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Numerical investigation of heat transfer enhancement in a fin and tube heat exchanger using vortex generators

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ABSTRACT

In presented work, numerical analysis of heat transfer and pressure drop using vortex generators in fin and flat tube heat exchanger has been presented. Conjugate heat transfer 3D numerical model has been developed and successfully carried out. Rectangular winglets were set in pairs, with downstream orientation. The effects of impact angles of 5°, 10° and 20° as well as winglet height were examined through Nu number and *j*/*f* factor. Reynolds number is ranged from 350 to 2200. The numerical results showed that in the range of the present study, the variation of these parameters can result in the increase of heat transfer but with a penalty of pressure drop. Pressure drop increases for larger impact angles and with winglet height. Optimum heat transfer without significant pressure drop increase gives the vortex generator geometry of 0.64 × 1.92 mm (i.e. winglet height equals 2/3 fin spacing) with impact angle 10°.

1. Introduction

Fin and tube heat exchangers are widely used in industrial, commercial and residential HVAC systems. During recent years serious attempts have been made to apply different methods for heat transfer enhancements on this type of heat exchangers. The total thermal resistance of fin and tube heat exchanger is comprised of: air side thermal resistance, wall conductive thermal resistance and the liquid side thermal resistance. Air side thermal resistance is critical part of heat transfer process due the thermo physical properties of the air, so the research and improvements of heat exchangers are mainly focused on air side surfaces. Usage of finned surfaces on the air side is a very common way to improve thermal performance of heat exchangers. Application of rectangular winglet vortex generator over a plain fin is a common type of heat transfer improvement. During the past years a lot of research has been done on fins with vortex generators.

Rectangular winglet vortex generator application on fin and circular tube heat exchanger investigated through experimental analysis [1,2] showed substantial increase in the heat transfer. Average heat transfer could be improved up to 46% while pressure drop increase penalty is up to 18%. Additionally, heat transfer performance of longitudinal vortex generator in pair is better than longitudinal vortex generator on one side.

Leu et al. [3] carried out numerical study on 3D model with conjugate heat transfer, approved by experimental analysis of fin and circular tube heat exchanger with rectangular vortex generators placed downstream. Parametrical investigation of winglet geometry resulted with angle of 45° as the best heat transfer enhancement. Chu et al. [4] performed similar study, but instead of circular tubes, oval tubes were used with downstream placement of rectangular vortex generators. Their research resulted with optimal angle of 30°.

He et al. [5–7] investigated numerically through 3D model heat transfer enhancement and pressure loss penalty for fin and circular tube heat exchangers with rectangular winglet pairs. Their research included analysis of winglet pairs, row numbers and winglet placement. They concluded that heat transfer can be improved with moderate pressure loss, which additionally can be reduced by altering the placement of winglet from inline array to staggered array.

Recent research of fin and tube heat exchangers with rectangular vortex generators mostly focused on heat exchangers with circular tubes. Only several papers investigated this type of vortex generators on heat exchanger with flat tubes.

Fin and tube heat exchangers with flat tubes are frequently used as the radiators of vehicles for the significant advantages as high efficiency, small volume and smaller hydrodynamic diameter of flat tubes in comparison with circular tube with the same cross section area. In contrast to circular tubes, the flat tubes yield a lower pressure drop for flow normal to the tubes, due to lower form drag, and thus avoid the low-performance wake region

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Nomenclature

a	flat tube width, mm
b	flat tube length, mm
c	winglet width, mm
d	winglet height, mm
d_e	equivalent diameter, mm
f	friction factor
h	heat transfer coefficient, W m^{-2} K^{-1}
L_z	stream-wise length of the fin, mm
Nu	Nusselt number
$S_{1,}$	transversal pitch between the tubes, mm
S_2	longitudinal distance between the tubes, mm
St	Stanton number
q	heat flux, W m^{-2}
Re	Reynolds number
w	velocity, m s^{-1}
T	temperature, K
T_p	fin spacing, mm

Greek symbols

α	winglet attack angle, °
δ_w	tube wall thickness, mm
δ_{rw}	winglet wall thickness, mm
δ_f	fin thickness, mm
λ	thermal conductivity, W m^{-1} K^{-1}
ρ	density, kg m^{-3}

Subscripts

a	air
f	fin
in	inlet
out	outlet
ref	reference state
rw	winglet
tw	tube wall
vg	vortex generator
w	water

behind the tubes. In addition, the heat transfer coefficient is higher for flow inside flat tubes than for circular tubes, particularly at low Re [8].

