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Review on Heat Transfer Enhancement by Rectangular Fin

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ABSTRACT
Heat generation of engineering appliances has bad effect in handling the system can cause the trouble, short life cycle of machines, frequent maintenance requirements and low reliability of systems. The passive cooling technique has been widely used to solve such problems. This review work summarizes the heat transfer enhancement technique in a rectangular fin with economic way. So many research about the enhancement of heat transfer by rectangular fins experimentally and numerically and found very significant result. In this review, various types of rectangular fin structures are studied simultaneously. It is revealed through reviewing the related literature that the highest value of equivalent heat transfer enhancement is found the increase in average heat transfer performance of inverted triangular notched fin 50.51% as compared with plane rectangular fin and the perforated fin total heat transfer rate increased by 38.9% compared to regular fin. Furthermore, by reduction of the optimal fin spacing, heat flux can be changed by 20% in standard rectangular fin when compared with regular fin spacing. Also cooling performance of the inclined rectangular fin with 60° of tilt angle is seen to be as 6% higher than solid rectangular fin. This article can be considered as a benchmark in the practical application for enhances the heat transfer rates.

Keywords: Heat Transfer Enhancement, Rectangular Fin, Active Method, Various Fin, Passive Method, Fin geometry.

1 INTRODUCTION

Heat generation of engineering appliances has bad effect in handling the system can cause the trouble, short life cycle of machines, frequent maintenance requirements and low reliability of systems. There are two methods are used to minimize the overheating problems. These are active and passive methods. In active methods, to maintain the enhancement mechanism of heat transfer external power is required. In passive methods, surface modification or geometrical shape changes are mostly performed in the existing material or additional devices like rough surface or extended surface are added in the system. In passive methods heat transfer rate is often increased by providing extended surfaces which increases the effective heat transfer area. This is done by adding fins, pins, or other extensions to the heat transferring surface. These methods have so many advantages than active methods so that it is preferred for widely used. As these have many advantages the fin arrays are commonly used in heat exchangers, air conditioning, chemical reactor and refrigeration systems and other application areas that require high heat flux removal rates [1, 2]. Basic methods of the heat transfer are conduction, convection and radiation. Convection is a widely used cooling technique. Three types of convection and these are natural, forced and mixed convection [3]. Several types of the rectangular fins, which are used to increase heat transfer in the literature, are given in figure 1 [4]. The parameters should optimize to enhance the heat transfer rate, these parameters are fin diameter, fin shape, fin height and inter fin distance. The present study investigated the heat transfer enhancement in various arrangements of several types of rectangular fin by using passive heat transfer technique and their impacts on different mediums and configurations.

Heat dissipation of parallel plates has been presented by Elenbaas [5]. In 1963, Starner and McManus [6] were carried out an experimental study with four sets of rectangular fins. Number of fins in the array was changed between fourteen and seventeen and fin height and spacing was altered and found that space and height of the fin has a direct impact on heat transfer performance, and it was also insufficient number of fins to the surface provides lower heat transfer rates. It is also revealed that to reach maximum heat transfer rates, narrow fin spacing should be provided in the surface. An experimental Investigation of Free-Convection Heat Transfer from Rectangular-Fin Arrays was investigated by Welling and Wooldridge [7].

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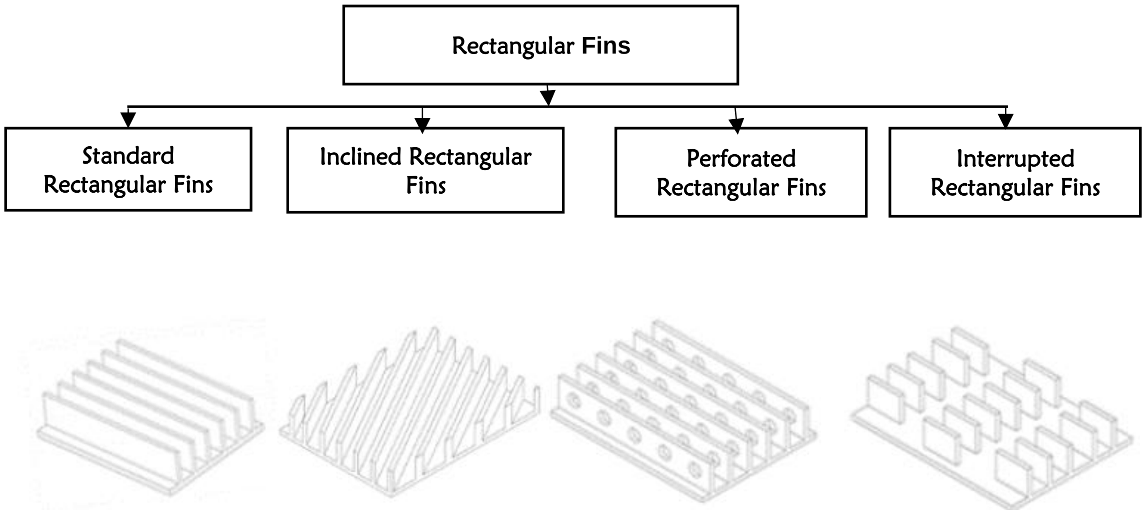


Figure 1. Different rectangular fin types and schematic view of the fin arrays [4]

