of the channel as well as dimensions of the ribs.



(a)



(b)

Fig. 4. (a):Cross-sectional drawings depicting the rib cases and (b):Structure schematic.

Case#212 rib has (D_{outlet}/D_{inlet}) and inclination angle equals 1,30 respectively.it shows enhancing the performance in the range of 4.35 and 6.39% compared with solid rib. The tilted angle has the major influence on the increase of the thermal performance. The convergence of horizontal holes ribs provides larger heat transfer, larger pressure drop loss and improve of OTP, tilted holed in convergence ribs lower the thermal performance while Divergence ribs (horizontal and angled holed) lead to reductions in heat transfer, pressure loss and thermal performance. Friction factor ratios for all cases become greater since Re increases. All cases that have perforation give a lesser pressure drop as compared with solid case.

V. P. Singh et al.[50] study the effect of Relative roughness width on heat transfer characteristics by using a roughened surface composed of a plastic grid of perforated multi-V and continuous multi-V ribs and The Re range is 2000–18000 with e/D_h of 0.043,(P/e) of 10,(α) of 60° and W/w of 2-10. The findings indicate that using Perforation decreases the flow reattachment distance and the zone of recirculation, which tends to an increase in thermal performance. The enhancement in Nu for perforated multi-V ribs was 7.22 times and for continuous multi-V ribs were 5.02 times as compared with smooth channel. On the other hand, friction losses are significantly reduced when using holed multi-V ribs where average friction factor 3.89-5.06 while in Continuous multi-V rib, the average friction factor was 4.05-6.20. The highest value of thermo-hydraulic performance parameter was detected at 4.27 for holed multi-V rib roughness. A boost in the relative roughness width (W/w) leads to a rise in Nu and gets the maximum

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magnitude at W/w = 6, and an additional boost in the W/w value lowered the Nu. At W/w of 6, fluid mixing results due to the existence of roughness that reaches its ideal value, and any more rise in the relative roughness width value impedes the progress of secondary flow, which could lead to a loss in heat exchange.

V. P. Singh et al.[51],[52] studied the impact of open area ratio on heat transfer characteristics where open area ratio has changed from 0 to 0.31 (0,0.21,0.27,0.31), relative width value different from 2-10 and Re in range of 2000–18000. The results indicate that the optimal value of β is 0.27 with W/w = 6 where mixing created by roughness arrived at its optimum value and rise W/w impedance improvement of secondary flow, resulting in reduction in heat transfer.

Friction factor continue to increase as a result of the turbulence that formed. Nu is getting higher as β increases till β =0.27, then it starts to decrease. Optimum value of Nu achieved at β = 0.27and the lowest value of Nu achieved at continuous rib. THPP reached its maximum value at β = 0.27 and W/w = 6, which equals 5.41. Maximum enhancement of Nu/Nus and f/fs was noted as 8.19 times and 4.78 times higher compared to smooth channels.

2.2. *Improve Heat Transfer by Baffles Insert*

2.2.1. *Effect of Variety of Shapes and Angles*

S. Sripattanapipat and P. Promvonge[53] studied the impact of multiple baffle angles (staggered diamond-shaped baffles) up on pressure drop and heat transfer with laminar fluid flow. The results indicate that the diamond baffle, comes with an angle range of 5°–10°, provides thermal performance more than flat baffle for all Re numbers used. Improvement is 200–680% when employing diamond baffles and friction loss in the range of 20–220 times higher than smooth channel.

W. Jedsadaratanachai et al.[54] had an analytical study to examine a square channel laminar flow (Re=100-2000) consisting of a baffled insert with different pitches(PR=0.5-2.5) and an attached angle is 30°. Baffles put in-line arrangement on the bottom and upward wall. This arrangement gives a pair of vortexes, which leads to a rise in heat transfer rate. The reduction in PR will boost the friction factor only. Heat transfer increment is related to an increased pressure loss that ranges of 1-21.5 times larger than smooth case. TEF for the baffle that has PR = 2.5 is discovered to be the greatest at around 3.78, While PR = 1.5 is a little lower, and the smallest TEF was for PR = 0.5.

