Review on Heat Transfer Enhancement Technique In Fin & Tube Heat Exchanger

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***Abstract*—Enhancing heat transfer surface are used in many engineering applications such as heat exchanger, air conditioning, chemical reactor and refrigeration systems, hence many techniques have been investigated on enhancement of heat transfer rate and decrease the size and cost of the involving equipment especially in heat exchangers. One of the most important techniques used are passive heat transfer technique. These techniques when adopted in Heat exchanger proved that the overall thermal performance improved significantly. This paper reviews experimental and numerical works taken by researchers on this technique to enhance the thermal efficiency. The authors found that variously developed vortex generator are popular researched and used to strengthen the heat transfer efficiency for heat exchangers.**

***IndexTerms*—Heat-exchanger, Heat transfer enhancement, Vortex-generator, Fin-tube**

I. INTRODUCTION

A heat exchanger is a complex device that provides the transfer of thermal energy between two or more fluids, which are at different temperatures and are in thermal contact with each other. Heat exchangers are used either individually or as components of a large thermal system, in a wide variety of commercial, industrial and household applications, e.g. power generation, refrigeration, ventilating and air-conditioning systems, process, manufacturing, aerospace industries, electronic chip cooling as well as in environmental engineering. The improvements in the performance of the heat exchangers have attracted many researchers for a long time as they are of great technical, economical, and not the least, ecological importance. Performance improvement becomes essential particularly in heat exchangers with gases because the thermal resistance of gases can be 10 to 50 times as large as that of liquids, which requires large heat transfer surface area per unit volume on gas side. The traditional methods of reducing the air-side thermal resistance are by increasing the surface area of the heat exchanger, or by reducing the thermal boundary layer thickness on the surface of the heat exchanger. Increasing the surface area is effective but it results in the increase in material cost and increase in mass of the heat exchanger. Vortex generation is a new and innovation strategy of enhancing air-side heat transfer. Vortex generators such as wings and winglets can introduce vortices into the flow field causing heat transfer enhancement. Vortex generator can be punched, mounted on a heat transfer surface. When fluid flows through vortex generators, vortices are generated due to friction and separation on the edge of the vortex generator. Wide studies have been done on heat transfer on heat transfer characteristics and flow structure for heat exchangers with longitudinal vortex generator. In recent years the usage of vortex generator in fin and tube heat exchangers has got more and more attention.

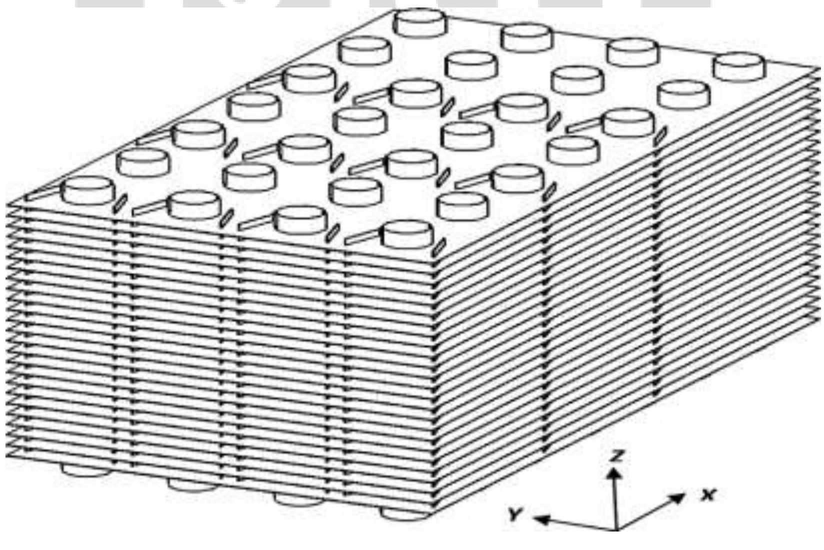

Figure 1 Schematic diagram of fin & tube heat exchanger with vortex generator [14]

