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Experimental Investigation of Different Finned Tube Heat Exchanger

Farah Abdulzahra Taher and Zena Khalefa Kadhim

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Farah Abdulzahra Taher *[1], Dr.Zena Khalefa Kadhim [2]
Mechanical Engineering Department, University of Wasit, Iraq
*Correspondence Author: Ftahar@uowasit.edu.iq
drzena@uowasit.edu.iq

Abstract:

This study presented the experimental effect of heat transfer through the cross-flow heat exchanger and the impact of changing the height of the fins on improving the heat transfer of four exchangers with eight-corridor (smooth tube, low, medium and high integral finned tubes) those are cooled by air, each corridor has a length of 250 mm inside the air duct. The working conditions are (1, 1.7, 2.3) m /sec air velocity, water flow rates (2-6) L/ min, water entry temperature (50, 60, 70)°C. The experimental results show that the heat transfer coefficient for the air side when using the finned tubes is higher than the smooth tube and the best improvement of the high integral finned tubes are (291%, 329.95%, 182.5W/m^2.°C and 0.180) the enhancement factor, heat transfer rate, overall heat transfer coefficient and effectiveness respectively.

Empirical correlations were found for the Nusselt's number in the air side of the three exchangers (low, med, high) and a model for these correlations with a water flow rate of (6L/min) and the water temperature of (70°C).

$$\mathrm{Nu_a} = 0.2449\, \mathrm{Re_a^{0.4577}}\, \mathrm{Pr_a^{1/3}}\, (\mathrm{A_o}/\mathrm{A_i})^{0.7661}$$

$(20496.54 < \mathrm{Re_a} < 48394.26)$

Key Word: Heat transfer coefficient, cross-flow heat exchanger, Fins, Integral fins tube.

Introduction

The heat exchanger is a device, used to exchange heat between two fluids, without mixing between them. The heat exchanger is one of the primary parts for the heat systems. The general utilizations of the heat exchangers are in the ventilating, heating, electronic chip cooling, refrigeration, ecological building, air conditioning systems and power generation. An air conditioning unit improvement depends on the performance of its devices as the heat exchangers, compressors and fans. The improvement of the heat exchangers decreases of electrical power consumption. Finned tubes are utilized when the heat transfer coefficient on the outside of the tubes is apparently lower than that within. Therefore fins using to improve performance of the heat exchanger by excess the surface space (region) to tubes of heat exchange. There are several types of fins such as cylindrical, square, rectangular, pin and annular fins [1, 2, and 3]. The integral finned tubes are tubes that can be formed the ring fins on their outside surface to improve heat transfer [4]. Area ratio is standard to determine type fins height for the heat exchangers as follows:

$A_o/A_i < 5$ Low integral finned tube
$A_o/A_i = 5$ Medium integral finned tube
$A_o/A_i > 5$ High integral finned tube

The literature survey will be related to improving the heat transfer coefficient in the heat exchangers in general and in cross-flow heat exchanger in particular. **Kumar et. al. (1998) [5]** presented a trial examination to expand heat transfer rate by means of raising heat transfer coefficient to working liquid as unadulterated vapor steam R134a and R12.The tubes and fins were produced using copper. The examination centered about smooth tubes and impact of various integral finned tube for example: (circular integral finned tubes, somewhat spine roundabout integral finned tubes and spine integral finned tubes). The water was a working liquid with stream rate going between (480-1680) kg/hr. The refrigerants were stream with rate 20 kg/hr. The cooling water was stream inside tubes while the refrigerants were condensed over horizontal finned tubes and smooth tubes in case one, yet in the other case the water of cooling was stream outside tubes while condensed inside horizontal finned tubes and smooth tubes. The outcome demonstrates that the spine integral finned tubes gave greatest heat transfer coefficient.

The experimental examination carried out by **Kumar et. al. (2005) [6]** to the condensation of R-134 vapors over five single horizontal round integral fin tubes of 472 fpm , 417 mm length and diverse fin heights of (0.45, 1.14, 1.47, 1.92 and 2.40) mm. The round fins were rectangular in style with thickness 0.70 mm. The tube with the fin height of 0.45 mm gave the most maximum improvement factor (*EF%*) was 3.18 in compare with that anticipated for a plain tube.

