Experimental investigation of the effect of hot finnedtube position on the heat transfer coefficient

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Abstract:

In the present study, an experimental investigation is carried out to calculate heat transfer coefficient from the change in position of a finned tube in the cross-flow heat exchanger in two different conditions, which are a constant temperature at 90°C and constant heat flux at 45W/m^2. A standard laboratory device (crossflow heat exchanger) was used in experiment process, that which manufactured by EDIBON company. The air flow over finned tubes inside heat exchanger was studied at Reynolds number ranging from 3600 to 11600. The comparative of experiments results between two cases shows that the Nu number in four positions at the constant temperature condition are higher than symmetrical positions in constant heat flux. The results indicated that the position3 gives higher values of Nu number in both cases.

Keywords: Cross-flow heat exchanger, finned tube heat exchanger, heat transfer coefficient

الخلاصة :

تشمل الدراسة الحالية تحليل نتائج اختبارات التي اجريت لحساب قيمة معامل انتقال الحرارة و تاثيرها بتغير موقع انبوب مزعنف في مبادل حراري متعامد وفي حالتين من التسخين (ثبوت درجة حرارة 90 مئوية و فيض حراري ثابت 45 واط/م^2). حيث اجريت الدراسة في مدى لجريان الهواء تتراوح من 3600 الى 11600 رقم رينولد وذلك من خلال استخدام مبادل حراري مختبري نوع متعامد مجهز من قبل شركة EDIBON المتخصصة في صناعة الاجهزة المختبرية. من خلال مقارنة نتائج للحالتين، تبين بان رقم نسلت عند المواضع الاربعة في حالة ثبوت درجات الحرارة اعلى من مواضع مماثلة عندحالة ثبوت الفيض الحراري ومن مجمل النتائج الاختبارات تبين بان الموضع رقم 3 تعطي اعلى قيم لرقم نسلت للحالتين.

الكلمات المفتاحية :- مبادل حراري ذو جريان متعامد، مبادل حراري ذو انبوب مزعنف، معامل انتقال الحرارة.

Nomenclature

A: Area m^2
c: specific heat $J/kg.^oC$
d: Diameter m
G: Mass velocity kg/m^2
h: heat transfer coefficient $W/m^2.^oC$
H: Hight m
L: Length m
k: Thermal conductivity $W/m.^oC$
$\dot{m}$: Mass flow rate kg/s
N: Number
Q: Heat transfer rate W
T: Temperature ^oC
W: Width m
X: Pitch m

Subscribes
b:Bulk
Conv: Convection heat transfer
e:Outside
f: Film
h:Hydraluic
i: Inlet
in: Input
o: outlet
rad: Radiation heat transfer

Dimensionless Group
Re: Reynolds number -
Nu: Nusselt number -

Greek letters
δ: Thichness m
η: Efficiency -
μ:Dynamic Viscosity $kg/m\ s$
ρ: Density kg/m^3

1. Introduction

Heat transfer coefficient plays a major role in convection heat transfer and it depends on geometry, fluid properties, fluid motion and temperature difference [1].These parameters cause difficulty in evaluating the value of heat transfer coefficient. Numerous experimental and numerical studies have been conducted on heat transfer coefficient and pressure drop.These studies mainly focused on fluidized bed(Kim and Chao;2015), heat exchangers (Kim and Tahseen;2005) and Nano-fluids (Hamid and Andhare;2015) . (Jeong *et.al.*,2009) developed a theoretical model for the estimation of heat transfer coefficient in natural convection condition in longitudinally finned vertical tube with four fins that was exposed in two cases as non-uniform wall heated flux and non-uniform wall temperature.They obtained a new correlation to an estimation of Nu number as in equation (1).

