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Research Paper

Effect of winglet location on heat transfer of a fin-and-tube heat exchanger

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HIGHLIGHTS

- A fin-and-tube heat exchanger using winglets has been proposed.
- Effects of winglets configuration on thermo-fluid performance have been presented.
- Winglets present at the central tube shows the highest heat transfer performance.
- The attack angle of the winglets plays crucial role in increasing the heat transfer.
- Optimum stream wise and span wise distance of winglets is presented.

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ABSTRACT

Heat transfer enhancement and pressure loss of a fin-and-tube heat exchanger with rectangular winglet pairs has been numerically investigated by solving the conservation equations of mass, momentum and energy. The flow is assumed to be laminar at different Reynolds numbers. The winglets are placed in common flow up configuration which increases the heat transfer in the wake region of the tube. It was found from the numerical investigation the rate of heat transfer is increasing with number of winglets. It was also found that the placement of winglets near the central tube is more effective in transferring heat compared to entrance and exit of the heat exchanger. Keeping other parameters fixed it was found from the numerical experiment that the heat transfer performance was increasing significantly with the attack angle (β) of winglets. There also exists an optimum stream wise distance (ΔX) for placement of winglets for which the heat transfer is found to be highest. An optimum value of span wise distance (ΔY) could be decided where the heat transfer to the fluid was found to be maximum.

1. Introduction

Fin-and-tube heat exchangers are used in various applications such as refrigeration and air-conditioning, heating, ventilation, petroleum distillates industries and in cooling of electronic equipments. Compact fin-and-tube heat exchangers are in great demand due to their less space occupancy and low weight. Due to the thermo-physical properties of air the heat transfer coefficient on the air side is low and hence its contribution to the overall thermal resistance is very high. Therefore improving the effectiveness of these heat exchangers can be achieved by focusing on the air side surfaces and reducing the air side thermal resistance. Placement of winglets in the flow channel is one of the techniques of heat transfer augmentation by accelerating the flow over the tube surface and causing the flow destabilization. These winglets are placed near the tube and they serve to increase the heat transfer in the tube wake region. Winglets can be stamped, mounted or punched on the heat transfer surface.

The concept of heat transfer augmentation using longitudinal vortex generators is not new and a lot of investigations have been performed to investigate the heat transfer and fluid flow characteristics for heat exchangers with winglets. Edward and Alker [1] examined experimentally the influence of longitudinal vortices on heat transfer performance. They concluded that the delta winglets gives greater heat transfer augmentation compared to cubes placed on a flat plate. Patankar and Prakash [2] numerically analyzed the effect of thickness of the plate on flow field and heat transfer performance. They observed the flow field to be complex confined with recirculation zones behind the trailing edges of the plates with considerable deflection of the thorough flow. Russel

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Nomenclature

A	cross sectional area (m^2)
A_T	total heat transfer surface area (m^2)
A_{min}	minimum free flow area (m^2)
B	span length (m)
C	specific heat of Aluminum (J/kg K)
C_P	specific heat of air (J/kg K)
D_h	hydraulic diameter (m)
f	friction factor
h	heat transfer coefficient (W/m^2 K)
H	fin spacing (m)
k_a	thermal conductivity of air (W/m K)
k_{al}	thermal conductivity of aluminum (W/m K)
L	flow length (m)
$\dot{m}$	mass flow rate (kg/s)
n	number of winglet pair
Nu	Nusselt number
p	pressure (Pa)
p_a	atmospheric pressure (Pa)
ΔP	pressure drop (Pa)
$\bar{p}$	total average pressure (pa)
Q	heat transfer capacity (W)
Re	Reynolds number
T	temperature (K)
T_{in}	temperature at inlet (K)
T_O	outlet temperature (K)
T_w	tube wall temperature (K)
ΔT	log mean temperature difference (K)
$\bar{T}$	total average temperature (K)
t	time (s)
u_{in}	inlet velocity (m/s)
u_i, u_k	velocity component in i and k direction
u	velocity in x-direction
v	velocity in y-direction
w	velocity in z-direction
x_i, x_k	space variables in i and k direction
ΔX	stream wise centre to centre distance
ΔY	span wise centre to centre distance