Fiebig et al. [9] experimentally measured local heat transfer and flow losses in fin and tube heat exchangers with rectangular vortex generators comparing circular tube and flat tube. Their research concluded that heat transfer is marginally increased for circular tubes, but the heat transfer is significantly improved for flat tubes, by almost 100% in comparison with the case without vortex generators. Heat exchanger with flat tubes and vortex generators gives nearly twice as much heat transfer and only half as much pressure loss as the corresponding heat exchanger with round tubes.

With computer power increasing and numerical method development, numerical methods are widely used to develop the optimal fin pattern. There are two ways to treat boundary conditions. The first one, which is easier to apply, is to treat the tube and fin surface with uniform temperature, neglecting wall conductive thermal resistance and the liquid side thermal resistance. The second one is to use conjugate numerical model which needs more numerical effort. Wang et al. [10] developed three dimensional model of flat tube bank plain fin heat exchanger with conjugate heat transfer between water, tube, fin and air. Their research pointed out that under most conditions the non-conjugate heat transfer model can obtain good results but the limitation factor is the fin efficiency.

Most of available numerical research of heat exchangers with rectangular winglets dealt with nonconjugate models, either 2D or 3D, with uniform fin and vortex generator temperature which neglects liquid side thermal resistance by assuming constant fin and winglet temperature. In case of 3D conjugate models, liquid side thermal resistance was neglected assuming constant temperature of internal tube surface.

Promoted by facts stated above and based on available research and results, this paper investigates impact of rectangular vortex generator on heat transfer and pressure drop characteristics of heat exchanger with fin and flat tubes through numerical 3D conjugate model with both, liquid and air side heat transfer and flow modeling. Tubes are placed in staggered array. In presented paper parametrical investigation of winglet geometry has been carried out to find out optimal angle as well as winglet heights combination.

2. Physical model and formulation

To enhance heat transfer on air side physical model of fin and tube heat exchanger with rectangular winglet vortex generators presented in Fig. 1 has been considered. This type of heat exchanger typically consists of a large number of parallel tubes and numerous plain fins. In this study tubes are flat and located in a staggered arrangement. Water flows through the tubes and air flows around the tubes through the channels formed by the tubes and the fins.

Due to the symmetric and periodic arrangement, the computational domain is chosen as shown on Figs. 2 and 3. Six pairs of longitudinal winglets have been applied to plain fin. Main geometric parameters of heat exchanger are as follows: T_p = 1.92 mm, L_z = 66 mm, a = 2.5 mm, b = 18.5 mm, δ_w = 0.35 mm, δ_f = 0.08 mm, S_1 = 16 mm, S_2 = 22 mm, c = 1.92 mm, d = 0.64 mm, δ_w = 0.1 mm.

In order to analyze the influence of winglet attack angle as well as winglet geometry, two winglet heights (0.96 mm i.e. winglet height equals full win spacing, 0.64 mm i.e. winglet height equals 2/3 fin spacing) as well as the attack angles of 5°, 10° and 20° have been considered.

Computational domain of improved model presented in Fig. 3 consists of three subdomains: air, water and fin with winglets.

The upstream region which length is 0.5 times from actual air channel length has been added to ensure inlet uniformity. The

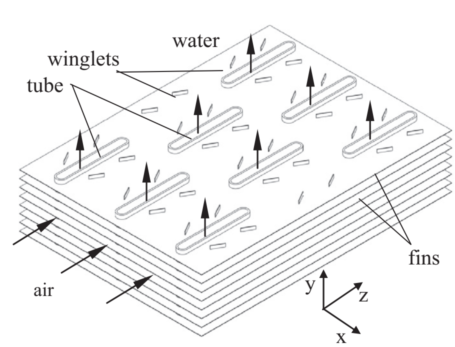

Fig. 1. Physical model of heat exchanger.