The analysis of heat transfer and pressure loss for the air flow through heated cylinders with concave delta winglet vortex generators in rectangular channel: an experimental study

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Abstract. The use of vortex generators to increase heat transfer in the evaporator fin-and-tube heat exchanger. Therefore the purpose of this study is to determine the effect of the use of vortex generators on increasing heat transfer coefficient and flow loss at heated tubes in rectangular channel. The experimental method is to compare the use of vortex generators and without (baseline). Vortex generators include 1, 2, 3 rows of pairs of concave delta winglet vortex generators (CDWP) and delta winglet vortex generators (DWP). Both of types of vortex generators at angle of attack ($\beta$) 15°, inlet velocity variation from 0.4 m/s - 2.0 m/s. Vortex generators were mounted on aluminum plate, heated tube with 35 watts and temperature 38°C. Inlet, outlet and tube temperatures are measured using a thermocouple. The experimental result show that with the use of vortex generators the values of convection heat transfer coefficients and flow loss increased compared to those without vortex generators. The highest heat transfer coefficient on reynold number range 11000-12000 when using 3 pairs of concave delta winglet vortex generators are 46.76%, and 52% value pressure loss at inlet velocity 2 m/s on 3 pairs of concave delta winglet vortex generators, compared to baseline (without vortex generators).

1. Introduction

Fin and tube heat exchangers are widely used in the chemical industry, power plants, automotive industry, refrigeration and air conditioning. Fin and tube heat exchanger performance needs to be done to obtain competitive heat exchanger products on the market. This performance can be increased by increasing the value of the convection heat transfer coefficient. One way is to generate longitudinal vortex using a vortex generators [1, 2].

Wu and Tao [3] was study experimentally and numerically about the longitudinal effect of delta winglet vortex generators on convection heat transfer in a rectangular channel with different variations of attack angles 15°, 30°, 45°, 60°. The average convection heat transfer with the use of delta winglet vortex generators increases with increasing reynold number and attack angle.

He et al. [4] was examine the increase in heat transfer and decrease the penalty pressure for fin and tube heat exchangers with rectangular winglet pairs (RWPs) investigated numerically with a relatively low reynold number. RWP attack angle effect, RWP line number and RWP placement on heat transfer characteristics and flow structure are examined in detail. It was observed that longitudinal vortices caused by RWPs and RWP directed flow impingement on downstream tubes were important reasons for
increasing heat transfer for tube heat and exchangers with RWP. It is interesting to find that loss of penalty pressure from the tube heat and exchanger with RWP can be reduced by changing the placement of the same RWP number from the inline array to the staggering array without reducing heat transfer increases. The results show that rectangular winglet pairs (RWP) can significantly improve the heat transfer performance of the tube heat exchanger and by losing penalty pressure. Zhou and Feng [5] was examine the performance of the plane and curved winglet (rectangular trapezoidal and delta) vortex generators (VGs) with and without experimentally punched holes. The effect of hole diameter and position on performance for VGs has been studied using dimensionless numbers. The results showed a curved winglet type (CRWP, CTWP and CDWP) improved heat transfer and lower flow resistance compared to winglet VGs in both laminar and turbulent flow regions. CDWP has the best thermohydraulic performance followed by the CTWP which covers all flow areas. VG performance and reduce flow resistance for all cases. The smaller the area of VG, the smaller the relative diameter of the hole is better. The results show the advantages of using VG winglets curved with punched holes on the surface for increased heat transfer.

Tian et al. [6] was studied three-dimensional numerical simulations of flow and heat transfer characteristics for plain fins with many lines of delta winglet punched. Overall analysis of thermal performance was carried out for all fin configurations, including fins and wavy fins with one-line delta winglets, plain fins with delta winglets bent toward the wind showing better performance with delta winglets [3].

Arora et al.[7] was stated that the heat transfer from fin and tube type heat exchangers by the type of vortex generators is highly dependent on the location of the tube center winglet, they examined optimizing the location of the "common flow up" delta winglet for maximum thermal compactness of a line of fin and tube heat exchangers.

Syafiful et al. [8] was examine the effect of concave rectangular winglet vortex generators on convection heat transfer coefficients. The types of vortex generators used are two types of rectangular winglets and concave rectangular winglets. The influence of geometry and the number of vortex generators can increase the heat transfer coefficient. Type Concave rectangular vortex generator 3 lines has the highest increase in heat transfer coefficient compared to rectangular vortex generator and baseline (without vortex generator) [9]

Hosseini et al. was explained the difference between Sinusoidal (Sin) vortex generators, Wave and Broken obstacle rectangular and triangular mounting bars on cooling for hot bars in heat transfers carried out experimentally and numerically.

Wu et al. [10] was examined the effect of fin pitch and tube diameter on the performance of air side heat transfer from a tube of heat exchanger banks using winglet vortex generator (CDVVGs) curves investigated experimentally.

Song et al. [11] stated the vortex generator has received wide attention and is widely applied for increased heat transfer. To further improve the heat transfer performance of compact heat exchangers, winglet vortex generator curve with different geometric sizes was studied experimentally for fin-and-tube heat exchanger.

Naik and Tiwari [12] was studying the heat transfer performance for fin-tube heat exchangers can be increased by increasing the longitudinal vortex using vortex generators (VGs). They examined numerical three-dimensional effects of winglet locations on the heat-transfer characteristics of fin-tube heat exchangers for inline tube installation. The types of vortex generators used are rectangular vortex generators (RWP).

Chosed angle of attach 15° because formance of the winglet is best [13]. The Novelty of this research is the use of delta winglet and concave delta winglet vortex generators with inline installation on heated tube in rectangular channels.