P. Sriromreun et al.[55] had been used 45° Z-baffles to study the impact of it up in the heat transfer increment in a rectangular channel which it generated co-rotating vortex flows having a strong effect on the flow turbulence intensity that resulted in a larger heat transfer improvement in the investigated channel. The impact of the Z-baffle height and pitch spacing length were evaluated to figure out the best possible thermal performance at the Re number in the range of, 4400–20,400 where blockage ratio =0.1, 0.2 and 0.3 and PR =1.5, 2 and 3. The findings show in-phase Z-baffles at angle 45° are higher than those for the out-phase Z-baffle at angle 45° where in-phase 45° Z-baffle that has a bigger e/H gives better heat

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transfer and f than smaller e/H while the smaller pitch length provides more Nusselt number, friction factor and TEF than the larger one. Regarding an in-phase Z-baffle The raises in Nu associated with (e/H=0.1, 0.2, and 0.3) range between 430–440%, 530–550% and 640–670% as compared with a smooth channel. In the case of e/H=0.1, raising of the Nu for (P/H=1.5, 2 and 3) ranges between 430–440%, 310–380% and 310–330% as compared with a smooth channel. The friction factor obtained at P/H = 1.5 and e/H=0.3 is about 2 and 5 times greater in comparison with e/H=0.2, 0.1. In-phase Z-baffle that has e/H=0.1, PR =1.5 gives the maximal TEF at a value of 2.2 at the lowest value of Re

A. Paul, D. Sen, and A. K. Das [56] had a computational study to estimate the impact of two factors upon heat transfer and pressure losses of air through rectangular duct for small height of baffle. The factors include baffle angle(α=30°,60°,90°,120°,150°) and Re number which is in the range of 10,000 to 50,000. Factors have a crucial importance in heat transfer in addition to flow properties and effects TEF. The findings show that Nu number and friction factor reach a peak at 90°, where the maximum increase of Nu by 35.12% at Re=50,000. The highest TEF is 0.997 at 30◦ with a Re value of 10,000 and a peak Nu is 150.407 at 90◦.

S. Skullong et al.[57] had investigated the effect of oblique HB placed in square-duct with specific parameters on heat transfer. Air flow through HB- inserted duct within constant surface heat flux. Re number in range of 4000 to 25,000. Specific parameters of 30° horseshoe baffles include baffle pitch to duct height ratio was 0.5, 1 and 2, blockage ratio was 0.05, 0.1, 0.15, 0.2 and 0.25. Findings reveal that at a specific BR, the lowest PR (PR =0.5) gives the maximum heat transfer and friction factor. HB provides an increase to two longitudinal counter-rotating vortices, which help to boost the intensity level of turbulence. When BR = 0.25 and PR = 0.5 give the largest heat transfer and friction factor where Nu/Nuo = 3.40–4.05, however, at BR = 0.2 and PR = 1 provide the largest thermal performance which was1.6. In a Furthermore, the thermal performance of using the HB is much higher than that of the wire coil insert (Thermal performance about 1.33). Thermal performance factor of horseshoe baffles are disposed to be reduced with the rise in Re values. Average friction factor rises where it reaches in range of 3.8 to 41.7 times as compared with smooth duct.

P. Sriromreun and P. Sriromreun[58] study the effect of inclined baffles on heat transfer enhancement where inclined baffles create co-rotating vortex flow in a rectangular duct, air used as a working fluid and the Re number is varied from 12,000 to 35,000 also e/H =0.1,0.2 and 0.3 and angle of attack is 30°, 45° and 60°. Higher values of angle of attack and baffles height, which allow raising co-rotating vortex flow in the face of a reduction in TEF. e/H =0.3 provide more heat transfer than, e/H = 0.2 and 0.1, raise in angle of attack provide turbulence intensity of the flow better. Maximum TEF was 1.74 at angle 45° and (e/H)= 0.3.

Y. Menni et al.[59] had examined the effect of put two S-shaped baffles in top and bottom walls of the channel with staggered arrangement up on heat transfer, the orientations of S-shaped are S-downstream and S-upstream. Adding S-shaped baffles in a channel causes increases in friction loss (f/f0 = 3.319–32.336) and rises heat transfer where Nu/Nu0 = 1.939–4.582, relied on the S-baffle orientations and Re. S-upstream gives a larger friction loss and heat transfer rate in comparison to S-downstream, about 56.443%-19.414 at Re=12000-32000. Optimum thermal performance factor was about 1.513 at the maximum Reynolds number and S-downstream. TEF of the S- downstream baffle are observed to be significantly greater than the S-upstream baffle at the same flow conditions.