2 STUDIES ON STANDARD RECTANGULAR FINS

The heat transfer enhancement of rectangular fin depends on fin geometry [3]. It has been concluded that heat transfer coefficients fell 10 to 30% below compared with parallel plates. It was also the arrays with 45^0 yielded results 5 to 20% below those of the vertical. A study on to see the effect on flow field of rectangular fin experimentally was performed by Harahap and McManus [8]. Chimney type flow pattern is observed for all of the cases and the researchers suggest choosing proper ratio of fin height to fin height to avoid sliding chimney strip flow. Some experimental results on rectangular fin array arrangement optimization were presented by Jones and Smith [9]. In this research average heat transfer coefficients and spacing effects are reported in [5] and [7] in agreement with the found data from the experiment. It is also the correlation that was obtained by Harahap and McManus [8], were compared with found data. Data correlations suggest that, correlation parameters of ref [8] are debatable. Leung et al. [10] compared the heat transfer characteristics of vertical and horizontal fin array. An experimental investigation to see the effect of increasing the fin length to the heat loss was performed by Leung et al. [11]. In this research it was found that increase of the fin length and small fin separation distance causes large reduction in the heat loss. Leung and Probert [12, 13], conducted an experiment vertical and horizontal rectangular fin arrays. In these research it is concluded that when fin thickness is reduced, number of fins is increased at same base area condition so that heat transfer area is also increased. Due to this confliction situation, authors claimed that there should be a critical fin thickness, which corresponds to a maximum heat transfer rate. Bar and Cohen [14, 15] predicted this critical value theoretically for free convection conditions. Vertically and horizontally based non dimensional correlations are generated for vertical-finned systems [16-18]. The heat dissipation rate on steady state condition of stainless-steel, vertical rectangular fins, under natural-convection have been measured experimentally by Ko et al. [19]. In this experiment two materials (Duralumin and stainless steel) are used. Results suggest that the duralumin fin array have higher heat transfer performance than stainless-steel fin arrays with similar geometries. Babus'Haget al. [20].

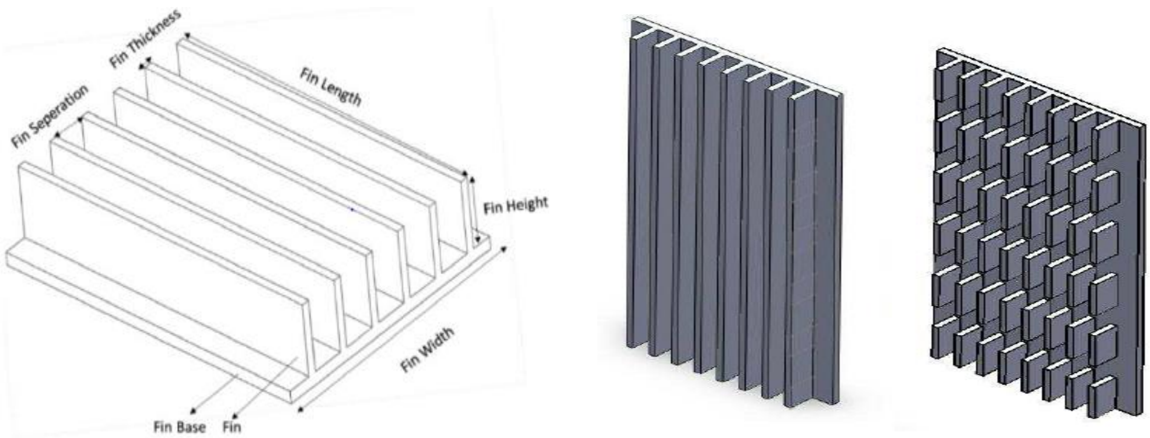
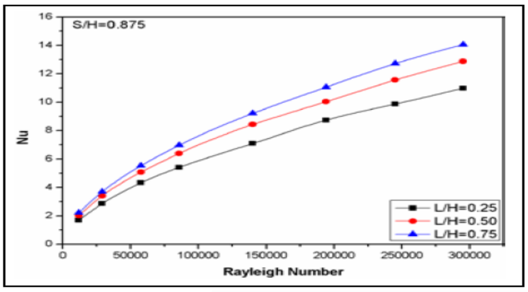


Figure 2. (a) Geometrical fin parameters (b) Continuous and Interrupted rectangular fin [3]