$$Nu_o = 0.0033Re^{0.4088} \tag{1}$$

Islam and Mozumder, 2009 investigated experimentally the heat transfer coefficient and pressure drop of T-section internal fin in circular tube which was heated by electricity and was cooled by air under fully developed turbulent flow. The result of the study showed that the finned tube gives the friction factor five times higher and heat transfer coefficient two times higher than smooth tube for same operating conditions.**Hofmann *et. al.*, 2007** experimentally studied heat transfer coefficient and pressure drop for three ships finned tubes bundles (I- soled ship, I-serrated ship and U-serrated ship) in force convection conditions. They compared their results with correlation relations and their results show that the two types of the I-finned tubegood predictive ability for the Nu number at given pressure drop values. **Kadhim and Nasif 2016** carried out experimental investigation to study finned tube which was subjected to vertical oscillation of vibration frequency arranged from 2 to 60Hz and various heat fluxesarranged from 500 to 1500 W/m^2. The results showed that the heat transfer coefficient values for horizontal angle 0^o were increased by 8% and 30% compared with angle 30^o and 45^o respectively.**Matos *et.al.*, 2004** carried out comparative studies on the non-finned and finned circular and ellipse tubes heat exchanger. Their results show that the circular tubes gave better results than ellipse tubes in both of heat transfer coefficient gain about 20% and 30% reduction in pressure drop.

In the present study, the change in heat source position in finned tube crossflow heat exchanger was investigated. The heat transfer coefficient was evaluated in forced convection in two cases constant heat flux and constant wall temperature and at similar operating conditions.

2. Calculation and data analysis

In crossflow heat exchanger, the heat transfer coefficient and pressure drop has been calculated as following procedures:

a) Physical properties of the working fluid (Air).

Air physical properties at low temperature are assumed to linearly be proportional to air temperature. The interpolation relation has been used to calculate the physical properties based on tabulated data from (Holman ,2010) for air properties at atmospheric pressure between 300 and 350 K.

$$\mu_f = \mu_{300} + \frac{T_f - 300}{50}(\mu_{350} - \mu_{300}) \tag{2}$$

$$\rho_f = \rho_{300} + \frac{T_f - 300}{50}(\rho_{350} - \rho_{300}) \tag{3}$$

$$k_f = k_{300} + \frac{T_f - 300}{50}(k_{350} - k_{300}) \tag{4}$$

$$c_f = c_{300} + \frac{T_f - 300}{50}(c_{350} - c_{300}) \tag{5}$$

where

$$T_f = \frac{T_b + T_s}{2} \tag{6}$$

and

$$T_b = \frac{T_i + T_o}{2} \quad (7)$$

b) Heat transfer coefficient

The convection heat transfer coefficient has been calculated based on energy balance through finned tube in the working space and expressed by

$$Q_{in} = Q_{conv} + Q_{rad.} \quad (8\text{-a})$$

where the $Q_{rad.} \ll Q_{conv}$ so the $Q_{rad.}$ can be ignored.

$$Q_{in} = Q_{conv} \quad (8\text{-b})$$

$$Q_{conv} = A_t\, h\, (T_s - T_b) \quad (9)$$

or

$$Q_{in} = \dot{m}\, c_f (T_o - T_i) \quad (10)$$

and

$$h = \frac{Q_{in}}{A_t (T_s - T_b)} \text{ or } h = \frac{\dot{m}\, c_f (T_o - T_i)}{A_t (T_s - T_b)} \quad (11)$$

$$Nu = \frac{h\,.D_h}{k} \quad (12)$$

c) Heat Exchanger Surface Geometrical Characteristics

Heat transfer surfaces are calculated based on the dimensions of the finned tube heat exchanger as shown in Fig. (1), as follows:

$$A_t = A_s + \eta_f A_f \quad (13)$$

$$A_s = \pi d (L - N\delta) \quad (14)$$

$$A_f = \pi N \left[\frac{1}{2}(D^2 - d^2) + \delta D\right] \quad (15)$$

$$Re = \frac{G\, D_h}{\mu_f} \quad (16)$$

where

$$G = \frac{\dot{m}}{A_o} \quad (17)$$

$$D_h = \frac{4 A_o L_2}{A} \quad (18)$$

$$A_p = \pi d_o L_1 (1 - \delta N_f) N_t + 2\left(L_2 L_3 - \frac{\pi d_o^2}{4}\right) N_t \quad (19)$$

$$A_f = \left[\frac{2\pi(d_e^2 - d_o^2)}{4} + \pi d_e \delta\right] N_f L_1 N_t \quad (20)$$

$$A = A_p + A_f \quad (21)$$

$$A_o = \left[\left(\frac{L_3}{X_t} - 1\right) \times 2a' + (X_t - d_o) - (d_e - d_o)\delta N_f\right] L_1 \quad (22)$$