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Y. Menni et al.[60] studied the impact of placed V-baffled upon heat transfer where solid- type obstacles have a two-geometry shape are flat fin rectangular placed on hot upper wall and 45° V-shaped placed on the lower wall of the channel with staggered arrangement. Air as working fluid with Re number in range of (12,000-32,000) and five separation distances between obstacles (S = Pi/2,3Pi/4, Pi, 5Pi/4 and 3Pi/2). Results show that a greater Re number leads to a greater heat transfer compared to a lower Reynolds number. Small separation distances give bigger magnitudes of the ratios (f/fo), (Nu/Nuo) and a higher (TEF) was about 1,981 when compared with longer distances, where heat transfer improvement goes up from 2.025 to 6.258 depending upon Re number and separation distance

H. Ameur[61] had a numerical study to evaluate the effect of inserting corrugated baffles in rectangular channel in which corrugation angle varied from 0° to 45° and (h/H) is 0.4, 0.5 and 0.6,where h represent height of corrugated baffle and H represent channel height. Overall performance factor improved from 1.27–1.53 in the case of angle rise from 0° to 45° as compared with no baffled channel and baffle height has an effect in increasing the thermal efficiency, findings show that best configuration was h/H = 0.5.The straight baffle has been noted to be more efficient than the wavy baffle in terms of heat exchange acceleration, since the vortex size zone, in which there are strong molecular strong, is wider. Also, the greatest value of pressure loss was obtained for the case (angle = 0 °).

Y. Menni et al.[62] studied influence of orientation and geometrical shape of baffle upon heat transfer in a channel and top surface has constant temperature while bottom surface maintain at adiabatic condition with incompressible Newtonian fluid and turbulent flow, Re number in range of 12,000 to 32,000. There are two kinds of obstacles, flat rectangular(fin-type) and V-shaped(baffle-type) with staggered arrangement placed into channel. A fin-type obstacle put on upper surface and other put on lower surface. Five cases of obstacles had been considered as the following case1 (VVU):V-Upstream fin and V-upstream baffle,case2 (FF):flat fin and flat baffle,case3(VVD):V-downstream fin and V-downstream baffle,case4(FVU):flat fin and V-upstream baffle and case5(FVD):flat fin and V-downstream baffle.

The largest value of a variation in Nu and skin friction is observed in the region that is in facing of the baffle, another hand minimal value is in the region that is close to the fin, for all cases. The TEF for FF, FVD, FVU, VVD and VVU were 1.273-1.368, 1.377-1.573, 1.444-1.833, 1.398-1.565 and 1.348-1.592, respectively. At the largest Re number was the highest value of TEF was about 1.833 for FVU so it became the best geometrical configuration used to enhance heat transfer efficiency, it provides larger heat transfer than others kinds of obstacles and highest average of Nu number compared with others was 235.987-529.044 for FVU. When comparing the finding with case 2 show that the friction factor drops by 3.199% and 29.535% when using FVU and VVU respectively at same Re number.

H. Olfian et al.[7]evaluated impact of two varies kinds of baffles upon thermal performance of SAH. Angled rectangular baffles and angled V-shaped baffles are placed on lower and upper walls. The two types of baffles were evaluated separately. Baffle angles are 90°, 60°, 45° and 30°. In rectangular baffles with angle 90°pressure drop and average Nu number was raised 316.67% and 148.15% at Re = 2000 as compared without baffle Also thermal efficiency at angle= 90° is significant higher than the other cases and angles 45° and 60°.V-shaped angled baffles in which thermal efficiency at an angle = 90°, 60°, 45°, and 30° are 27%, 18%, 13% better than without baffle at Re = 2000. The optimum angle =90° which

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provides the highest thermal performance with the greatest pressure drop. Lastly, compare between rectangular and V-shaped angled baffles shows that at large Re, the angle= 90° of rectangular shape produces highest values of average Nu and V-shaped angled baffles at angles= 90°and 60°was the second and third ones. It is worth noting that when there is low Re (somewhere Re below 300) using baffles has no impact on the thermal efficiency compared without baffle.

L. F. M. AL-Juhaishi et al.[63] studied the influence of attack angles and number of baffles upon the thermal and hydraulic efficiency by employing horseshoe baffles on the inside of curved channel where water acts working fluid which flows through curved channel at a constant temperature state of 358 K and turbulent flow. Number of baffles are 9 and 13 and attack angle is 45°, 60° and 90°. Baffles have the advantage of generating swirls which improve heat transfer where swirls allow a good mixing between cold stream and hot stream close to curved walls. Findings show that using baffles provide a large improvement of heat transfer rate when compared to the channel without baffles, which is close to 2.5 to 3.8 times. The greatest heat transfer is achieved at angle = 90°, NB = 13, and Re = 5000. Furthermore, THPF gets higher with an upward in the baffle number and the maximum angle, where peak THPF is 4.4 at the same parameter. Average Nu has improved with an upgrade in Re, maximum angle and baffle number, but also there is a raise in the value of the friction factor.