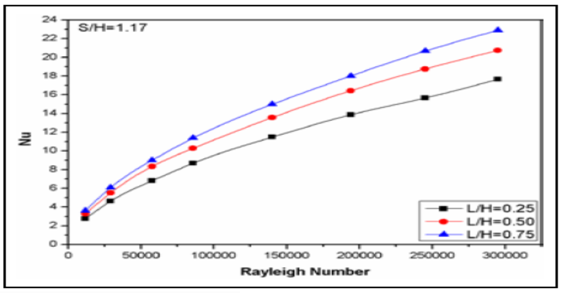
observed that a little effect had on heat transfer performance of fins material thermal conductivity. Also, confirmed that fin material has no effect on fin spacing. Fin geometry roles and base-to-ambient temperature difference on heat transfer performance of rectangular fin were investigated by Yazicioglu and Yüncü [21, 22]. It was concluded that the rectangular fin heat transfer performance depends on difference of base-to-ambient temperature and fin geometry. It was also convective maximum value of heat transfer rate from fin arrays as a function of fin geometry and a correlation of maximum heat transfer and fin spacing was developed. Dogan and Sivrioglu [23, 24] were concluded that the optimum transfer yields on the optimum fin spacing and value depends on fin height and modified Rayleigh number. From numerical and experimental study Hong and Chung [25] it is observed that there is an optimal fin spacing range and when the optimal fin spacing increased then the Prandtl number decreased. Ayli et al. [26] showed that the turbulent fully developed flow and a correlation was developed and compared with experimental results. Sana and sukhatme [27] analyzed the single chimney flow patterns of rectangular fin array and obtained an agreement with the experimental data. Vollara et al [28] was concluded that the heat flux can be changed of 20% by reduction of the optimal fin spacing. Arquis and Rady [29] found high fin height, wide fin spacing make the finned surface more effective and when low Rayleigh number, high fin height then linearly increases effectiveness. A theoretical investigation of the fin geometry and temperature difference between fin and surroundings was carried out by Bakaya et al [30] and concluded that the optimum value in terms of overall heat transfer cannot be obtained. A numerical study of natural convection of air in a differentially heated horizontal rectangular enclosure with finned base plate, the variation of average with Rayleigh number, for different fin length and spacing was investigated by Pathak et al. [31]. It was observed that the heat transfer performance increases with increasing the number of fins, Nusselt number and Rayleigh. An experimental investigation to observe the heat transfer enhancement in duct with rectangular fin arrays was performed by Islam and Barsoum [32]. The researchers identified a promising configuration and expected the improved heat transfer performance from the end wall and the fin surface. Partner and Raseelo [33] showed that when increasing some parameters of fin then the heat rapidly dissipates to the ambient temperature. Osman et al [34] results showed that extension of surface of fin geometries, enhanced the heat transfer coefficient, but this thing depends on the Reynolds number of both fluids.

3 STUDIES ON INTERRUPTED RECTANGULAR FINS

In this part of the research, several researches about natural and forced convection heat transfer from interrupted vertical and horizontal rectangular fins are summarized. In continuous fin surfaces, rate of heat transfer decreases as flow becomes fully developed after critical length. On the other hand, interrupted fins disturb the thermal boundary layer and reset the boundary layer growth in each fin leading edge corner by this way a thermally developing flow regime is maintained which leads to higher heat transfer coefficients. Also using interrupted fins provides lower weight and provides cost reduction to the manufacturers. A model to observe the thermal performance of rectangular heat sinks using at plate boundary layer was presented by Culham, J et al. [35]. The researchers obtained an excellent agreement in comparisons between experimental data, the analytical cuboid and heat sink models of Yovanovich and the conjugate model. An experimental investigation of rectangular fin mounted on a vertical base under natural convection heat was carried out by Yuncu and Anbar [36]. The results showed that the optimum value for the fin spacing maximized the heat transfer performance of fin array. Interrupted fins are made by creating slots on solid continuous fins also Interrupted fin provide lower weight and provides low cost to the manufacturers [37].



(a)



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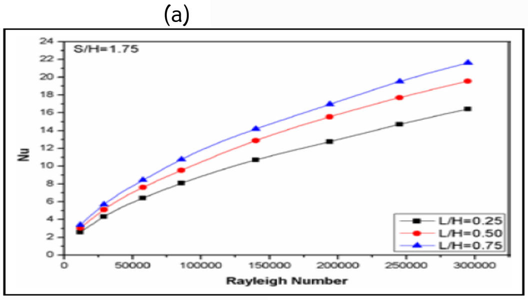

(c)

Figure 3: Effect of Fin Length on Nusselt Number for Different Fin Spacing: (a) S/H = 0.875; (b) S/H = 1.17; (c) S/H = 1.75 [31]

Ahmedi et al [38] was proposed a new compact correlation for calculating the optimum interruption length. Kharce and Farkade [39] concluded that the heat transfer rate in notched fins is more than the un-notched fins. It was also the copper gives more heat transfer rate than aluminum plate. In addition, as the notch area of fin increases the heat transfer rate also increases and the copper plate gives better heat transfer rate than aluminum plate. Wange and Metkar [40] were concluded that the heat transfer coefficient is more in notch fin array than without notch fin array. It was also appropriate selection fin geometry and depth of notch is needed for achieving superior heat transfer rate of fin. An experimental investigation to observe the effect of notch in the heat transfer performance was carried out by Dixit and Mishra [41]. It was found that when notch depth increases then heat transfer coefficient also increases. Shehab [42] concluded that the convective heat transfer coefficient of notched fin array is 28% to 45% higher than un-notched fins at the same conditions. It was also found that Average Nusselt number is about 45% higher in case of 37% notched fins array than un-notched fins array. Experimental investigations to observe the effect of different notch sizes on heat transfer coefficient was carried out by Bakale et al. [43]. The study showed that as the notch size increases so does the heat transfer rate. Singh and Singh [44] studied on steady state heat transfer for notched fins for different heat inputs and different notch geometries. It was concluded that the inverted triangular notched fin, inverted trapezoidal notched fin, inverted circular notched fin and inverted rectangular notched fin average heat transfer coefficient performance increases fin are 50.51%, 36.81%, 37.98% and 26,01% respectively as compared with plane rectangular fin. Kallanavar and Kapale [45] concluded the heat transfer coefficient increases with increase in fin spacing. Taji et al. [46] commented that rectangular notched fin arrays provide high heat transfer rate compared with triangular and semicircular notched structures. What's more, it was revealing that with raising the fin spacing; heat transfer coefficient reaches an optimum value. After reaching the critical value, heat transfer starts to drop. An experimental investigation to observe the heat transfer coefficient of fin with different rectangular notch size for cylinder fins was investigated by Beldar [47]. It was observed when notch percentage increasing then heat transfer coefficient and nusselt number also increases.