Dasgupta (2011) [7] studied the heat transfer rate through air to the deionized water cross flow serpentine small scale channel heat exchanger through air cooling in the single stage. The working conditions were for air and deionized water side Reynolds number ($283 \leq Re_a \leq 1384$) and ($105 \leq Re_w \leq 159$) separately. The entry temperature was steady for the air (38 ±0.5) °C and water temperature (9 ±0.5) °C. The mass stream rates of deionized water were fluctuated in four levels, from (0.0169 kg/s to 0.024 kg/s) and air confront speeds were varied in five stages from

(1m/s to 5m/s) at each deionized mass stream rate. Hydraulic diameter 3.49mm, fin type deep wavy height 16mm, fin dividing 2mm, thickness of fin 0.1mm, fin density 12fpi. The results showed that the heat transfer rate from hot air to the cool de-ionized water under 4%. The air side Reynold's number was effect on heat transfer more than the water side Reynold's number. The effectiveness and number heat transfer unit increased with the air side Reynold's number non directly.

Ayad Mezher et. al. (2011) [8] examined the heat transfer qualities for cross stream air cooled single aluminum tube multi passes (smooth and integral low finned tube) and the impact of the indispensable low fins (trapezoidal or rectangular) in upgrade the heat and concentrate all factors which have impact on heat transfer phenomena. The speeds of air over the test area are (1, 2 and 3) m/sec, the water stream rate is (5l/min) and the temperatures of the entry water to the test tube are (50, 60, 70, 80) ^{o}C. The main test area has a smooth aluminum tube of eight corridors with internal diameter 17mm and external distance across 19mm.The second test segment has an essential low finned aluminum tube of eight corridors with internal diameter 17mm, root diameter 19mm and external diameter at the tip of fin 22 mm. The corridor has a length 251mm inside the conduit with 125 fins. The fin's height is 1.5 mm with a thickness of 1mm and pitch 2mm. The test showed that the air side heat transfer coefficient of the smooth tube was lower than that of the low finned tube and the improvement proportion was (1.86 to 2.38) for eight passes. The heat load of the low finned tube was higher than the smooth tube about (1.8 to 2.13) times. The Enhancement of the outside heat transfer coefficient increased with increasing the air velocity.

Chen et. al. (2014) [9] was study for the qualities of the heat transfer and pressure drop in finned tube banks through a trial open high-temperature wind and the impacts of the dimensions of the fins (width , height , pitch) and air velocities (6, 8, 10, 12 and 15) m/s on fin efficiency as well as the convective heat transfer coefficient. The results showed that as the air speed, fin height and fin width increment, fin efficiency diminishes. The convective heat transfer coefficient was directly proportional with fin pitch but conversely relative with height and fin width. The heat transfer limit is identified with fin efficiency. The Pressure drop increased with the increasing the fin height and width. **Wolf et. al. (2006) [1]** presented a three-dimensional steady state numerical model to anticipate the air side heat transfer characteristic of a wavy fin and tube heat exchanger. The heat exchanger had three lines of round tubes. A physical procedure of heat transfer reporting in real time side of a wavy fin (wave height 1.15

mm, wave angle19.2^o degree, venture fin design length 3.3 mm, fin length 48 mm, fin thickness 0.1 mm, fin pitch 1.6 mm) and tube heat exchanger (outside tube diameter 7.94 mm, longitudinal tube pitch 16 mm, transversal tube pitch 24 mm, number of lines 3).the air velocity was (1 - 4) m/sec. Fluid stream and heat transfer arithmetical model tackled utilizing CFD technique by used the control volume numerical method. The cooling systems R410a forced to move through the tubes, while air is coordinated over the tubes. The numerical outcomes compared with the experimental results were (4-10) %. This work displayed great heat transfer expectation which gave rules to improvement of a fin and heat exchanger.