P. Nithish Reddy et al.[64] investigate various shapes of baffles which include Broken V- shaped, circular, and triangular and its impact on heat transfer rates where number of baffle sets(N)=15,20,30 and Re=1800-22000. V-shape baffles obtain a larger average Nu number, reached to 56.46 at Re=22000 as compared to other shapes. Effective turbulence created by put more N when Re number is of a lower value, while N decreasing as Re number attains high value. Increasing baffle set gives more friction factor where at N=30 friction factor was 0.92 and at N=15 it was 0.76 at Re=1800. V- shaped offers more friction factor (f=0.81) compared with triangular baffles which offer a lower friction factor(f=0.54).

2.2.2. Effect of Gaps and Perforation

R. Karwa and B. K. Maheshwari[65] had an experimental study to test the effect of fully perforated baffles and half perforated baffles upon heat transfer and friction where fully perforated baffles have open area ratio of 46.8% and half perforated baffles have open area ratio of 26% with relative roughness pitch of 7.2–28.8. The baffles are placed on one of the walls which exposed to uniformly heated, while the rest of the walls are thermally insulated. The Re number in range of, 2700 to 11,150. In broad, half perforated baffles tend to be thermo-hydraulic higher than full perforated baffles which have same pitch. Fully perforated baffles give improvement of 79–169% in Nu number, while half perforated baffles were 133-274% as compared with those of smooth duct. Friction factor regarding fully perforated baffles has a range of 2.98–8.02 and half perforated baffles is 4.42–17.5 as compared with those of smooth duct. Of all the design choices studied, half-perforated baffles that had a relative roughness pitch with a value of 7.2 achieved the significant performance benefit of 51.6–75% when compared with a smooth duct with equal pumping power

D. Sahel et al.[66] had studied the effect of perforated baffles on heat transfer properties in a rectangular channel fitted with two baffles positioned on the top and bottom walls. Perforated baffles overcome the problem of generation of Lower Heat Transfer Areas (LHTA), especially in the downstream part of baffles (baffle-wall corners) by creating vortex flows. Perforated baffles contain from a row with four holes put at three various locations. These locations are represented by a ratio known as PAR (Pores Axis Ratio= H_w/H_c) which have the following values are 0.190, 0.425 and 0.660, respectively. The flow was turbulent at Re in the range of 10^4 to 10^5. Results reveal that PAR=0.19 was shown to be optimal design where advancement in a thermal transfer rate was 2%-65 %, as comparison with simple baffle. pressure drop lower till 12 times than simple baffle.

J. M. Alhumoud and N. Almashan[67] had studied the effect of using gaps upon enhancement of the thermal-hydrodynamic performance in a rectangular sectional channel exposed to a constant temperature on upper wall. Square-shaped gap comes in three varying positions dg = 0.25h, 0.5h and 0.75h represented by A, B and C kinds with Re = 5×10^3 - 2×10^4.TEF based on Re and dg values, where thermo-hydrodynamic improvement magnitude in case C is reduced by 2.747% compared to the case which hasn't gap with Re = 2×10^4. But the magnitude of this same factor is raised by 5.901% and 2.794% when dg = 0.25h and 0.5h So baffle case which has a small d_g such as d_g= 0.25h is chosen to be an optimal geometry case. At Re = 5000, friction factor provides a boost of 610%, 339%, 330%, and 321%, respectively, when using hollowed baffles (0.25h, 0.5h, and 0.75h).

S. Eiamsa-ard et al.[68] examined impact of holed baffles on local Nu and perforated baffles has two designs: perforated-baffle(b) while the other has squire wings(c) and transverse solid baffle(a), all of them. The e/H ratio equals 0.3, and the height of the baffle is 12mm. The findings show that perforated baffles with square wings give more Nu as compared with perforated baffles, and it is worth noting that both of two designs provide less pressure loss as compared with Transverse solid baffles by about 20.49% and 13.98%, respectively.

R. Pandey[69] studied the influence of pitch ratio and Dh/e ratio on improving heat transfer and flow characteristics by using V-shaped baffles with two are form V-down and V-up baffle arrangements. Pitch ratio of 1 and 0.84, Reynold number in the range of 5500–15000. The findings reveal that the value of Nu rises with a reduction in pitch ratio, while the value of the friction factor rises with a decrease in hole - hydraulic depth.

2.3. Improve Heat Transfer by Tapes Insert

2.3.1. Effect of Different Shapes of Tapes

S. V. Patil and P. V. Babu [70] had comparative study between two differing styles of twisted tape one of them twisted tape and another helical screw tape with core-rod inside that has constant temperature and water used as working fluid, both of them have a full length. Thermal performance of screw tape is greater as compared to twisted tape. Friction factor of helical screw and twisted are much higher than normal duct, about 14 times and 7 times respectively. The finding indicated that mean Nu number of helical and twisted are larger than normal duct, about 5.3 and 2.81 times respectively. Thermal performance ratio of screw and twisted inserts was 3.52 and 2.81 times more as compared to plain square duct. Heat transfer rate of using screw tape is higher 3.52 and 6.57 times than normal duct.