Greek symbols

α	thermal diffusivity (m^2/s)
β	attack angle (degree)
μ	dynamic viscosity (pa s)
ρ	density of air (kg/m^3)

Subscript

a	air
Al	aluminum
in	inlet parameter
o	outlet parameter
Up	top surface of the domain
down	bottom surface of the domain
w	wall

et al. [3] presented experimental comparison of inline and staggered arrangement of winglets and found that rectangular winglets are more effective compared to delta winglets in two staggered rows arrangement.

Fiebig et al. [4] experimentally compared various types of winglets such as delta wing, rectangular wing, delta winglet pair and rectangular winglet pair for a laminar flow and concluded that delta winglet is found to be more efficient from heat transfer point of view. Fiebig et al. [5] experimentally found that the second delta winglet pair serves as a booster for the coming longitudinal vortices in a two row inline arrangement of delta winglet pairs. Torri et al. [6] and Zhu et al. [7] experimentally and numerically investigated the implanted vortices in internal flow of a channel and found that longitudinal vortices gives better heat transfer augmentation as compared to transverse vortices. Biswas et al. [8] experimentally and numerically analyzed the influence of longitudinal vortices on the flow structure and heat transfer performance. They observed that the flow structure is complex, consisting of a main vortex, an induced vortex and a corner vortex. Distortion of the temperature field takes place due to the resultant effect of all these vortices which results in heat transfer augmentation. Torii et al. [9] experimentally investigated the heat transfer and pressure loss for inline and staggered tube arrangements for low Reynolds number flow (350–2100). They found that in staggered tube arrangement the increase in heat transfer by 30–40% whereas the pressure loss is reduced by 40–50% compared to inline arrangement. Pesteei [10] experimentally investigated the effect of winglet location on heat transfer performance and pressure loss and concluded that the winglets are more effective when they are placed in the downstream side of the flow. Hiravennavar et al. [11] numerically examined the winglet effects on the heat transfer performance and flow field. They have found that in comparison to no winglet case the heat transfer increases by 33% by using a single winglet and 67% by using a winglet pair. It was found that with increase in thickness of the winglet the cross sectional area of heat transfer from the bottom plate increases and results in higher heat transfer performance.

Joardar and Jacobi [12] experimentally investigated the heat transfer and pressure drop performance by mounting the delta winglet pairs in common flow-up configuration on the plain fins. For Reynolds numbers variation range of 220–960, they found that the air side heat transfer coefficient was increased to 44% for single row vortex generator pair and 69% for three row vortex generator pairs. Chu et al. [13] numerically investigated a fin-and-oval-tube heat exchanger with delta winglets vortex generators at different Reynolds numbers. They reported that by providing longitudinal vortex generators the average Nusselt number was increased by 13.6–32.9% compared to base line case without vertex generator and the corresponding pressure drop was increased by 29.2–40.6% respectively. Jeong et al. [14] studied numerically the air flow and heat transfer in a fin-tube heat exchanger using the CFD to investigate the effects of the delta winglet vortex generator on fin performance. They found the pressure loss of a fin with delta winglet vortex generators to be lesser than that of a plain fin. The heat transfer performance was found to be improved at higher Reynolds number value.

He et al. [15] numerically investigated heat transfer and pressure drop for a fin-and-tube heat exchangers with rectangular winglets. They found that pressure loss of the heat exchanger could be reduced by changing placement of the winglets from inline array to staggered array. Russi and Dhingra [16] numerically investigated the thermal performance of curved and rectangular winglet pairs at low and high Reynolds number. They found that curved winglet type vortex generators gave better heat transfer enhancement than plain winglet type in both laminar as well as turbulent flow regions. They have also observed that the thermal enrichment