Hossainpour and Hassanzadh (2011) [10] carried out a three dimensional numerical examination completed in turbulent forced convection in a tube with helical ribs to improve the heat transfer by utilizing helically corrugated tubes. Inner diameter for tube (24mm) and Reynolds numbers between (25000-80000). The diameter proportion of the rib pitches ranging from (0.6 to 1.2). The entry water temperature is 10^{o}C and tube wall is at 80^{o}C uniform temperature. Three dimensional turbulent streams has been emulation utilizing a limited volume code and the outcomes are contrasted and accessible test information. It has been demonstrated that the helical ribs significantly affect the heat transfer enlargement and pressure drop.

Chaudhari et. al. (2014)[2] presented experimental and numerical examination for heat transfer coefficient and pressure drop on finned tube and without finned tube heat exchanger. The dimensions of the round fin which manufactured from aluminum with outer diameter 0.0343 m, thickness 0.001 m, space 0.03933 m, and number of fins 900. The heat exchanger was internal diameter 0.013 m and tube outer diameter 0.0146 m. The heat transfer coefficient for the coolant water by utilization of round about finned tube and without fin tube exchanger with force convection, both heat exchanger with air velocity (3, 4, 5 and 6) m/s and coolant flow (180, 260, 340, 420, and 500) L/hr. The results showed that the overall heat transfer coefficient (14.07W/m^2), as well as the overall heat transfer rate of finned tube is more marked than without finned tube and also heat transfer rate is increases.

Abdul Hassan (2016) [11] used CFD examinations to estimate the temperature variation for cross-flow heat exchanger with smooth tube and low integral finned tube with (internal diameter 19 mm, root diameter 21 mm, and external diameter 24 mm). Fin height is 1.5 mm. The geometry creation with measurements (250×500×1200) mm. Air is stream external tube and water is stream inside. The air velocity was (1-4) m/sec. The water flow rate was (2- 6) L/min. The water temperatures at the entry of test tube were (50, 60, 70, 80)°C. The outcomes demonstrated that the temperature distinction and the heat transfer coefficient for heat exchanger with finned tube is larger than with smooth tube and the temperature decline of finned tubes obtain greater than that of smooth tube due to the air speed are raised between the pass over on tube test.

Three dimensional numerical and experimental examinations had been represented by **Jassam(2019) [12]** to enhancement heat transfer rate for the cross flow heat exchangers (Smooth and Low integral finned tube). Number of passes was eight. The utilizing working fluids were water, oil without and with Nano fluid (SiO_2). The study centered on Nano fluid effect of the heat transfer and heat transfer coefficient. The dimensions of smooth tube are inner and outer diameter (19, 24) mm respectively. The low integral finned tube had inner and root diameter as well as the height, thickness and pitch of fin, (19, 21, 1.5, 1, 2) mm respectively. The numbers of fin were 500 fpm. The results showed that the heat transfer, heat transfer coefficient and the enhancement in general higher in low integral finned tube than the smooth tube. The enhancement was 72.05 % for oil and 104.1% for water.

Motivation:

The extensive uses of heat exchangers and their importance in industrial applications researchers prompted to think of improving the performance of heat exchangers. My study is aim to reduce the thermal resistance of heat exchangers and obtain high heat transfer coefficient with reducing the exchanger volume by using different finned tubes that increase the rate of heat transfer from the fluid to the surrounding.

Theoretical equations

The energy balance in heat exchanger total heat transfer rate in heat exchanger. [13]

$$Q = \dot{m}_w C_{ph}(t_{h1} - t_{h2}) = \dot{m}_a C_{pc}(t_{c2} - T_{c1}) \tag{1}$$

$$Q = UA\theta_m \tag{2}$$

The overall heat transfer coefficient

$$U = \frac{1}{\frac{1}{h_a} + \frac{1}{K} + \frac{1}{h_w}} \tag{3}$$

Log mean temperature difference (LMTD)

$$LMTD = \frac{\theta_1 - \theta_2}{\ln\left(\theta_1/\theta_2\right)} \qquad 4$$

Calculations heat transfer coefficient for smooth tube, [14]

For smooth tube

$$h_a = \frac{1}{\frac{1}{U_o} - \frac{d_o\, ln\left(d_o/d_i\right)}{2k} - \frac{d_o}{h_w d_i}} \qquad 5$$

For integral finned tubes

$A_{of} = A_{os} = \pi\, d_o L$, Clean surfaces, [14 and 16].