S. V. Patil and P. V. V. Babu[71] study the influence of order of twisted tape on heat transfer and pressure drop in an imperial study with uniform temperature for laminar flow(Re=100-2100), water was used as test liquid. The rising in twist ratio and reducing in twist ratio haven't significantly varied in heat transfer coefficient enhancement, rising twist order led to a larger swirl at the start and a smaller swirl at the end. Square duct consists of twisted tape with a reduction and rise in twist ratio sets, have better Thermohydraulic performance than plain duct. Thermohydraulic performance is noted to be 4.27 and 3.46 times greater compared with smooth duct.

P. Promvonge et al.[72] had tested the impact of both twisted tape and rectangular winglet (V-winglet) inserts on pressure loss and heat transfer. The square duct has a constant heat flux and the air as working fluid flow through a duct with Re in range of 4000 to 30,000. The design parameters include twist ratio has two value (y= 4 and 5) while blockage ratio has three different values (BR = 0.1, 0.15 and 0.2), attack angle of winglet of 30° and four value winglet pitch ratio (PR = 2, 2.5,4 and 5). The findings indicate that Nusselt number and friction factor for the both of twisted-tape and V-winglet raise with a rise in BR but lowering RP. When RB = 0.2, PR = 2 and y = 4 give the best heat transfer rate and friction factor; however, the one at BR = 0.1, PR = 2 and y = 4 provides the best thermal performance where TEF value about 1.62 or around 17% more than the twisted tape.

Y. Q. Song et al.[12] had examined the impact of employing RTT on heat transfer, fluid flow thermal performance and twisted tapes have a two cases fixed and rotating, the last of those have three different rotational speeds. The flow laminar where Re in range of 50-1000 and the outer surface of the wall supply by heat flux of 5000 Wm^{-2}.height of tape is equal to 90% of the channel height for generating secondary flow and the findings show that elevating the Re number rises both the pumping power and the Nu number. Pumping power requirement rising by 50%- 250% so The optimum operational state of applying tapes from the standpoint of pumping power consumption is achieved at the minimal inlet fluid velocity and average Nu number raised by 24% -179% as a result of applying twisted tapes. In states of Rotating Twisted Tapes (RTT), the local and average Nu numbers are much greater in comparison with corresponding magnitude in fixed twisted tape and the reason is mainly owed to stronger secondary flows.

S. V. Patil et al.[73] had an empirical study to improve heat transfer by using full-length helical inserts with a variety of twist ratios placed in a square duct. Water was a working fluid. The results show that helical inserts give a higher f and Nu compared with a smooth duct, and the thermo hydraulic performance ratio provided by inserting helical tape that has twist ratios of 1.44, 2.55, 3.66, and 4.66 has been observed to be 5.20, 4.44, 4.01, and 3.50 times greater than the smooth duct.

H. Ranjan[74] studied improving heat transfer by using ribs and helical screw tape placed in the duct with an aspect ratio of 1. The performance is better compared to the smooth and square ducts that have ribs, and the performance of 45° inclined ribs with helical screw tape is better as compared with the couple of helical screw tapes with transverse ribs. At Re = 200, Nu produced by 45° inclined ribs with helical screw tape is 4.3% larger as compared to 30° inclined ribs with helical screw tape, 22.26% larger as compared to 60° inclined ribs, and 35.82% larger than the transverse ribs with helical screw tape.

2.3.2. Effect of Different Angles of Tapes

P. Promvonge et al.[75] examine the flow properties in square duct set diagonally with 30° angle-finned tapes at three ratios of PR (PR=1,2,3), Re=4000-23000, BR=0.1,0.15,0.2,0.25 and 0.3 .Tapes are intended to create longitudinal vortex flow pair through the heated duct. Findings produce that at BR=0.3and PR=1 gives maximum heat transfer and friction factor (f/f_0=67–109 and Nu/Nu_0=5.9–6.3),.At BR=0.2 and PR=1.0 offer the highest thermal performance(TEF=1.8).

P. Promvonge et al.[76] had examined the effect of 30°-angle finned tape fitted diagonally in isothermal-fluxed square-duct upon heat transfer and pressure drop where Re=4000-20000. Angle-finned tape creates a couple of longitudinal counter-vortices which help of turbulent flow mixing in the duct. Vortex allows producing impingement/attachment flows on the walls, and this give drastic rise in the heat transfer. Improvement is around 150–650% by utilizing the finned tape with a BR=0.1–0.3. but finned tape insert provide increase to excessive pressure drop about 2 to 55 times as compared with smooth duct based on the PR, BR and Re values. The increases of the BR and the reduced value of the PR led to an uptick in Nu and f values. TEF was highest around 1.95 at lowest Re and BR=0.2, PR=1 while Nu ratio is closer to 4.5 at the lowest Re.