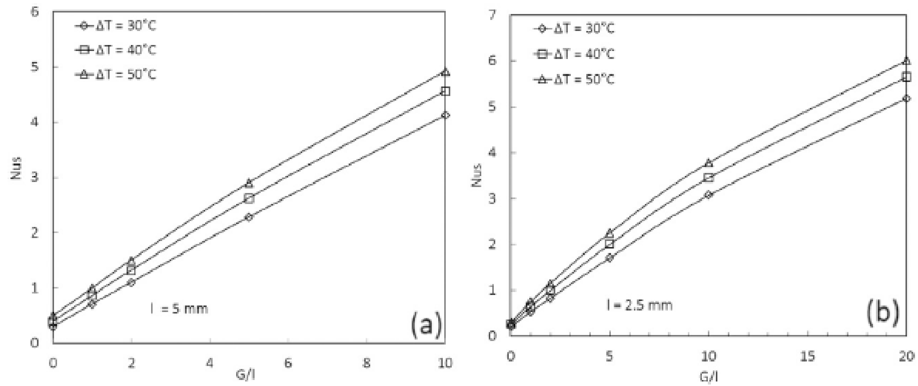

Figure 4: Graphical presentation of Effect of interruption length on the Nusselt number for natural convection heat transfer from the fins, (numerical results), a) fin length l =12.5 mm, b) fin length l = 2.5 mm [38]

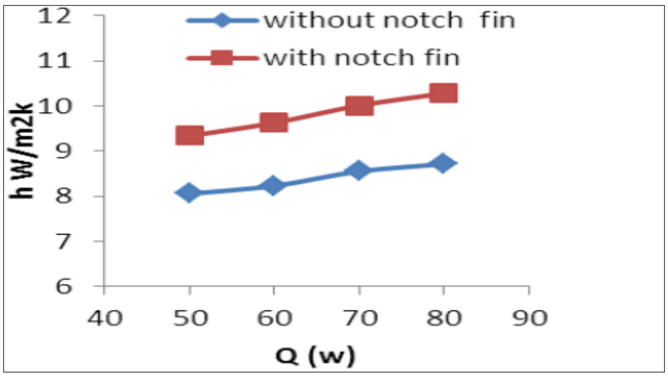

Figure 5: Graphical representation of Comparison of heat transfer coefficient for without notch and notch fins [39]

Table 1: Heat transfer coefficient for without notched and notched fins [40]

#	Heat Input in Watt	h for without notched fin (W/m²k)	h for 20% notched fin (W/m²k)
1	50	8.0595	9.3397
2	60	8.2307	9.6269
3	70	8.5519	10.0100
4	80	8.7130	10.2790
	Avg	8.3887	9.8139

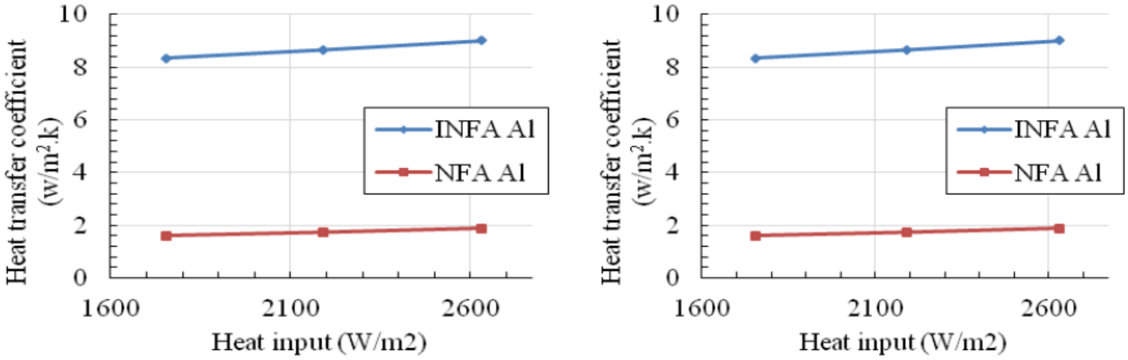

Figure 6: Heat Transfer Coefficient for Fin Arrays [40]