From eq.(3) we get h_o

$$h_a = \frac{1}{\frac{1}{U_w} - \frac{d_i\, ln\left(d_r/d_i\right)}{2K} - \frac{1}{h_w}} \qquad 6$$

Reynolds number, Prandtle number and Nusselt's number for air side:

$$Re_a = \frac{U_{air} d_h}{v_a} \qquad 7$$

$$Pr_a = \frac{\mu_a\, Cp_a}{K_a} \qquad 8$$

$$Nu_a = \frac{h_a\, d_o}{K_a} \qquad 9$$

Reynolds number, Prandtle number and Nusselt’s number for water

$$Re_w = \frac{u_w\, d_i}{v_w} \qquad 10$$

$$Pr_w = \frac{\mu_w\, C_{pw}}{K_w} \qquad 11$$

$$Nu_w = \frac{h_w \times d_i}{K_w} \qquad 12$$

To turbulent flow by Dittus and Boelter, [17]:

$$Nu_w = 0.023 {Re_w}^{0.8} {Pr_w}^{n} \qquad 13$$

$(0.6 < Pr < 100)$

The actual heat transfer for the counter flow exchanger can be calculated from equ.1

$$Q_{max} = C_{min}(t_{h1} - t_{c1}) \qquad 14$$

For cross flow C_{max} mixed and C_{min} unmixed or vice versa

$$\varepsilon = \left(\frac{1}{C}\right)\{1 - \exp[-C(1 - e^{-\mathrm{NTU}})]\} \qquad 15$$

$$\varepsilon = 1 - \exp\{-\left(\frac{1}{C}\right)[1 - exp - (\mathrm{NTU} * C)]\} \qquad 16$$

Where, the heat capacity ratio is,

$$C = \frac{C_{min}}{C_{max}}$$

The number of transfer units (NTU)

$$\mathrm{NTU} = \frac{U_a * A_{os}}{C_{min}} \qquad 17$$

Enhancement factor,[18]

$$E.F\,\% = \frac{h_{a,fin} - h_{a,smooth}}{h_{a,smooth}} \times 100 \qquad 18$$

Experimental apparatus

The laboratory device in this study consists of main parts which are designed and manufactured with all the accessories and measuring equipment as in figure (1). The test sections are (1200×250×500) mm as in figure (2) and Experimental apparatus in figure (3). The heat exchangers are put at a distance (300) mm from the end of test section. Eight slots are placed on two side of the test section to pass the copper tubes. The passes are put horizontally through the test section with length (250) mm. Head of pump water is 24m, power electric 370W and flow rate 30L/min. Volume of water heater is 20 liter, It is supplied the laboratory apparatus with hot water at constant temperature, while the temperature is control by thermostat. Dimensions of the reservoir (250x250x400) mm made from galvanized steel and covered by thermal rubber insulation. The cold air passes through the centrifugal blower with impeller diameter (4 inch), (1700 W, 2.8 A) and velocities range (1-3) m/sec at the test section. The air duct is made from galvanized steel, with dimensions (250×500×900) mm, one side is joined to the diffuser and other side to the test section.

The working conditions were utilized as in table (1) and description of the dimensions of heat exchangers are shown in table (2).

Table (1) explains working conditions of this study.