Y. Kaewkohkiat et al.[77] had investigated of influence of V-ribbed tape inserted diagonally in the square duct with attack angle of 45° upon heat transfer and friction factor where the duct has uniform heat flux walls and air was employed as working fluid with Re number from 4000 to 25,000,BR=0.1, 0.15,0.2 and 0.25 and PR=0.75 and 2. V-ribbed tape Predicted to create a longitudinal vortex flow pair in each tape side along the heated duct. BR and PR of the V-ribs produce a huge impact on the thermal performance and at the lower PR, the V-rib with BR=0.25 achieves the biggest heat transfer and f, but best thermal performance achieves at BR=0.2, PR=0.75 where TEF value around 1.88 at the smallest Re. V- ribbed tapes produce large heat transfer improvement around 416%-791% depends on the Re, BR and PR values as compared with smooth duct. The friction factor reveals a lowering tendency with increase of PR but with a reduction in BR where it values is revealed to be 23–148 times than smooth duct.

R. A. Albaldawi et al. [78] have empirical examine for properties in a square duct inserted angle-ribbed straight diagonal tape at different angles (10^o,20^o,30^o,45^o,60^o,90^o) as shown in figure 5, which shows the ribs placed at a specific distance (P) and a specific height (b).

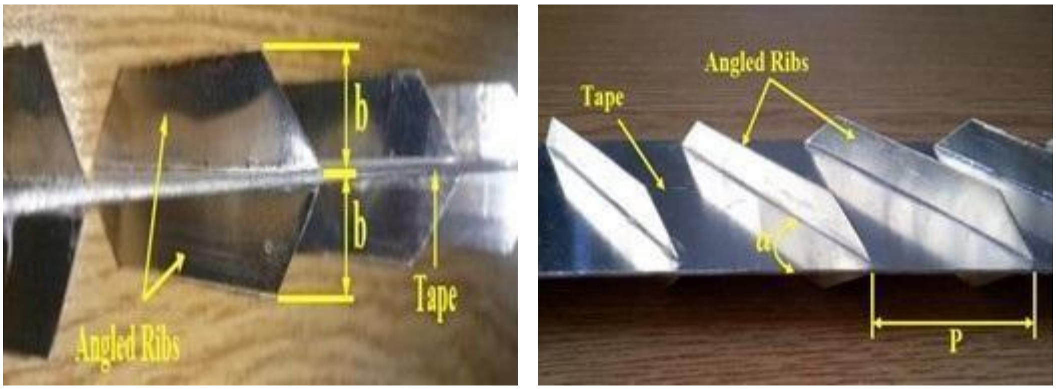

Fig. 5. Straight diagonal tape.

A pair of vortexes will be generated due to diagonal tape, so heat transfer rate will rise. Ribs at angle 45 ^{o} show a higher Nu, Re as compared with residual angles and without inserting tape. Friction factor rise with changing the angle of diagonal ribs and slight decrease at Re rising. At angle 45^o friction factor has the largest boost (97.14%-98.42%) than smooth duct while at 10^o has a lesser boosted (79.29%-86.6%). Maximum TEF was at 10^o. Adding tape which has ribs with a varied angle(10^o,20^o,30^o,45^o,60^o,90^o) causes increases in Nu about (45.08-57.7) %, (51.65 -62.4) %, (57.37-67.24) %, (65.57-77.78) %, (62.52-76.06) % and (59.41-71.86) % respectively, more than smooth duct based on Reynold number value.

2.3.3. Effect of Gaps and Perforated Tapes

W. Noothong et al.[79]had investigation into the influence of insert diagonally 45°discrete V–finned tapes (DFT) in square–duct which has constant heat–flux on heat transfer and pressure loss with different relative fin heights and pitches (BR=0.075, 0.1, 0.15 and 0.2, and PR=0.5, 1.0, 1.5 and 2.0) for the turbulent flow, Re from 4000 to 25000 and attack angle of fin 45°.DFT inserts rise values of friction factor and heat transfer with increment of BR but with a lower value of PR. At PR=0.5 and RB=0.2 achieves the maximum heat transfer and friction factor where Nu/Nu_0 is around 10%, 13%, and 27% higher than BR=0.15, 0.1, and 0.075 and around 9%, 14% and 22% higher than PR=1.0, 1.5, and 2.0 while friction factor is around 32%, 50%, and 66% more than BR=0.15, 0.1, and 0.075 and around 32%, 49%, and 60% more than PR=1.0, 1.5, and 2.0. The greatest thermal performance obtains at PR=1.5 and BR=0.1. DFT provides increase to two longitudinal counter–rotating vortices throughout duct, which tend to higher turbulence intensity.