II. HEAT TRANSFER AUGMENTATION

The subject of heat transfer enhancement is of serious interest in the design of compact heat exchangers. The emphasis is given on minimizing the space occupied by the equipment for the desired rate of heat transfer. A large number of augmentation techniques have been developed in the last few decades and these are applicable to diverse areas such as, single phase flows, two phase flows and convective mass transfer.A detailed account of the various techniques of heat transfer augmentation is given by Bergeles [2] Augmentation techniques can be classified either as **passive** methods, which require no direct application of external power, or as **active** methods, which require the external power. The effectiveness of both active and passive types depends strongly on the mode of heat transfer, which might range from single-phase free convection to dispersed-flow film boiling. Some of the passive techniques are [3]:

A. Active Method

This method involves some external power input for the enhancement of heat transfer and has not shown muchPotential owing to complexity in design. Furthermore, external power is not easy to provide in several applications. Some examples of active methods are induced pulsation by cams and reciprocating plungers, the use of a magnetic field to disturb the seeded light particles in a flowing stream, etc.

B. Passive Method

This method does not need any external power input and the additional power needed to enhance the heat transfer is taken from the available power in the system, which ultimately leads to a fluid pressure drop. The heat exchanger industry has been striving for improved thermal contact (enhanced heat transfer coefficient) and reduced pumping power in order to improve the thermohydraulic efficiency of heat exchangers. A good heat exchanger design should have an efficient thermodynamic performance, i.e. minimum generation of entropy or minimum destruction of available work (exergy) in a system incorporating a heat exchanger. It is almost impossible to stop exergy loss completely, but it can be minimized through an efficient design.

III. LITERATURE REVIEW

Torii et al. 2002 [5] propose new technique which can increase heat transfer with reduction in pressure loss in a fin tube heat exchanger with circular tubes in low Reynolds number flow, by placing delta winglet type vortex generators in CFU (Common flow up) configuration. CFU configuration causes significant separation delay, reduces form drag & eliminates the zone of poor heat transfer from the wake of tubes. This proposed technique has been successfully justified by experiments in the CFU configuration. After the successful experiments on different arrangement inline & staggered it is concluded that in case of staggered tube arrangement the heat transfer was increased by 10% to 30%, with reduction in pressure loss by 34% to 55% for Reynolds number ranging from 350 to 2100, and in case of inline tube arrangement these were found to be 10% to 20% increase & 8% to 15% reduction, respectively.

Leu et al. 2004 [6] preformed numerical & experimental analyses to study the heat transfer and flow in the plate fin and tube heat exchangers with inclined block shape VG placed behind the tubes. The effect of various span angles α ($\alpha = 30^\circ, 45^\circ, 60^\circ$) are investigated for the range of Reynold no 400 to 3000. Numerical simulation was performed by 3D turbulence analysis of heat transfer and fluid flow. Experiments were carried out by infrared thermos vision and water tunnel system. After performing analysis the results shows that the technique which proposed is able to generate longitudinal vortices and improve the heat transfer performance in wake regions. The case of $\alpha = 45^\circ$ gives the best heat transfer augmentation. Both the numerical & experimental results indicate that heat transfer coefficient (*h*) is increased with increase of span angle the h for VG_{60} is only 5-11% are larger than those of VG_{45}, while they are 7-18% & 21-29% larger than VG_{30}, VG_0 respectively.

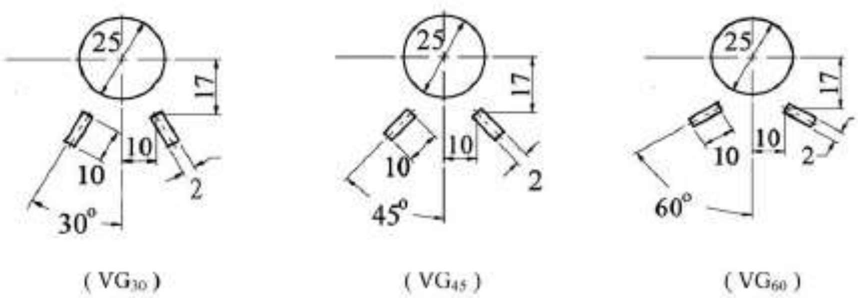

Figure 2 Three different span angels [6]

Pesteei et al. 2004 [7] measured local heat transfer coefficients on fin & tube heat exchanger with winglets using a single heater of 2 inch diameter & five different positions of winglet type vortex generators. The measurements were made at Reynolds number about 2250. With measuring the static pressure drop in the system flow losses were determined. Results showed increase in the heat transfer with winglet type vortex generators. It has been observed that average Nusselt number increases by 46% while the local heat transfer coefficient improves by several times as compared to plain fin tube heat exchanger. The maximum improvement is observed in re-circulation zone. The best winglets location was ΔX = 0.5D and ΔY = 0.5D. The increase in pressure drop for the same situation was of the order of 18%.

