International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Thermal-Hydraulic Performance of Elliptic Shape Staggered Tube Cross Flow Heat Exchanger at 45° Angle of Attack

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Accepted 15 June 2016, Available online 20 June 2016, **Special Issue-5 (June 2016)**

Abstract

Experimental investigation is carried out to study thermal-hydraulic performance of elliptic shape tube cross flow heat exchanger with staggered tube arrangement at 45°angle of attack. The staggered tube arrangement is having longitudinal and transverse pitch equal. Hot water passed through the tubes at 45° angle of attack and cold atmospheric air flows over the tubes in a cross arrangement. Heat transfer takes place from hot water to cold atmospheric air by the mode of convection. Effect of different mass flow rate of air on convective heat transfer coefficient, Reynolds number, Prandtl number and heat transfer would be calculated. Effect of using elliptic shape staggered tube arrangement at 45° angle of attack would be compared with Zukauskas correlation for circular staggered tube bank arrangement.

Keywords: *Elliptic shape tube, Angle of attack, staggered tube arrangement, friction factor, convective heat transfer coefficient.*

1. Introduction

Heat exchangers are found in different industrial sectors where heat has to be transferred between different media. Circular tubes are generally used in the construction of heat exchanger because of the manufacturing easiness. The problem with the circular tubes is that causes separation, wakes and produces high pressure drop. A non-circular tubes offer very low hydraulic resistance and require less pumping power. In recent years non circular tubes flat, oval, elliptical, cam shaped tubes are considered as heat transfer element in cross flow heat exchangers.

Heat exchangers have wide range of application such as in the chemical process, thermal power, air conditioning, refrigeration, cryogenic, heat recovery and automobile industries. The applications of heat exchanger increases rapidly, it leads to increase demand of higher thermal performance and economical heat exchanger. Increase in thermal performance leads to increase in size, energy, material, and cost of heat exchangers.

2. Literature review

A. Nouri-Borujerdi. carried out experimental study of forced convection heat transfer from a cam shaped tube in cross flow. In this work heat transfer characteristics and pressure distribution was investigated. The angle of attack is varied in the range of 0< α <180 the Reynolds number $1.5\times10^4 < Re_{eq} < 2.7\times10^4$. The result show that the heat transfer from a cam shaped tube is maximum at α = 90° and minimum at α = 30°. Also cam shape tube give larger value of St/Cd except at α = 90° and 120° relative to the circular tube.

Mesbah G. Khan, carried out the experiment for characterization of cross-flow cooling of air via an in-line elliptical tube array. For experimental analysis, range of Reynolds number for air side is $1\times10^4 < Re_a < 3.3\times10^4$ and for water side $1\times10^3 < Re_a < 3.7\times10^3$ is considered. Result shows that Nusselt number and hence the heat transfer rate increases with increase in Reynolds number in a power law fashion. Nu-Re correlation is found as $Nu_a = 0.26Re_a^{0.66}$.

Sayed Ahmed E study the cross flow air-cooling process via water-cooled wing-shaped tubes in staggered arrangement at different angles of attack. In this study both experimental and CFD analysis is carried out for different angle of attack. For water Re_w=500 and for air Re_a=1800 to 9700. Results were obtained that Wing shape tube bundle in heat exchanger gives best result for heat transfer coefficient, effectiveness, efficiency at zero angle of attack and as the value of Re_a increases, Nu_a increases whereas St_a decreases. The highest value and lowest value of Nu_a and St_a occurred at α= 45°, 135°, 225°, 315°and at α= 0°, 180° respectively. From experimental results they develop new correlation for Nu_a and St_a numbers in

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terms of Re_a , Pr and angle of attack and compare with previous work which shows that Nu_a increased by 24% compare to circular tube whereas by 76% compare to elliptic tube at zero angle of attack.