S. Suwannapan et al.[80] investigate the effect of 45° DFTVD on heat transfer and pressure drop with constant heat fluxed square duct and air as working fluid with turbulent flow where Re number 4000 to 25000. 45° discrete V-finned tape with V-tip pointing downstream (45° DFTVD) as shown in figure 6 had inserted diagonal in duct at different BR and PR parameters, BR=0.075, 0.1, 0.15 and 0.2, PR=0.5, 1.0, 1.5 and 2.0 while attack angle equal to 45°.

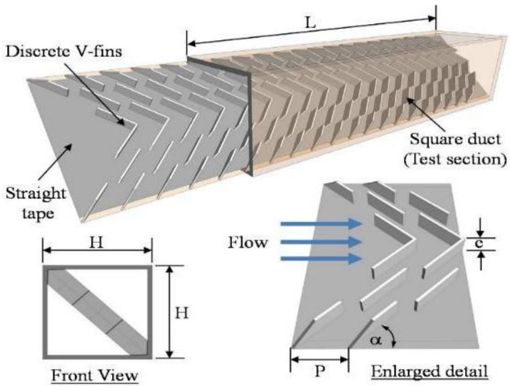

Fig. 6. 45° DFTVD.

The findings show that friction factor and heat transfer magnitude which rise with raising in BR but with lower in PR and the largest values of them were found at BR=0.2 and PR=0.5 while largest TEF was noted at BR=0.1 and PR=1.5 where TEF around 1.66 at Re= 4130. Varying the V-tip direction to be directed upstream provide in an unimportant boost of 3% in thermal enhancement factor.

Enhancing heat transfer using any of the above methods is dependent on several factors that have been studied previously, and the best and optimum design that balances between the maximum heat transfer that can be achieved and pressure losses. The table below introduces an overview of tapes, ribs and baffles.

Table 1. Comparison between different kinds of obstacles.

Types of obstacles	Tape	Ribs	Baffles
Advantage	Low-cost	High heat transfer enhancement	Enhanced heat transfer
	enhance heat transfer	Relatively stable performance	Improved fluid mixing
	Minimal impact on pressure drop	Used in many application	Relatively simple to implement
Disadvantage	Low heat transfer enhancing compared with other methods	Significant pressure drop	Increased pressure drop
	Design can be complex and the shape of tape have a large effect on heat transfer.	Complex design and installation	Potential for flow poor distribution
		flow obstruction	Possible mechanical wear

3. CONCLUSIONS

3.1. Ribs

Varied shaped of ribs were tested such as rectangular, semicircular, hybrid, triangular, S-shaped, V-shaped ribs, M-shaped, W-shaped,45°ribs, right triangular ribs, circular ribs, isosceles ribs, square ribs and the result was as the following:

1- The hybrid rib achieves better magnitude for the efficiency indices compared with rectangular, semicircular where the improvement of heat transfer in range of 1.3-2.14 on the other hand, V-shaped ribs

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provide best heat transfer improvement (7%greater than 45° ribs,28% greater than W-shaped,35% greater than M-shaped ribs).

2- In S-shaped ribbed was found to be the highest valve of overall enhancement ratio was 1.48 and When upsurge in Re number, Nu number increases as a result heat transfer coefficient while friction factor goes down.
3- Square ribs give a significant increase in heat transfer by (28.22-58.23) % as compared with no ribs, then came triangular and circular ribs with percentage enhancement (20.14- 45.62) (10.87-28.13) % respectively.
4- The optimum angle of rib is 60° where in ribs that have angle 60° provide 19.3% improvement of heat transfer than inclined ribs at angle 90° also same case in V-shaped where V-shaped with 60° provide 32.6% improvement of heat transfer than inclined ribs at angle 90°.

Gaps give a large effect on Nu and f in different shapes of ribs, where in V-shaped ribs optimum number of gaps equal 3 which provide enhancement in Nu is 2.05 and f is 3.39 as compared with smooth plate. Multiple broken transverse ribs has a heat transfer enhancement found to be 3.24 as compared with square wave ribs which equal 2.50, S-shaped ribs with gaps that resulted in the greatest heat transfer improvement for Nu = 5.42 and f= 5.87 at Re=19258. Continuous rib at attachment angle 60° which has gaps provide range of an increase in Nu and f is greater 1.48-2.59 and 2.26 -2.9 than smooth duct.