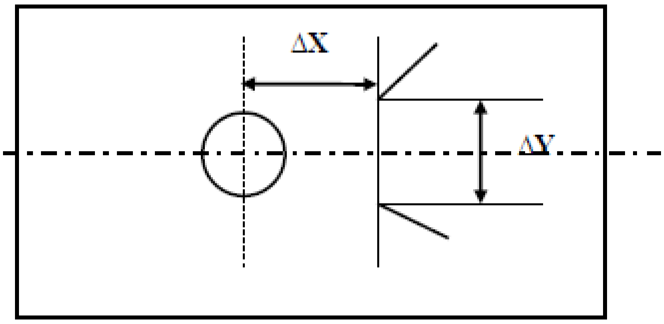

Figure 3 Position of winglet pair [7]

Ferrouillat et al. 2006 [8] focused on vortex generators. The main objective is to determination of turbulent flow inside various geometries by CFD methods. The longitudinal vortices they generate in a channel flow turn the flow perpendicular to the main flow direction and enhance mixing between the fluid close to the fin and that in the middle of the channel. Two types of vortex generators are considered, a delta winglet pair and a rectangular winglet pair. The vortex generator is found to be very efficient in terms of heat transfer enhancement and macro mixing. Their study shows that DWP is more efficient than RWP in terms of compactness criterion. Heat transfer and mixing efficiencies are optimum when distance between VG rows is around 7–10 times the channel heights.

Hiravennavar et al. 2006 [9] investigated the flow structure and heat transfer enhancement by winglet pair of non-zero thickness. The delta winglet pair in laminar flow is considered in study. Delta winglet pair type VG is placed in hydro dynamically developed & thermally developing laminar channel flow. Computations are done by solving unsteady, 3-D incompressible N-S equations using MAC method. After the examination the result it is observed that, as compared to channel without winglets, the heat transfer is enhanced by 33% when single winglet is used & by 67% when winglet pair is introduced. It also notices that thickness of winglets & Reynold no on the heat transfer augmentation are affected.

Wu et al. 2007 [10] presents numerical computation results on laminar convection heat transfer in a rectangular channel with pair of rectangular winglets. The effect of the punched holes and the thickness of the RWP to the fluid flow and heat transfer are numerically studied. After study it is found that the case with punched holes has more heat transfer enhancement in the region near to the VG and lower average flow frictional coefficient compared with the case without punched holes. The thickness of winglet can cause less heat transfer enhancement in the near to VG and almost has no significant effect on total pressure drop of the channel. The average friction factor of the whole channel with holes is slightly lower than without holes.

Joardar et al. 2007 [11] invested the potential of winglet type VG arrays for air side heat transfer enhancement. This is done by experimentally on wind tunnel testing of compact fin & tube heat exchanger. The effectiveness of a 3VG inline array of vortex generators is compared to single row vortex generator arrangement and the baseline configuration. The winglets are placed in CFU orientation. The overall heat transfer & pressure drop result are examined under dry surface conditions over Reynolds number range based on hydraulic diameter of 220 to 960. After experiment it is found that the air side heat transfer coefficient increases from 16.5 to 44% for single row winglet arrangement with increase in pressure drop of less than 12%. For 3VG array, the enhancement in heat transfer coefficient increases from 29.9 to 68.8% with increase of pressure drop 26%. The result conclude that VG arrays can significantly enhance the performance of fin and tube heat exchangers typical to those used in air cooling and refrigeration application.