3. Experimental setup

The cross-flow heat exchanger manufactured by EDBON, technical teaching equipment is shown in Fig. (2),was used as experimental setup. It consists of four major components (air tunnel, centrifugal fan, heating source and interface). Air tunnel is made of stainless steel with a rectangular section of 65X170mm and 1.2m height and it has a rectangular opening in the mid-height of 200X150mm. A centrifugal fan installed in the bottom of the apparatus and it pushes the air vertically through the tunnel.A (500W) electric heating element of 15.8mm nominal diameter and 50mm of length has been used as a heating source that which it includes a thermocouple type J to measuring the average temperature of the surface. This system is controlled by interface device from the feeding of fan speed and the electric resistors, in addition to receives the signal of all the thermocouples and air flow meter, providing a computerized outcome of all the measurements. The experiments have been achieved in both cases in sequence procedures, were started by selecting the heating source from position 1 and finished in position 4. All experiments were conducted under Reynolds number ranging from 3600 to 11500 in ten equality steps.

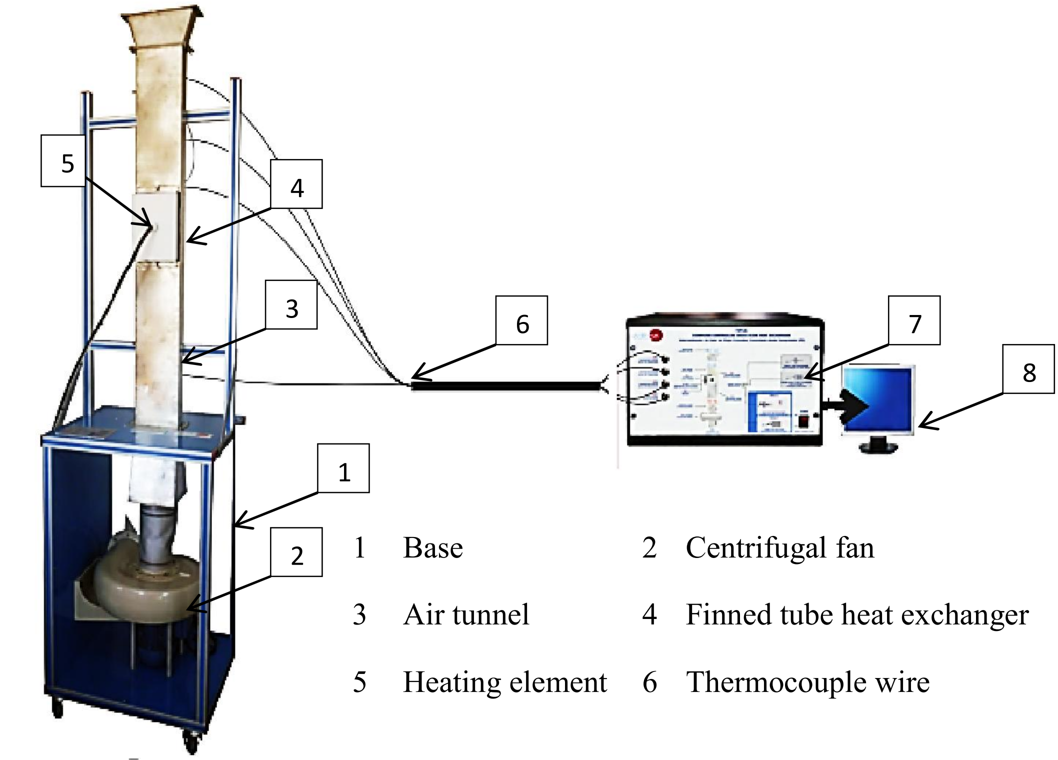


Fig (2) components of experiment apparatus (Edibon,2016)