4 STUDIES ON PERFORATED RECTANGULAR FINS

To improve ventilation and to create more turbulence in the fin array holes, cavities, grooves which are generally circular are introduced to the fin surface. Essa et al. [48, 49] studied numerically to observe the heat transfer enhancement of a horizontal rectangular fin embedded with triangular perforations under natural convection. The first study [48] showed that perforated heat dissipation of perforated fin was improved of over the equivalent solid fin. Furthermore, increasing the thermal conductivity of fin and its thickness as heat transfer also enhanced. Second study [49] concluded that dimensions, the perforated fin enhance the heat transfer for certain values of triangular dimensions. It was also observed that the extension of heat dissipation rate of perforated fin was a complicated function of the perforation geometry. Modeling natural on convection heat transfer from perforated plates was performed by Zan et al. [50]. The researchers concluded that Perforations can enhance heat transfer for isolated isothermal plate, vertical parallel plates with low H/s ratios, and vertical rectangular fins with specified dimensions. The researchers [51] showed the heat transfer power of heat sink increases by 16.7% compared with the prototype. Furthermore, the heat transfer power of heat sink increases with the increasing number of holes and when the holes reach to a value, further increasing will not function properly. The perforated rectangular blocks heat transfer enhancement in a channel flow was studied by Sara et al [52]. It was found that to achieve energy gains up to 40% by perforations opened in the blocks. The Solid and circular perforations along the length of the rectangular fins array turbulent heat transfer performance was experimentally investigate by Ehteshum et al. [53]. The perforated rectangular fin arrays heat transfer enhancement with different inclinations on natural convection experimentally investigated by Awasarmol and Pise [54]. It was concluded that the perforated fin heat transfer coefficient increases by 32% at the angle of orientation 45° as compared to the solid fin array and material saving by mass of nearly 30%. Sahin and Demir [55] experimental results showed that heat transfer performance can enhance by using the square pin fins. A research to investigate the heat transfer enhancement of a vertical rectangular fin embedded with circular perforations was carried out by Muthuraja et al. [56]. The design and analysis of perforated rectangular fin array with varying percentage of perforation experimentally investigated by Patil et al. [57]. Analysis gives the idea about heat transfer and behavior of perforated fins. A research paper on effect of perforation area on temperature distribution of the rectangular fin under natural convection was studied by Ibrahim et al. [58]. The experimental results [59] showed that square fins provide higher Nusselt number when compared to circular perforated fins. Prasad et al. [60] observed that the fin porosity can play a vital role to enhance the heat transfer. With increase in the number of perforations up to certain level the heat dissipation rate is increased in the range of 20% to 70%.

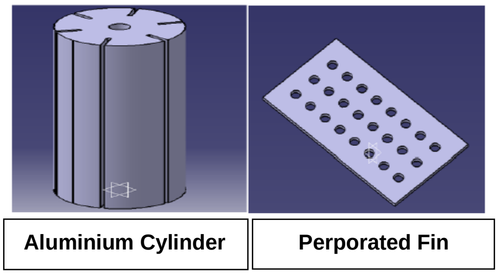

Figure7: 3D Image of aluminium cylinder and perporated fin [60]

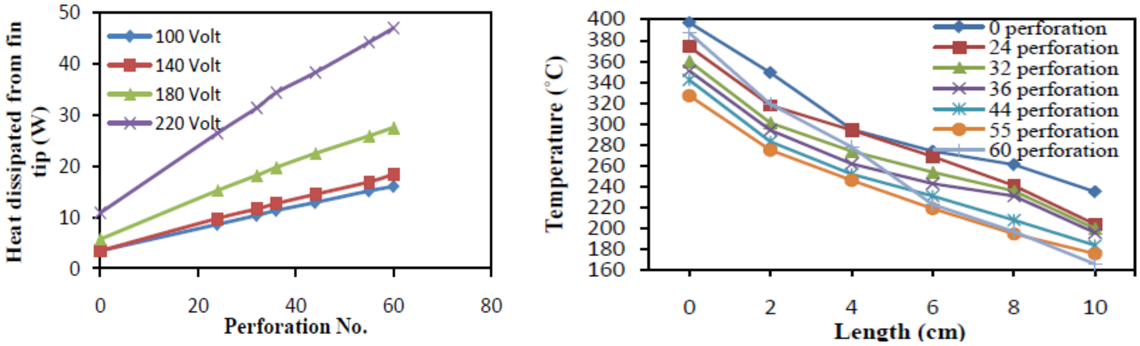

Figure 8: Effect of Perforation No. on Heat Transfer Front the Fin Tip at varying Voltage and Effect of length on temperature distribution for varying perforations at constant voltage (220V) [60]

Huang et al. [61] has found that the perforated fin heat transfer coefficients better than without perforations. Bassam and Abu [62, 63] showed that the permeable fins compared to the solid fin with similar configuration can provide much higher heat transfer rate. [64] Results showed that the circular perforations fins reduced pressure drop and have remarkable heat transfer enhancement. Jonsson and Moshfegh [65] found that the fin geometry, duct geometry, fin-to-fin distance and the Nusselt number influenced the heat transfer rate. Shaeri and Yaghoubi [66] showed that performances and effectiveness of perforated fins increased with increasing number of perforations. Represent numerical data is compared with the numerical and experimental results of ref [67] for solid fin structure. Shaeri and Jen [68] experimentally and numerically investigated the laminar flow from the leading edge of a flat and found data indicate that the boundary layer thickness and nature or blockage ratio had a strong influence on the structure of the laminar junction flow. A numerical study to investigate the turbulent convection heat transfer on a rectangular plate mounted over a flat surface had been performed by Ismail et al. [69]. Heat transfer analysis of lateral perforated fin heat sinks had been studied by Shaeri et al. [70]. Results showed that higher heat transfer performance provides the perforated fins in comparison with solid fins. Vyas et al. [71] concluded Heat transfer rate is high for Rectangular shape of perforation decreasing with elliptical and circular shape. It shows that shapes with lower eccentricity have good heat removal capacity. So, eccentricity as low as possible should be manufactured when perforated fin are manufactured. It is also Heat transfer from first some fins are high as compared to later fins. So increasing the number of fins in lateral direction had no effect on heat transfer rate especially when space and weight are constraints. Ziaoqin et al [72] concluded that the total heat transfer rate of tube heat exchanger of perforated fin under the frosting condition is increased by 38.9% and the heat transfer coefficient 31.8%.