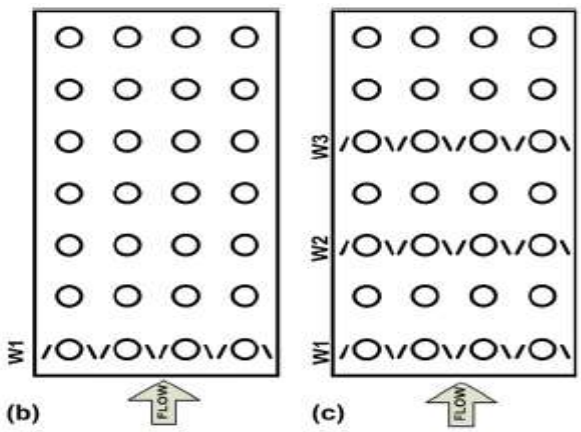

Figure 4 Single & 3 inline array configurations [11]

Joardar et al. 2007 [12] are assessing the potential of winglet type VG arrays for multi row inline tube heat exchangers with providing fundamental understanding of relation between local flow behavior and heat transfer enhancement mechanisms. There are three different winglet configurations in CFU arrangement are tested in the seven row compact fin & tube heat exchanger. First is single-VG pair second is 3VG inline array and third one is 3VG staggered array. The numerical study involves 3-D time-dependent modelling of unsteady laminar at range of Reynold number between 330 to 850. At Re = 850 with a constant tube wall temperature, the 3VG inline array causes enhancement about 105%, 72%, 102%, 30%, 46% for 2^{nd} to 6^{th} tubes respectively. The heat transfer performance for 1 & 7 tube is almost identical for all cases. Interestingly, both 3VG array configurations show heat transfer augmentation of around 32%, but pressure drop increases of 33% & 41% for staggered & inline array respectively.

Chu et al. 2008 [13] investigate heat transfer characteristics & fluid flow structure of fin and oval tube heat exchangers with LVG. For Re ranges between 500 to 2500, after study it was found that the average Nu for the three row fin and tube heat exchanger with LVG is increased by 13.5-33% over baseline case and the corresponding pressure loss is also increased by 29.3-40.8%. Three different geometrical parameters & placement of LVGs upstream and downstream, angle of attack (15°,30°,45°,60°) and tube row number (n=2,3,4 & 5) were also investigated for optimize the parameter value. For fin-and-oval-tube heat exchangers with LVGs, with the increase of the angle of attack α (α < 30), the strength of the longitudinal vortex is intensified and the average Nu number are increased. For angle of attack α > 30, the vortex may break down when the angle of attack α is too large and the average Nu decreases with the increasing α. There exists an optimum angle of attack $\alpha = 30^{o}$ at which the average Nu number can reach the maximum. However, the friction factor *f* always increases with the increasing angle of attack a due to that the larger angle of attack leads to larger form drag and results in more pressure loss penalty. Both the average Nu number and the friction factor f decrease with the increase of the tube row number *n*. The less number of tubes raw (*n*) results in better the heat transfer rate. Thus it is concluding that LVGs with placement of downstream, angles of attack $\alpha = 30^{\circ}$ and minimum tube-row number provide the best heat transfer performance for fin & oval tube heat exchanger.

Tian et al. 2009 [14] performed 3-D simulation on the air side heat transfer & fluid flow characteristics of wavy fin & tube heat exchanger with delta winglets. 3-D simulations are performed with RNG k-ϵ model to lay the foundation for the design of the high-performance heat exchanger. The wavy fin-and-tube heat exchangers which have three-row round tubes in staggered or inline arrangements are studied. The numerical results show that each delta winglet generates a downstream main vortex and a corner vortex. For the in-line array, the longitudinal vortices enhance the heat transfer not only on the fin surface in the tube wake region but also on the tube surface downstream of the delta winglet; for the staggered array, longitudinal vortices are disrupted at the first wavy trough downstream from the delta winglet and only develop a short distance along the main-flow direction, and the vortices mainly enhance the heat transfer of the fin surface in the tube wake region. The longitudinal vortices generated by delta winglet cause considerable augmentation of heat transfer performance for wavy fin-and-tube heat exchanger with modest pressure drop penalty. When Re = 3000, compared with the wavy fin, the j and f factors of the wavy fin with delta winglets in staggered and in-line arrays are increased by 13.1%, 7.0% and 15.4%, 10.5% respectively. For both staggered and in-line arrangements, the longitudinal vortices generated by the delta winglet significantly enhance the heat transfer of the wavy fin-and-tube heat exchanger, and improve the overall performance of the heat exchanger.