Using perforation ribs increase heat transfer where increment reaches a 34.1% and increase inclined angle of the perforation, leading to a bit higher overall average Nu than with straight cases where the improvement ratio is in the range 1.85 %- 4.94 %. The square holed ribs better than cylinder, round holes with lower interval are better than square and round with short interval. Using multi V-ribs perforation improve heat transfer more than single V-ribs and multi V-ribs.

3.2. Baffles

Placing baffles improve heat transfer only if Re more than 300 influence on heat transfer and friction factor. Various geometry of baffles include Diamond shaped, HB, V-shaped, Broken V-shaped, S-shaped, Z-shaped and wavy baffles have been investigated. The result was as the following: -

1. Diamond shaped has enhancement is around 200–680% while friction losses vary 20-220 times greater than the smooth case.
2. V-shaped heat transfer enhancement reach up from 2.025 to 6.258 depending up on Reynold number and separation distance, while z-shaped had maximum TEF=2.2.
3. HB has maximum THPF=4.4 and HTE from 2.5 to 3.8 times as compared without baffles. 90° rectangular baffles have pressure drop and average Nu number goes up to 316.67% and 148.15% compared without baffles.
4. Optimum angle of baffle was 90° and design parameters like height of baffle, orientation spacing between baffles, PR, BR all of them have influence on heat transfer and flow characteristics.
5. Gaps minimize of resistance to the flow and lower the skin friction, gaps position have a critical effect on TEF where the smallest distance position give the largest TEF reach to 5.901% at distance position of 0.25. Another important factor is relative width, which impact on enhancement of heat transfer.

6. Perforated baffles are applied to generate vortex flows, thereby resolving the issue of the generation of LHTA therefore increase heat transfer. The most effective parameters which impact on heat transfer are PAR and numbers of holes, where half holed baffles provide 133- 274% increment in Nu number that means number of perforations reduced result Nu number improve also same thing in PAR where at PAR =0.19 provide more heat transfer enhancement 2%-65 % as compared in traditional baffle.

3.3. Tapes

The shape of tape effect on heat transfer, such as twisted tape, screw tape, rotating or fixed twisted tape and twisted tape with or without winglet all of them are investigated. The result show that Nusselt number increase with increase Reynold number and twisted tape have improved Nu number to 24% -179% and using RTT improve Nu more than just twisted tape.Varying Order of twisted tape have no impact on heat transfer coefficient. Screw tape provide higher friction factor and Thermal performance ratio than twisted tape, where friction factor and Thermal performance ratio of twisted tape and helical screw-tape reach to 7.7times,14 times,2.81 times,5.3 times respectively as compared with plain duct. It is worth mentioning that heat transfer and friction factor improve with reduce twisted ratio and taper angle.

Tape creates a pair of vortexes which increase heat transfer and Nu number increase with increase BR and reduction in PR where two side V-ribbed tapes have maximum improvement in heat transfer 416%-791 % depend on Re, PR, BR as compared with smooth duct. For angled ribs on tape, optimum attack or inclination angle 45° which provides the maximum heat transfer and friction losses 77.78 % and 98.42 % respectively higher than traditional duct, friction factor increase with raise attack angle and reduce with increasing Re number.

4. NOMENCLATURE

4.1. Symbols

b	Rib height
dg	Gap position distance
DPSAH	Double pass solar air heater
DPPFSAH	Double Pass Parallel Flow Solar Air Heater
e	Rib height
f	Friction factor
g	Gap width
H	Duct height
HB	Horseshoe baffle
HCW	Helical coiled wire

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LHTA	Lower heat transfer areas
N	Baffle set count
Ng	Number of gaps
P	Rib pitch
RTT	Rotating Twisted Tapes
S	Separation distance between obstacles

4.2. Dimensionless parameters

AR	Aspect ratio
BR	Blockage ratio
e/H	Height ratio (Blockage ratio)
f/f_0	Friction factor ratio
g/e	Relative gap width
Gd/Lv	Relative gap distance
THE	Heat transfer enhancement
Nu	Nusselt number
PAR	Pores Axis Ratio
p/e	Rib pitch to height ratio (pitch ratio)
P/H	Baffle pitch distance
PR	Pitch ratio
W/w	Relative roughness width
Re	Reynold number
OTP	Overall thermal performance
TEF	Thermal enhancement factor
THPF	Thermal-hydraulic performance factor
THPP	Thermo-hydraulic performance parameter
WTB	Waisted Triangular Baffles
Y	Wave ratio

4.3. Greek letters

α	Inclination angle, attack angle
β	Open area ratio

4.4. Subscripts

s, o	Smooth
rs	Rough surface

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