Table 2: Values of average heat transfer coefficient (h_{av}) and Nusselt number (Nu) for different cases [71]

Geometry of Perforation	Temperature Difference (T_{out}-T_{in})	Reynolds Number (Re)	Average Heat Transfer Coefficient (h_{av})	Nusselt Number (Nu)
Rectangular	6.05194	2000	18.93	55.448
	5.51926	4000	18.96	55.536
	5.33691	6000	18.9803	55.595
Elliptical	5.63324	2000	18.9601	55.536
	5.31223	4000	18.9820	55.600
	5.20923	6000	18.9890	55.621
Circular	5.61295	2000	18.9615	55.540
	5.30365	4000	18.9825	55.602
	5.20309	6000	18.9894	55.622

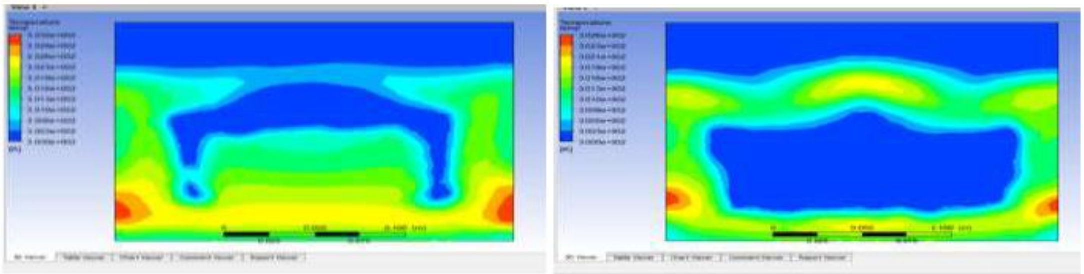

Figure 9: Temperature distribution at outlet for rectangular shape and elliptical shape [71]

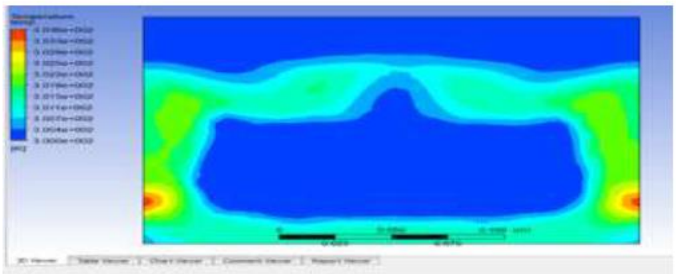

Figure 10: Temperature distribution at outlet for Circular shape [71]

5 STUDIES ON INCLINED RECTANGULAR FINS

Due to the rotation of some devices or lack of available place in some scenarios, inclined oriented heat sink becomes compulsory to use instead of vertical or horizontal orientations. These possible scenarios motive the studies, which define an inclination to the finned surface. This part of the survey indicates that few studies are available on inclined fin arrays. Heat transfer from a plate with arbitrary inclination under natural convection was experimentally studied by Fujii and Imura [73]. It was concluded that Nusselt number was proportional to one-fifth power of *Ra* number and slightly inclined heated plate and horizontal heated plate both facing downwards. It was also when larger the inclination of angle of fins then the inclined heated plate facing upwards. Mittelman et al [74] showed that the heat transfer rate substantially enhanced when the fin array tilting beyond a certain angle. Additionally, it was showed that the inclination angle did not depend on fin spacing and the researcher's advice to create inclination greater than 10° in order to enhance heat transfer rates. An experimental investigation to observe heat flux under the natural convection heat transfer from rectangular fins with five different figures was carried out by Khudheyer and Hasan [75]. The researchers had been found the CFD and experimental results and a good agreement between both. It was also found empirical correlations for the average Rayleigh number overall Nusselt number versus overall Nusselt number. An experimental investigation to investigate the effect of inclination of the fin array on heat transfer rate was performed by Naidu et al [76]. It was found that a satisfactory agreement from the experimental data. Rocha and Ganzarolli [77] investigation showed the Nusselt number can be evaluated by using a single correlation. It was also proposed a correlation for the local Nusselt number for natural convection heat transfer. A research to observe the cooling performance of electronic devices using the horizontal tubes with tilted rectangular fins was carried out by Lee et al. [78]. The researchers concluded that the inclined rectangular fin cooling performance with 60° of tilt angle is 6% higher than solid rectangular fins. In addition, the optimal cooling performance of the tilted finned tube is 9.2 times greater than that of the tube without fins. Therefore, tilted rectangular fins may potentially be used for the cooling of various electronic devices. Degao et al [79] observed that the inclination of vertical cross section rectangular fin does not reduce the convection heat transfer rate.