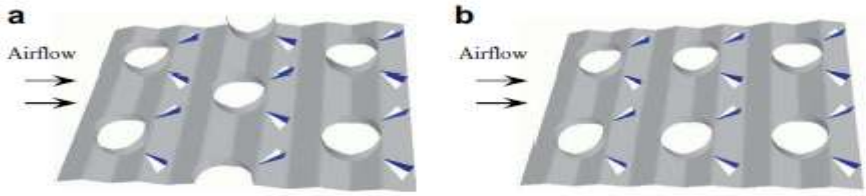

Figure 5 Schematic view of wavy fin with delta winglet [14]

Chu et al. 2009 [15] numerically performed 3-D investigation for heat transfer characteristic and flow structure of full scale fin & tube heat exchangers with RWP. For the Re ranging from 500 to 880, the baseline configuration (without RWP) is compared with three various enhanced configurations (With RWP) inline-1RWP case, inline-3RWP, inline-7RWP case & same configuration for staggered arrangement is also investigated. After analysis it was found that comparing with baseline case, the heat transfer co-efficient from air side improved by 28.1-43.9%, 71.3-87.6, & 98.9-131% for the inline 1RWP, 3RWP, 7RWP case respectively with corresponding pressure drop penalty is also increased. It is also conclude that the staggered arrangement of tube bank provides better heat transfer coefficient for the fin & tube heat exchanger compared with the inline tube arrangement

Sinha et al. 2012 [16] numerically investigated heat transfer enhancement of a plate-fin heat exchanger using two rows of winglet type vortex generators (VG). Five different strategic placements of the VG, namely, common-flow up in series (CFU–CFU), common-flow down in series (CFD–CFD), combined (CFD–CFU), inline rows of winglet (IRW) and staggered rows of winglet (SRW), were considered. Performance parameters in terms of Nusselt number and quality factor were evaluated from the velocity and temperature data obtained from the solutions of full Navier–Stokes and energy equations. The Reynolds number was varied in the range of 250–1580. Heat transfer enhancement in a narrow rectangular duct formed by two neighboring fins using DWP for different arrangement of VG is numerically studied. Results show that amongst the different types of arrangements of the VG, performance of CFU–CFU configuration is best followed by CFD-CFD & CFD-CFU in terms of heat transfer as well as quality factor.

Biswas et al. 2012 [17] Investigated both computational & experimental flow & heat transfer in heat exchanger zones with built in vortex generators. They summarize the current state related to improvement of the heat exchanger surfaces using stream wise longitudinal vortices. First, the improvements related to fin-tube cross-flow heat exchangers and the plate-fin heat exchangers have been addressed. Protrusions in certain forms, such as delta wings or winglet pairs, act as vortex generators, which can enhance the rate of heat transfer from the heat-exchanger surfaces that may be flat or louvered. The winglet type VG, placed inside the channel wall by inducing a swirling motion in the downstream of the winglets. The strategically placed vortex generators create longitudinal vortices, which disrupt the growth of the thermal boundary layer, promote mixing between fluid layers, and hence lead to augmentation in heat transfer. The flow fields are dominated by swirling motion associated with pressure penalty. Heat transfer is augmented substantially for all the proposed configurations of the longitudinal vortex generators, such as delta wings, rectangular winglet pairs, and delta winglet pairs, with varying value of pressure penalty. After the study it was found that the DWP (Delta winglet Pair) & RWP (Rectangular winglet pair) have shown great promise for enhancing heat transfer. The maximum enhancement nearly 41% of the mean Nusselt number in the channel is achieved by the DWP for an angle of attack of 55◦. In the case of the RWP, the angle of attack corresponding to maximum enhancement about 38% of the mean Nusselt number Nu_m is 45◦. For higher angles of attack, β, the Nu_m diminishes slowly for the DWP and quite rapidly for the RWP. However, the average friction factor in the channel increases monotonically with increasing β. For the usual fin tube heat exchangers, use of punched delta winglet pairs is recommended. It is observed that enhancement is always associated with pressure drop penalty.