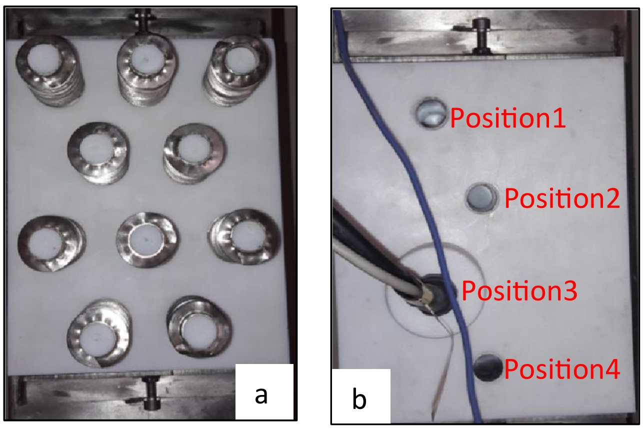


Fig (3) Finned tube heat exchanger photography
a- Front view b- Rear view

Results and Discussion

Experimental results of finned tube heat exchanger consistedof two cases (constant heat flux 45W/m^2 and constant temperature 90^{o}C) to study the effect of the position of hot finned tube in staggered arrangement heat exchanger shown in Fig.(3-a) on the heat transfer coefficient.A set of experiments has been conducted in both cases based on the previous procedures, hence the results that were obtained can be compared at the beginning for both cases at the same position, where for all four position of a hot finned tube, the Nu number of case of constant temperature gave higher values than Nu number that were obtained from the case of constant heat flux at the Re number ranging from (3600 to 11500) as shown in Figures 4 to 7, for position (1 to 4) respectively. The averagevalues of Nu and heat transfer coefficient in two cases for each of four positions are given in Table (1). Hence, the comparative between limits of Nu number in each of four positions in each case, the results are summing in Figures (5 and 6) for cases of (constant temperature and constant heat flux) respectively. In both cases, position3 gave higher values of Nu number comparative to the other positions, while the lower values of Nu number has been obtained at position2 in both cases. For other two positions, case 4 comes in the second sequence and position1 is the third sequence in the case of constant temperature, but in the case of constant heat flux, the sequence of these two positions comes opposite to the first case.

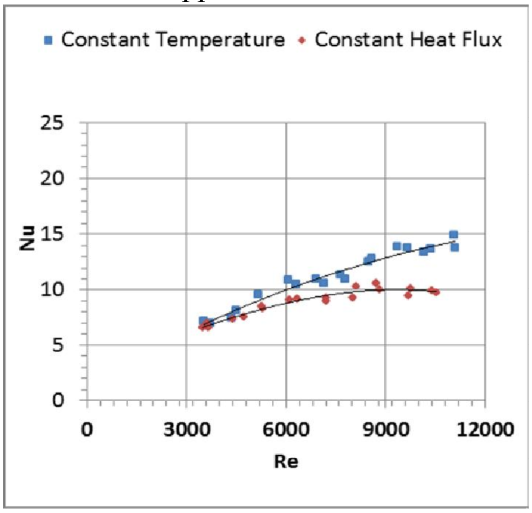


Fig.(4)Comparison of constant temperature results with constant heat flux results for position1

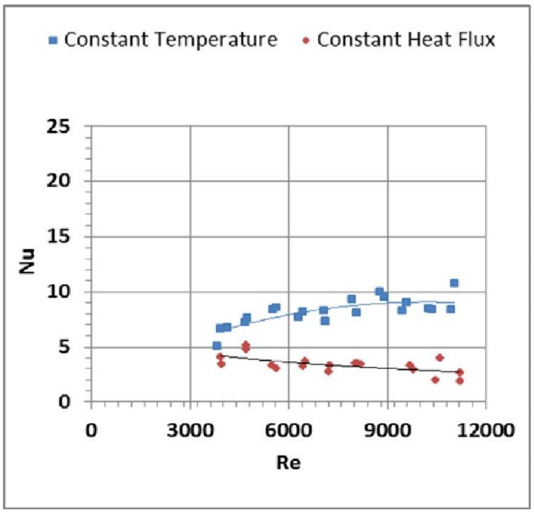


Fig.(5)Comparison of constant temperature results with constant heat flux results for position2

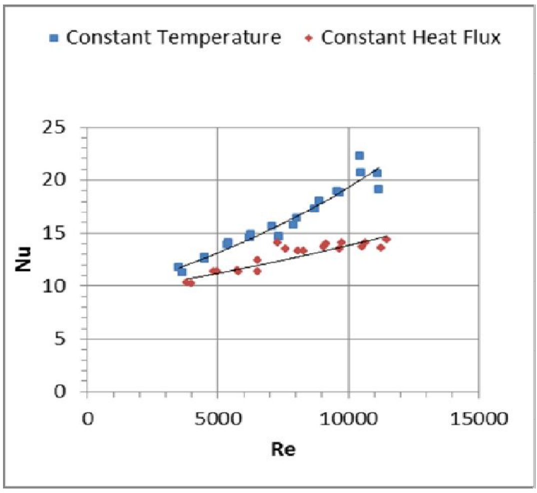


Fig.(6)Comparison of constant temperature results with constant heat flux results for position3