Tubes	Air Temp. ^{o}C	Air velocity m/sec	Inlet water temp. ^{o}C	Water flow rate L/min
Smooth	20-24	1-2.3	50-70	2-6
Low integral	20-24	1-2.3	50-70	2-6
Med integral	20-24	1-2.3	50-70	2-6
High integral	20-24	1-2.3	50-70	2-6

Table (2) Descripts of the copper tubes

Tubes	di mm	do mm	dr mm	H_f Mm	T_f Mm	T_w mm	S_f mm	A_o/A_i	N_f Fpm
Smooth	19	24	-	-	-	2.5	-	1.263	-
Low integral	19	24	21	1.5	1	1	1	2.96	500

Med integral	19	28.5	21	3.75	1	1	1.6	5.0	384
High integral	19	33.4	21	6.2	1	1	1.6	8.17	384

Fig. (1) Photo of the integral finned tube

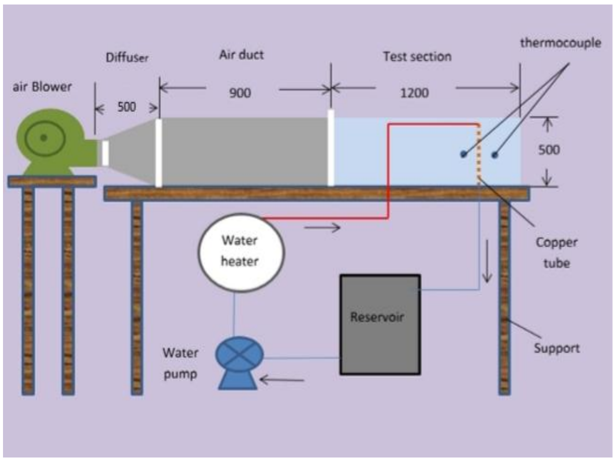

Fig. (2) Schematic diagram of the cold air cycle and dimensions in (mm)