Gholami et al. 2014 [18] numerically investigate the heat transfer enhancement and pressure loss penalty for fin-tube heat exchanger with wavy-up & wavy-down rectangular winglets. The rectangular winglets were used with particular wavy form for the purpose of enhancement of air side heat transfer performance. The effect of Reynolds numbers from 400 to 800 and the angle of attack 30° of wavy rectangular winglets are also examined. The result showed that the wavy rectangular winglet can significantly improve the heat transfer performance of fin-tube heat exchanger with moderate pressure drop penalty. In addition the numerical result has shown that the wavy winglet cases have significant effect on the performance.

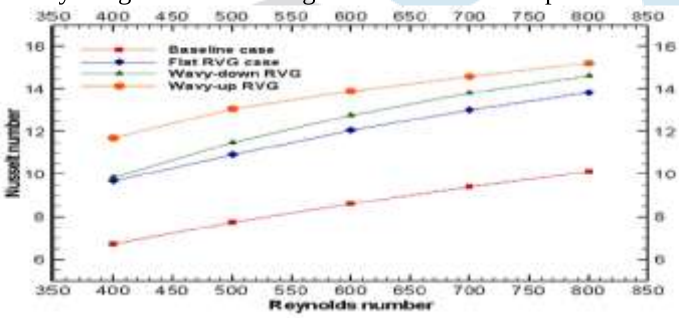

Figure 6 Variations in the air side Nusselt number for baseline and the inline four row tubes bank versus Reynold number [18]

Sinha et al. 2016 [19] Simulates the study of air flow through fin-tube type heat exchangers with rectangular winglet pairs (RWP) of half the channel height as vortex generators (VG). The heat exchanger is approximated as a periodic rectangular channel with heated walls and three rows of built-in tubes placed at an appropriate interval. Two different arrangements of the tubes in the heat exchangers are considered here – one with inline arrangement of three tube rows and the other with staggered arrangement of three tube rows. Further, the angles of attack in each orientation are varied. The heat transfer characteristics of the heat exchangers with vortex generators located near the tubes have been compared among the cases with varied angles of attack and orientations of tubes.. Performance parameters in terms of Nusselt number, vorticity and quality factor (a ratio between the Colburn factor to apparent friction factor, also refer to as area goodness factor with slight modification) were evaluated. For the inline tubes & RWP the performance of the heat exchangers increases with decrease in angle of attack. With pressure penalty & for staggered row of tubes with RWP the performance depends on the configuration as well as Re. This results show significant improvement in the heat transfer performance due to the nozzle-like flow passages created by the winglet pair and the region behind the circular tube which promote accelerating flow. There is an increasing trend of the above for the in-line row of tubes; whereas with the staggered row of tubes, there is slight deviation of this trend. Due to the alternate CFD–CFU orientations of the VG, the performance improves with increase in angle of attack up to a certain point and afterwards it is going down.

Zhang et al. 2016 [20] performed numerical simulation to investigate the effects of longitudinal vortices on the heat transfer enhancement of a laminar flow in a rectangle duct mounted with rectangular winglet pair on the bottom wall. The studied Reynolds number which was defined using the hydraulic diameter twice the channel height ranges from 500 to 7000. The same model without RWP is also carried out for comparison.. The effects of the height and attack angle of vortex generator pair on the heat transfer performance were investigated. The results show that mounting rectangular winglet pair on the bottom wall of the channel can significantly enhance heat transfer. The distributions of secondary flow on the cross sections are consistent with the distributions of Nu and j for different attack angles. The maximum heat transfer performance is obtained when the attack angle is 29° due to the maximum value of secondary flow generated by rectangular winglet pair. Thus, the best heat transfer performance of the studied physical model can be obtained when the attack angle of RWPs is 29°.