2. Materials and Experimental Method
This study uses an experimental method, testing is carried out in an air duct made of glass with a thickness of 10 mm, 500 mm long, 64 mm wide, and 165 mm high. This air channel has a rectangular
cross section equipped with a fan, hot wire anemometer, pitot tube, micromanometer, heater, compressor, laser, capillary pipe, motor regulator. The area in the test is divided into four parts, namely: inlet, straightener, test section, and outlet. The scheme of the testing tool is shown in figure 1.

Figure 1. Testing tool scheme

In this test, the specimens used were concave delta winglet vortex generators (CDWP VGs) and delta winglet vortex generators (DWP VGs) with 6 heated tubes average 35 watts and temperature 38°C. Test objects can be seen in Figure 2a, b, c.

Figure 2. Delta winglet and concave delta winglet test equipment (units in mm)
Variations in this study are baseline, delta winglet vortex generators, and concave winglet vortex generators delta inline 1, 2, and 3 pairs of lines, as shown in Figure 3 and Figure 4 below.

![Figure 3. Delta winglet vortex generators 1, 2 and 3 pairs](image)

![Figure 3. Concave delta winglet vortex generators 1, 2 and 3 pairs](image)

Convective heat transfer coefficient \( h \) calculated

\[
Q = \dot{m}C_p(T_{out} - T_{in})
\]

\[
\dot{m} = \rho A_c U
\]

\[
\Delta T_{lm} = \frac{\Delta T_{out} - \Delta T_{in}}{\ln \left( \frac{\Delta T_{out}}{\Delta T_{in}} \right)}
\]

\[
\Delta T_{out} - \Delta T_{in} = (T_{tube} - T_{out}) - (T_{tube} - T_{in})
\]

where, \( Q \) heat transfer rate (W), \( \dot{m} \) mass flow rate (kgs\(^{-1}\)), \( A_c \) area of air channel (m\(^2\)), \( A \) area tube (m\(^2\)), \( a \) wide (m), \( b \) high (m).

The flow Reynolds number (Re) is defined as:

\[
Re = \frac{bUD}{\mu}
\]

where \( \rho \) density (kg m\(^{-3}\)), \( U \) velocity (ms\(^{-1}\)), \( D \) hydraulic diameter of the air channel (m), and \( \mu \) dynamic viscosity (Pa s). Hydraulic diameter of the air channel is given as:

\[
D_h = \frac{4(ab)}{2(a+b)}
\]

Pressure drop is given as:

\[
\Delta P = \frac{f \rho U^2 L}{2D}
\]

Where \( Re \) Reynold number, \( C_p \) specific heat (Jkg\(^{-1}\) °C\(^{-1}\)), \( L \) length of tested channel along air flow direction (m), \( T \) temperature (°C), \( \Delta T_{lm} \) logarithmic mean temperature difference, \( f \) friction factor, and \( \Delta P \) pressure drop (Pa).

3. Discussion

This experiment was conducted to determine the effect of using delta winglet and concave delta winglet vortex generator against heat transfer coefficient, pressure loss, and flow visualization. This flow visualization includes plates without vortex generator (baseline), delta winglet, and concave delta winglet vortex generator.
Flow visualization

Figure 4. Air flow pattern passing the delta winglet concave and concave delta winglet vortex generators

Figure 5. Comparison of convective heat transfer coefficient between baseline, DWP and CDWP for variation of number of vortex generators and reynold number

Figure 6. Comparison of pressure drop among baseline, DWP, and CDWP for variation of number of vortex generators and inlet velocity

Figure 4 shows the pattern of air flow through delta winglet vortex generators and concave delta winglet vortex generators causing the emergence of longitudinal vortex in flow through vortex generators. Longitudinal vortex formed from concave delta winglet has a greater radius than delta, because the flow passes concave so the longitudinal vortex radius is greater.

Figure 5 shows the difference in convection heat transfer coefficient of delta winglet and concave delta winglet at angle of attack 15°. The convection heat transfer coefficient increases with increasing reynold number. At the Reynold number between 11000-12000, the increase in convection heat transfer coefficient in the delta winglet vortex generator geometry in variations 1, 2, 3 rows of pairs compare the baseline is 10.64%, 24.61%, and 38.82%. Concave delta winglet vortex generators at reynold number range 11000-12000 increases respectively 25.63%, 35.81% and 46.76% compare without vortex generator (baseline).

Figure 6 shows the difference in delta winglet and concave delta winglet delta geometry at the angle of attack 15°. At a flow rate of 2 m/s the increase in pressure drop in the delta winglet vortex generator geometry with angle of attack 15° in variations 1, 2, 3 rows of pairs of vortex generators compare baseline are 8.75%, 12.5% and 20% respectively. While the concave geometry of delta winglet vortex generators with variations of 1, 2, 3 rows of pairs of vortex generators at a speed of 2 m / s increase in pressure drop were 21.7%, 37.5%, and 52% respectively for geometry compare without vortex generator (baseline).
4. Conclusion
From the results of visualization the longitudinal flow of vortex is formed when using vortex generators. Longitudinal vortex generators produced Concave delta winglet vortex generators are greater than winglet vortex generators delta. When using delta winglet vortex generators and concave delta winglet the heat transfer coefficient and pressure loss values are greater than baselines (without vortex generators). The best heat transfer coefficient and pressure loss when using concave delta winglet vortex generators compared to winglet and baseline delta. The highest heat transfer coefficient on reynold number range 11000-12000 when using 3 pairs of concave delta winglet vortex generators are 46.76%, and 52% value pressure loss at inlet velocity 2 m/s on 3 pairs of concave delta winglet vortex generators, compared to baseline (without vortex generators).

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