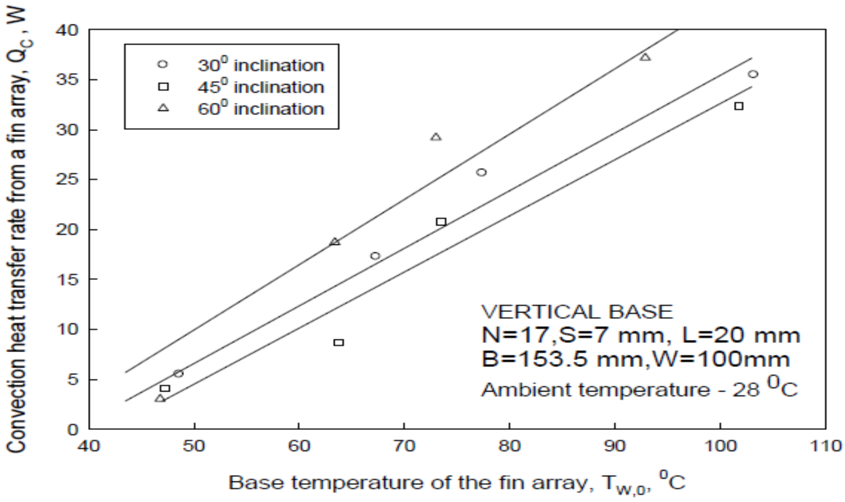

Figure 11: Effect of inclination on convection heat transfer rate from a fin array [76]

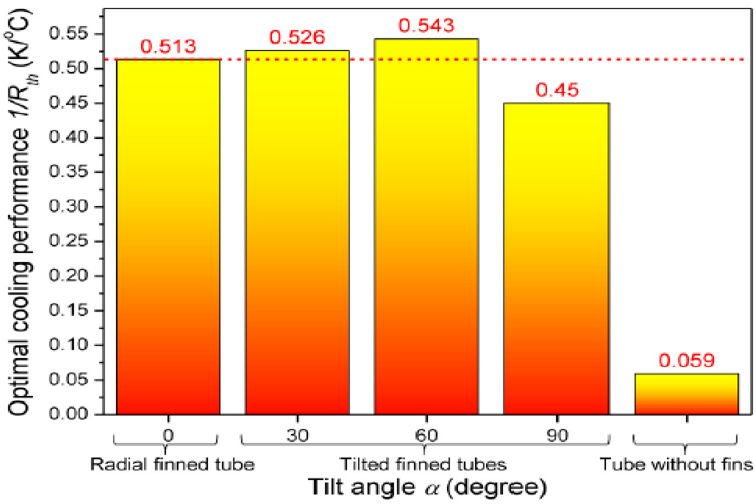

Figure 12: Comparison of the optimal cooling performances [78].

6 SUMMARY

Heat transfer enhancement through various types of rectangular fin.

Fin Type	Author	Type of Investigation	Investigated Properties	Observations
Standard rectangular fin	Starner and McManus [6]	Experimental	Fin spacing & Fin Height	1. Fin height and fin spacing has a direct impact on heat transfer rates. 2. Heat transfer rates become lower when compared to cases without a fin by insufficient applications of fins. 3. Narrow fin spacing can enhance heat transfer coefficient.
	Ko et al. [19]	Experimental	Fin material Duralumin & Stainless steel	The duralumin fin arrays provide higher heat transfer performance than stainless steel fin array with similar geometries.
	Babus'Haget al. [20]	Experimental	Fin material	The heat transfer rate had a small effect on thermal conductivity of the material.
	Yazicioglu and Yüncü[21]	Experimental	Fin Length& Fin Height& Fin Spacing	Correlation is obtained for maximum heat transfer rate.
	Dogan and Sivrioglu[23]	Experimental	Fin Spacing & Fin Height	1. To maximize heat transfer rate, fin spacing should be optimized. 2. Up to the critical fin spacing value, heat transfer coefficient rises and then it decreases with the increase of fin spacing.
	Dogan and Sivrioglu[24]	Experimental	Fin Spacing & Fin Height	The correlations of Nusselt number i.e., heat transfer rate is obtained.
	Vollara et al [28]	Experimental	Fin Surface	By reduction of the optimal fin spacing, heat flux can be changed by 20%.
	Pathak et. al. [31]	Numerical	Fin spacing & Fin Height	Nusselt number, fin thickness and fin height relationship is defined.
	Osman et al [34].	Experimental	Fin Geometries	By using different fin geometries with extending the surface enhanced the heat transfer coefficient.
Interrupted rectangular fin	Ahmadi et al. [38]	Experimental & Numerical	Fin Interruption Length	The correlation of heat transfer rate is obtained for fin interruption length.
	Kharce and Farkade [39]	Experimental	Fin material & notch effect	1. Interrupted fins provide higher heat transfer rates. 2. Heat transfer rate increases when aluminum plate is used instead of copper. 3. heat transfer coefficient rises at a level of 20% by using notch in the fin
	Shehab [42]	Experimental	Fin Spacing& Fin Number	1. Heat transfer coefficient is higher in notched one when it is compared with un-notched. 2. When the removal area of the fin increases, the average heat transfer coefficient also rises and an increase in heat input causes a peak in the heat transfer coefficient.