S. Toolthaisong et al. investigates the air side heat transfer and pressure drop characteristics of cross flow heat exchangers. The cross flow heat exchanger is with flat tubes with staggered tube bank arrangement. The effect of attack angle on heat transfer and pressure drop characteristics of cross flow heat exchanger with different aspect ratios have been investigated experimentally. In the experiment six attack angles (0, 30, 60, 90, and 150) with four aspect ratios (0.18, 0.39, 0.66, and 1) used. The hot water temperature of 75 ˚C and air flow velocity 2 to 6 m/s are used. By increasing the attack angle (0˚ to 90˚) the heat transfer rate and pressure drop increased, but thermal-hydraulic performance was decreased. The results show that the thermal and pressure drop characteristics governed by the attack angle and tube aspect ratio.

Literature reviews show that by changing shape of tube heat transfer rate increases. The objective of this project is to study the thermal-hydraulic performance of elliptic shape tube in cross flow heat exchanger.

Nomenclature

Alphabet
A_s Surface area, m²
D Hydraulic diameter, m
h convective heat transfer coefficient, W/m²K
LMTD Logarithmic Mean Temperature Difference, in °C
Q Heat transfer rate, W
P_L Longitudinal pitch, mm
P_T Transverse pitch, mm
U Overall heat transfer coefficient, W/m²K

Greek Letters
α angle of attack
ρ density
Δ difference
θ temperature difference

Dimensionless number
C_d Pressure drag coefficient
f Friction factor,
N Number of row or column
Nu Nusselt number
Pr Prandtl number
Re Reynolds number
S_T Stanton number

Subscripts
a Air
c column
i Inlet
o Outlet
r row

3. Experimental setup and procedure

Experimental setup is shown in Fig.1. The cross flow heat exchanger is having size 150 × 165 × 1000 mm³. Stainless steel material is used to manufacture heat exchanger. Surrounding air is flowing over the tubes with the help of centrifugal blower. Hot water is flowing inside the tubes. To measure air and water temperature PT100 sensors are used. Pressure drop is measured across the cross flow heat exchanger with the help of U-tube manometer.

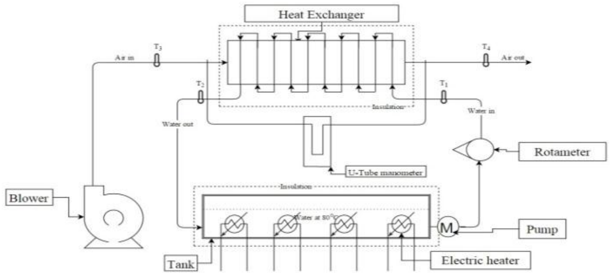

Figure 1 Schematic diagram of the experimental setup

4. Data interpretation

A heat balance applied to the cross flow heat exchanger,

$$Q = Q_{overall} = Q_{Convection} + Q_{Conduction} + Q_{Radiation} \quad (1)$$

Heat transfer takes place from hot water inside the tube to air flowing over the tube. As the thickness of tube is minimum value of $Q_{Conduction}$ is very small hence heat transfer occur due to conduction is neglected. The radiation heat transfer between tube wall and surrounding test section is also neglected. Hence,

$$Q = Q_{convection} = U \times A_s \times LMTD \quad (2)$$

Where, U is overall heat transfer coefficient, A_s is surface area, D is diameter, given as follows:

$$\frac{1}{U} = \frac{1}{h_{air}} + \frac{1}{h_{water}} \quad (3)$$

$$A_s = \pi \times D \times l \times N_c \times N_r \quad (4)$$

L, N_c and N_r are length of tube, number of column and number of rows respectively.

LMTD is the logarithmic mean temperature difference, calculated as follows:

$$LMTD = \frac{\Delta\theta_1 - \Delta\theta_2}{\ln(\Delta\theta_1/\Delta\theta_2)} \quad (5)$$
$$\Delta\theta_1 = T_2 - T_3 \; , \; \Delta\theta_2 = T_1 - T_4$$

Where, T_1, T_2 are water and T_3, T_4 are air, inlet and outlet temperature respectively. The Reynolds number is calculated using following formula for both air side and water side:

$$Re = \frac{\rho \times V \times D}{\mu} \quad (6)$$

To calculate Nusselt number for air side, Zukauskas equation is used for flow over the staggered arrangement of tube bank, given as follows:

$$Nu_a = 0.35 \times Re^{0.6} \times Pr^{0.36} \times (\frac{P_T}{P_L})^{0.2} \quad (7)$$