Table 1Literature Summary

Year	Author	Title	Method	Type of VG	Conclusion
2002 (Japan)	K. Torri et al	Heat transfer enhancement accompanying pressure drop reduction with winglet type vortex generators for fin & tube heat exchange	Experimental	DWP	Heat transfer is enhanced by 30-10%,& 55-34% for inline & staggered arrangement respectively for Reynold no 350-2100.
2004 (Taiwan)	Leu et al	Heat transfer and fluid flow analysis in plate fin tube heat exchanger with pair of block shape VG	Experimental	RWP	The case of $\alpha = 45^o$ provides best heat transfer augmentation for Reynold no 400 to 3000.
2004 (India)	Pesteei et al	Experimental study of the effect of winglet location on heat transfer enhancement & pressure drop in fin-tube heat exchanger.	Experimental	DWP	The best location of winglets was with $\Delta X = 0.5D$ &$\Delta Y = 0.5D$.
2006 (France)	Ferrouillat et al	Intensification of heat transfer and mixing in multifunction heat exchanger by artificially generated stream wise vorticity	Numerical	RWP & DWP	DWP is more efficient than RWP in terms of compactness criterion.
2006 (India)	Hiravennavar et al	Note on the flow and heat transfer enhancement in channel with built in winglet pair.	Numerical	DWP	The enhancement in heat transfer due to pair of winglets is almost double that due to single winglet.
2007 (China)	Wu et al	Numerical study on laminar convection heat transfer in rectangular channel with LVG.	Numerically	RWP	The average Nusselt no of the whole channel with holes is slightly higher than without holes.
2007 (USA)	Joardar et al	Heat transfer enhancement by winglet type VG arrays in compact plain fin-tube heat exchanger.	Experimental	DWP	VG arrays can significantly enhance performance of fin-tube exchangers typically those used in A.C & refrigeration.
2007 (USA)	Joardar et al	Numerical study of flow and heat transfer enhancement using array of DWP in fin-tube exchanger	Numerical	DWP	Increase in number of arrays it will also increase the heat transfer enhancement.
2008 (China)	Chu et al	3-D numerical study on fin and oval tube heat exchanger with LVG	Numerical	DWP	The LVG with placement of downstream side, angle of attack 30^o and minimum tube

					row number provide best heat transfer performance.
2009 (China)	Tian et al	Comparative study on the air side performance of wavy fin & tube heat exchanger with punched delta winglets in staggered & inline arrangement.	Numerical	DWP	Both staggered & inline arrangement the longitudinal vortices generated by delta winglet significantly enhance the heat transfer of wavy fin tube exchanger
2009 (China)	Chu et al	3D numerical study of flow and heat transfer enhancement using VG in fin-tube exchanger.	Numerical	RWP	The staggered arrangement tube bank provides better heat transfer coefficient for fin and tube heat exchanger compared with inline arrangement.
2012 (India)	Sinha et al	Effects of different orientations of winglet arrays on the performance of plate fin heat exchanger	Numerical	DWP	CFU-CFU configuration gives best performance in terms of heat transfer and quality factor.
2014 (India)	Biswas et al	Augmentation of heat transfer by creation of stream wise LV using VG	Numerical Experimental	DWP	The DWP & RWP have shown great promise for enhancing heat transfer.
2014 (Malaysia)	Gholami et al	Heat transfer enhancement and pressure drop for fin-tube compact heat exchangers with wavy rectangular winglet type VG	Numerical	Wavy RWP	Wavy winglet cases have significant effect on the heat transfer performance.
2016 (India)	Sinha et al	Enhancement of heat transfer in fin-tube heat exchanger using RWP VG	Numerical	RWP	The performance of heat transfer is improves with increase in angle of attack up to certain point and afterwards it is going down.
2016 (China)	Zhang et al	Numerical study of heat transfer enhancement by RWP VG pair in channel	Numerical	RWP	The maximum heat transfer performance is obtained when angle of attack is 29^o due to maximum value of secondary.

IV. Conclusion

From the above review it can be concluded that numerous experimental and numerical studies had been performed to establish the use of longitudinal vortex generator in heat transfer enhancement. However, very little research has been carried out to evaluate the performance of the delta vortex generators mounted on the fins, in a fin-tube heat exchanger. It is conclude that when winglet pair is used it increase heat transfer enhancement almost double than single winglet. VG arrays can significantly enhance the performance of fin and tube heat exchangers typical to those used in air cooling and refrigeration application. The winglet pairs are most effective to enhance heat transfer coefficient when these are placed in downstream side of tube.CFU-CFU configuration is best heat transfer enhancement among the CFD-CFD, CFD-CFU, IRW, and SRW. The RWP (Rectangular winglet pair) Vortex generator with attack angle of 45° provides better effectiveness of heat transfer enhancement when the range of hydraulic Reynold number is 500.

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