				3. Rising the fin spacing causes more fresh air entrance between the fins; therefore, heat transfer rate goes up.
	Bakale [43]	Experimental	Notch length & Notch Material	1. Heat transfer coefficient has direct proportion with the notch size. 2. The researchers reveal that a copper plate gives a better heat transfer rate than an aluminum one.
	Singh and Singh[44]	Numerical & Experimental	Heat Load & Notch Geometry	1. Rectangular notched fins provide higher heat transfer rates. 2. The increase in average heat transfer performance of inverted triangular notched fin 50.51% as compared with plane rectangular fin.
	Beldar [47]	Experimental	Notch Geometry	Increasing notch percentage also increases heat transfer coefficient and Nusselt number.
Perforated rectangular fin	Zan et al. [50]	Experimental	Perforation Geometry	The heat transfer rate increasing when Perforations in the fin surface decrease the weight of the fin.
	Meng et al. [51]	Experimental	Perforation Geometry	The heat transfer rate is 16.7 % increased with Introducing the circular holes.
	Awasarmol and Pise [54].	Experimental	Perforation Geometry & Holes are drilled 4 to 12 mm	Perforation fin with 12 mm hole and 45° angle of orientation creates 31% enhanced heat transfer while decreasing material weight by 30%.
	Dhanawade et al. [59]	Numerical & Experimental	Perforation Geometry	Results square fins provide higher Nusselt number when compared to circular perforated fins.
	Prasad et al. [60]	Experimental	Perforation Geometry	With increase in the number of perforations up to certain level the heat dissipation rate is increased in the range of 20% to 70%.
	Ismail et. al. [64]	Numerical	Fin and perforation length	Solid fins have higher Nusselt number distribution than perforated ones.
	Jonsson and Moshfegh [65].	Numerical & Experimental	Perforation Geometry	Solid fins have higher Nusselt number than square and circular perforated fins and also solid fins have higher thermal resistances compared with the perforated fins.
	Vyas et al. [71]	Numerical	shape of perforation	Rectangular perforated fin arrays provide higher Nusselt number distribution.
	Ziaoqin et al [72]	Experimental	Fin Tube Heat Exchanger	The perforated fin total heat transfer rate increased by 38.9% and the heat transfer coefficient increased by 31.8%.
Inclined rectangular fin	Mittelman[74]	Numerical & Experimental	0° to 30° inclination angle	1. Higher heat transfer performance can achieve flow separation as compared with no flow separation along the fin array cases. 2. Author's advice to define inclination angle higher than 10° to enhance heat transfer rate.

	Khudheyer and Hasan [75]	Numerical & Experimental	rectangular fins with 1,4 interruptions, inclination and v-fins	Interrupted fin surfaces have higher heat transfer coefficient than inclined fins.
	Naidu et al [76]	Experimental	inclinations (0°,30°,45°,60° and 90°)	Convective heat transfer rate increases with the rise of the inclination angle for the tested range.
	Lee et al [78]	Numerical & Experimental	30°,60° 90° inclination angle, number of fins	The inclined rectangular fin cooling performance with 60° of tilt angle is 6% higher than solid rectangular fins.
	Degao et al [79]	Numerical	Vertical and inclined plate	The inclination does not reduce the convection heat transfer rate.

It is revealed through reviewing the related literature that the highest value of equivalent heat transfer enhancement is found that the increase in average heat transfer performance of inverted triangular notched fin, inverted trapezoidal notched fin, inverted circular notched fin and inverted rectangular notched fin are 50.51%, 36.81%, 37.98% and 26, 01% respectively as compared with plane rectangular fin. The perforated fin total heat transfer rate increased by 38.9% and the heat transfer coefficient increased by 31.8% as compared with regular fin and introducing circular holes in perforated fin an enhancement of 16.7% in the heat transfer rate. Also Heat dissipation rate was increased in the range of 20% to 70% with increase in the number of perforations (24 to 60) up to certain level. Furthermore, by reduction of the optimal fin spacing, heat flux can be changed by 20% in standard rectangular fin when compared with regular fin spacing. Also cooling performance of the inclined rectangular fin with 60° of tilt angle is seen to be as 6% higher than solid rectangular fins.

7 CONCLUSIONS

This paper summarizes the literature review about rectangular fin structures which is one of the passive heat transfer enhancement techniques with low costs and high efficiency. The observations from many researchers can be summarized as given below:

1) In the standard rectangular fin, fin height and fin spacing has a direct impact on heat transfer rates. Heat transfer rates become lower when compared to cases without a fin by insufficient applications of fins, Narrow fin spacing can enhance heat transfer coefficient. The duralumin fin arrays provide higher heat transfer performance than stainless steel fin array with similar geometries. The heat transfer rate had a small effect on thermal conductivity of the material. Also, to maximize heat transfer rate, fin spacing should be optimized. Up to the critical fin spacing value, heat transfer coefficient rises and then it decreases with the increase of fin spacing. Furthermore, by reduction of the optimal fin spacing, heat flux can be changed by 20%.
2) In the interrupted rectangular fin, Interrupted fins provide higher heat transfer rates. The heat transfer rate increases when aluminum plate is used instead of copper. Performed with notch and without notch fins it was seen that heat transfer coefficient raises at a level of 20%. The rectangular notched fins provide higher heat transfer rates than other investigated notch geometries. The increase in average heat transfers performance of inverted triangular notched fin 50.51% as compared with plane rectangular fin.
3) In the perforated rectangular fin, the heat transfer rate increasing when Perforations in the fin surface decrease the weight of the fin. The circular holes provide an enhancement of 16.7% in the heat transfer rate. The perforated fin with 12 mm hole and 45° angle of orientation creates 31% enhanced heat transfer while decreasing material weight by 30%. The perforated fin total heat transfers rate increased by 38.9% and the heat transfer coefficient increased by 31.8%.
4) In the inclined rectangular fin, higher heat transfer performance can achieve flow separation as compared with no flow separation along the fin array cases. The interrupted fin surfaces have higher heat transfer coefficient than inclined fins. Convective heat transfer rate increases with the rise of the inclination angle for the tested range. The Rectangular fin cooling performance with 60° of tilt angle is 6% higher than solid rectangular fins.

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