Water is flowing inside the tube; hence Nusselt number is calculated by Dittus-Boelter equation:

$$Nu_w = 0.023 \times Re^{0.8} \times Pr^{0.3} \quad (8)$$

5. Result and discussion

A. Heat transfer

Heat transfer rate is depends on Nusselt number. Nusselt number is a function of Reynolds number, Prandtl number. As Reynolds number increases heat transfer coefficient and Nusselt number increases and hence heat transfer rate increases. Elliptic shape tube area is more compare to circular shape of tube, as area increases, fluid contact time will also increase and it helps to increase heat transfer rate. This cross flow heat exchanger is having staggered tube arrangement, to observe heat transfer rate correctly, analysis is carried out in to two parts: 3 row section and 2 row section. Theoretical and experimental value of heat transfer coefficient for corresponding Reynolds numbers are recorded in table 1.

Table 1: Readings for 1400 LPH water flow rate

Sr. No	Vavg	Δ p	Re	Theo. h	Expt. h
1	1.855	49.05	7737.45	51.2	79.81
2	2.588	98.1	10982.5	62.7	95.04
3	3.3	147.15	13828.6	72.4	135.6
4	4.122	245.25	17510.4	82.9	151.9
5	4.555	284.49	19238.4	88	176.1
6	4.555	323.73	19731.6	88.1	158.1
7	5.055	304.11	21482.8	93.7	186.7
8	5.277	377.68	22815.6	96.3	179.5
9	5.411	358.0	23116	97.7	191.2
10	5.755	412.02	24496	101	205.6

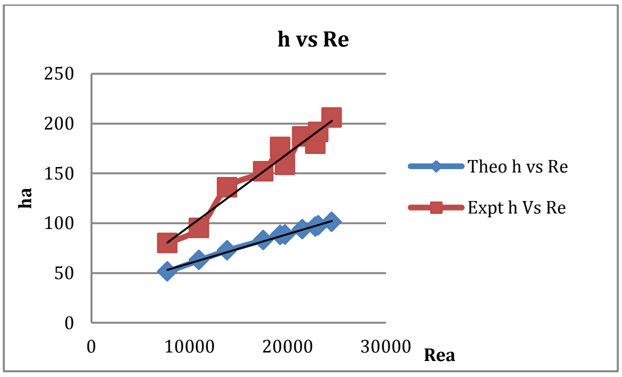

Figure 2 Graph of h vs. Re for air side

Figure 2 Shows average convective heat transfer coefficient for two sections which increases linearly with increase in Reynolds number. In case of 3 row section, air flow area is less and that will increase velocity of air in that section compare to 2 row section, hence Reynolds number is more in 3 row section compare to 2 row section. Average Reynolds number range varies from 7000 to 24000 and its corresponding value of heat transfer coefficient varies from 50 to 200. Heat transfer coefficient for elliptic shape tube shows that 80% to 90% enhancement compare to convective heat transfer coefficient of circular shape tube given by Zukauskas correlation. Frontal area of elliptic shape tube is less; hence pressure drop is less compare to other shape of tubes. Pressure drop increases as average air velocity increases as mentioned in table 1.

Conclusions

Heat transfer augmentation under constant wall temperature of 80°c is achieved. Experimentation is carried out with this cross flow heat exchanger and results are compared with Zukauskas equation for circular shape tube. Results show that, heat transfer coefficient increase linearly with increase in Reynolds number which helps to increase heat transfer rate. Heat transfer rate of elliptic shape tube increased 80% to 90% more than the circular shape tube. As Reynolds number increases, friction factor decreases and pressure drop increases. Future scope of this research is that the thermal performance of heat exchanger can be analyzed by changing staggered tube arrangement such as 30° triangular staggered array, 60° rotated triangular staggered array, 90° square inline array, 45° rotated square staggered array.

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