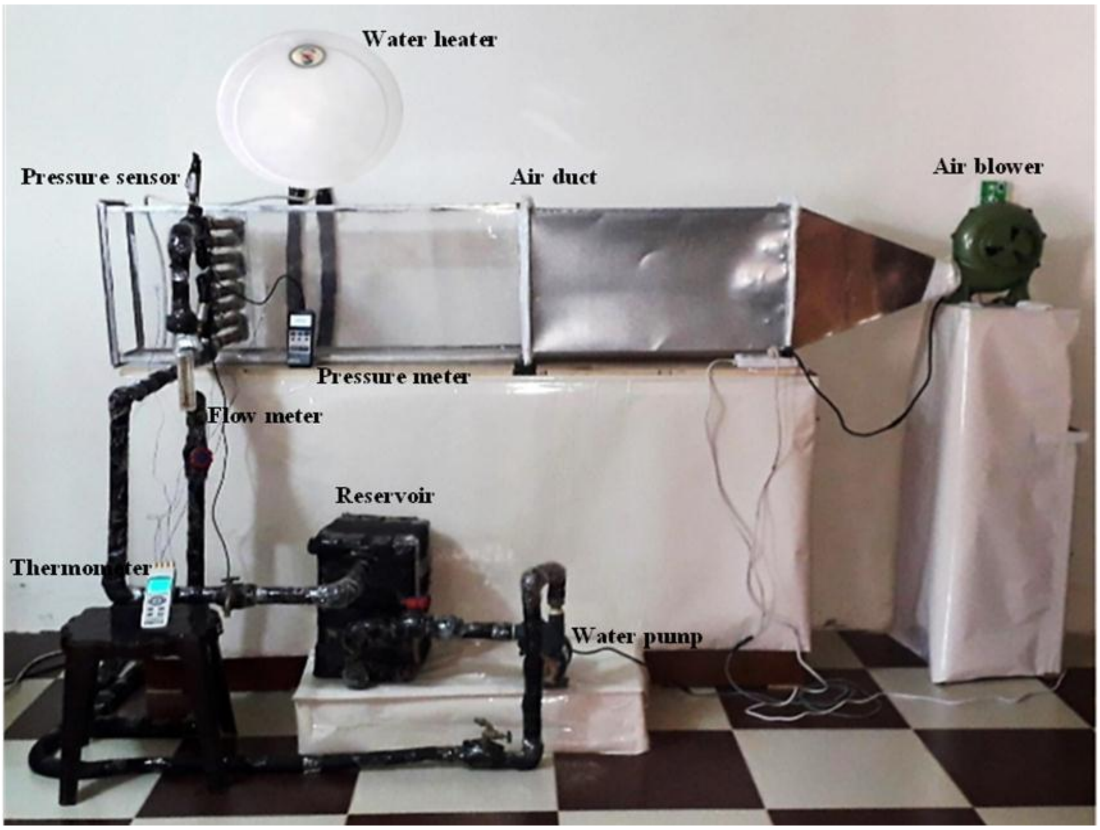

Fig. (3) Plate of the laboratory apparatus

Results and discussions

Figures (4) show the relation between the heat transfer rate with inlet water temperature and air velocity for the four heat exchangers (Smooth, Low, Med and High). The heat transfer rate increases with increasing the temperature of the water entering and air velocity due to high cold air velocity occurred higher disturbance outside the tube that increases the water side temperature difference (Δt_h) led to rise the surface temperature and the heat capacity of water within a little value. The heat transfer rate is increased with decreasing the water flow rate duo to provide enough time to remove the heat. Figure (5) illustrates the effectiveness of heat exchangers with (NTU), for all cases (smooth, low, med and high). From this figure is found that the effectiveness increases with increasing the number of the transfer units (NTU) that increasing due to rise outside overall heat transfer coefficient. The fourth case has highest area ratio and high fins give the highest (e and NTU) respect to the other cases as shown in table (3).

Table (3) Effectiveness for the four cases heat exchanger

Heat exchanger	NTU	Effectiveness
High integral finned tube	0.207	0.180
Medium integral finned tube	0.138	0.125
Low integral finned tube	0.089	0.084
Smooth tube	0.076	0.073

Figures (6) show the effect of the different air velocities and different inlet water temperatures on the water heat transfer coefficient for all test cases. These figures show the behavior of air heat transfer coefficient for all tested tubes which same phenomena but with different values for the air heat transfer coefficient. The value of air heat transfer coefficient increases with air velocity at the same inlet temperature water as a result of increasing Reynold's number of air. At the same air velocity and water flow rate with different inlet temperature notice that air heat transfer coefficient increases with decreasing inlet water temperature because that air heat transfer coefficient is a function of overall heat transfer coefficient and water heat transfer coefficient, When inlet water temperature decreases led to decrease in water heat transfer coefficient but overall heat transfer coefficient increases. The air heat transfer coefficient for all finned tubes is bigger than the air heat transfer coefficient for Smooth tube because of the fins that increase the surface area for tubes and thus increase heat transfer. The highest value of air side heat transfer coefficient equal to 215.89W/m^2.^{o}C in the case which has large area ratio and fins height (6.2mm) at water flow rate 6 L/min, inlet water temperature 50^{o}C and air velocity 2.3 m/sec. The reason for this rise due to the higher area ratio and fins height causes the largest heat transfer dissipation. The air side heat transfer coefficient has shown in table (4) of the highest value to the least at water flow rate 6 L/min, inlet water temperature 50^{o}C.

Table (4) Enhancement factor of heat exchangers

heat exchanger	*EF%*	H_f (mm)
High integral finned tube	291	6.2
Medium integral finned tube	205.1	3.75
Low integral finned tube	69.9	1.5

Empirical equations

Experimental relationships have been created depending on the experimental results by using the (IBM SPSS Statistics 22) program. In the cross flow heat exchangers that have the circular tubes are use the following empirical formula:

$$Nu_a = C{Re_a}^m {Pr_a}^{1/3} (A_o/A_i)^n \qquad \text{General formula} \qquad 19$$

The experimental equation obtained in the present study under the approved working conditions (inlet temperature, the water flow rate and the velocity of air flow) for the case of smooth tube show in equation (5.2) with the coefficient of determination (R^2) equal to (0.5663) and for the all cases integral finned tubes show in table (5). (R^2) is the ratio that shows the contrast between the independent and accredited variable and whenever close to 1 is the empirical correlation more accurate.

$$Nu_a = 0.60697\, {Re_a}^{0.435137}\, {Pr_a}^{1/3} \qquad \text{For smooth tube} \qquad 20$$