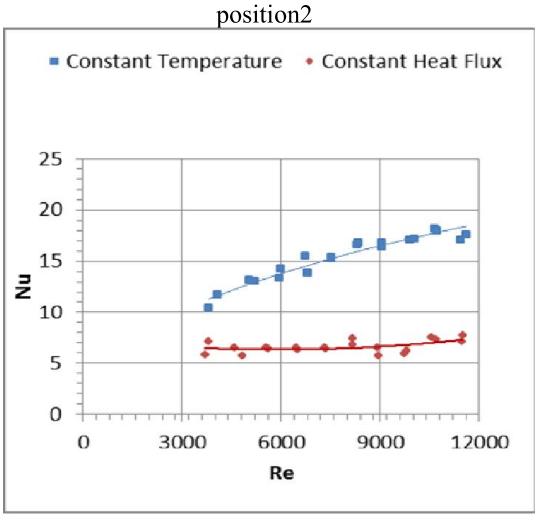


Fig.(7)Comparison of constant temperature results with constant heat flux results for position4

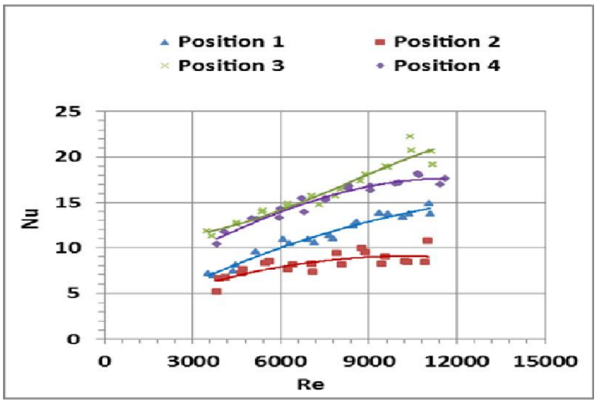


Fig.(8)Reynolds's number vs. Nusselt number for different position at constant temperaturecondition

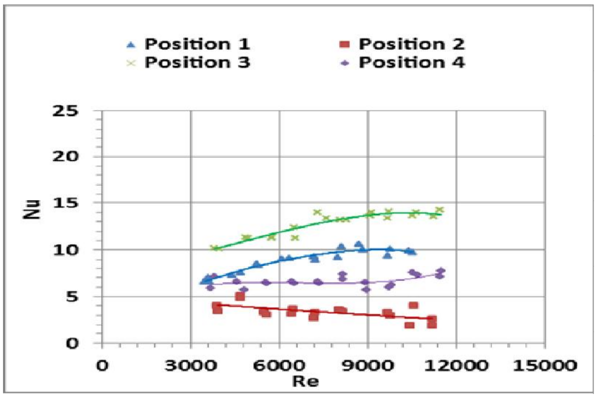


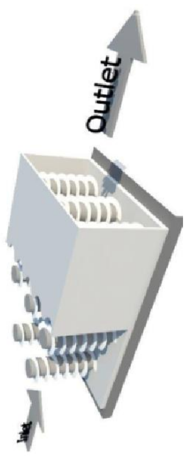
Fig.(9)Reynolds's number vs. Nusselt number for different position at constant heat fluxcondition

Table (1) The average values of Nu number and heat transfer coefficient for four positions in two cases of constant (temperature and heat flux)

Case type	Position1		Position2		Position3		Position4	
	$\overline{Nu}$	$\bar{h}$	$\overline{Nu}$	$\bar{h}$	$\overline{Nu}$	$\bar{h}$	$\overline{Nu}$	$\bar{h}$
Constant Temperature	11.216	13.813	8.156	10.083	16.218	20.097	15.376	19.062
Constant Heat Flux	8.884	10.89	3.372	4.133	12.672	15.533	6.621	8.116

Conclusion

Results of this study indicated that the position of the hot finned tube has a great effect on the heat transfer coefficient. The higher values of heat transfer coefficient are obtained at position3 in both cases, that which surrounded by five finned tubes and it has different boundaries than the other positions and this causes more resistance on the air flows over the tube.



Dimensions (mm)	
L_1	65
L_2	200
L_3	150
H	225
W	155
X_l	50
X_t	50

Fig(10) Technical description of the finned heat exchanger

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