Table (5) empirical correlations for three cases integral finned tubes

t_{h1} °C	C	m	n	R^2	(20496.54 < Re_a < 48394.26) Air velocity range (1, 1.7, 2.3) m/sec
V_w =6L/min					
70	0.2449	0.4577	0.7661	0.945	$Nu_a = 0.2449\, Re_a^{0.4577}\, Pr_a^{1/3}\, (A_o/A_i)^{0.7661}$
60	0.1166	0.5317	0.7921	0.959	$Nu_a = 0.1166\, Re_a^{0.5317}\, Pr_a^{1/3}\, (A_o/A_i)^{0.7921}$
50	0.2279	0.4798	0.7577	0.95	$Nu_a = 0.2279\, Re_a^{0.4798}\, Pr_a^{1/3}\, (A_o/A_i)^{0.7577}$
V_w =5L/min					
70	0.5883	0.3790	0.7051	0.931	$Nu_a = 0.5883\, Re_a^{0.3790}\, Pr_a^{1/3}\, (A_o/A_i)^{0.7051}$
60	0.3773	0.4258	0.7177	0.927	$Nu_a = 0.3773\, Re_a^{0.4258}\, Pr_a^{1/3}\, (A_o/A_i)^{0.7177}$
50	0.4339	0.4214	0.7264	0.926	$Nu_a = 0.4339\, Re_a^{0.4214}\, Pr_a^{1/3}\, (A_o/A_i)^{0.7264}$
V_w =4L/min					
70	0.0740	0.5849	0.6263	0.931	$Nu_a = 0.0740\, Re_a^{0.5849}\, Pr_a^{1/3}\, (A_o/A_i)^{0.6263}$
60	0.0949	0.5638	0.6431	0.942	$Nu_a = 0.0949\, Re_a^{0.5638}\, Pr_a^{1/3}\, (A_o/A_i)^{0.6431}$
50	0.1069	0.5687	0.6100	0.957	$Nu_a = 0.1069\, Re_a^{0.5687}\, Pr_a^{1/3}\, (A_o/A_i)^{0.610}$
V_w =3L/min					
70	0.0417	0.6250	0.6806	0.951	$Nu_a = 0.0417\, Re_a^{0.6250}\, Pr_a^{1/3}\, (A_o/A_i)^{0.6806}$
60	0.0451	0.6276	0.6536	0.951	$Nu_a = 0.0451\, Re_a^{0.6276}\, Pr_a^{1/3}\, (A_o/A_i)^{0.6536}$
50	0.0434	0.6430	0.6462	0.934	$Nu_a = 0.0434\, Re_a^{0.6430}\, Pr_a^{1/3}\, (A_o/A_i)^{0.6462}$
V_w =2L/min					
70	0.1641	0.5009	0.6493	0.965	$Nu_a = 0.1641\, Re_a^{0.5009}\, Pr_a^{1/3}\, (A_o/A_i)^{0.6493}$
60	0.2481	0.4680	0.6539	0.972	$Nu_a = 0.2481\, Re_a^{0.4680}\, Pr_a^{1/3}\, (A_o/A_i)^{0.6539}$
50	0.4128	0.4123	0.7543	0.974	$Nu_a = 0.4128\, Re_a^{0.4123}\, Pr_a^{1/3}\, (A_o/A_i)^{0.7543}$

Conclusions

1.The heat transfer rate (q) proportional with the inlet water temperature and the air velocity for the four all cases. The heat transfer rates of (Low, med and high) integral finned tubes were bigger than the smooth tube.

- The maximum enhancement of heat transfer rate at the volumetric flow rate of water 6L/min are (50.7 %, 203.9 % and 329.9%) for (low, med and high) integral finned tube respectively to the above smooth tube.

- The improvement in the heat transfer rate at inlet water temperature 70°C of the cases (low, medium),(low, high) and (med, high) increases with the increasing of the height of the fins with percentage (104.2% , 187.6% and 40.8%) respectively.

2- The effectiveness of the heat exchanger is directly proportional to the number of heat transfer units. The high integral finned tube has highest effectiveness value comparison with (low, med, smooth).

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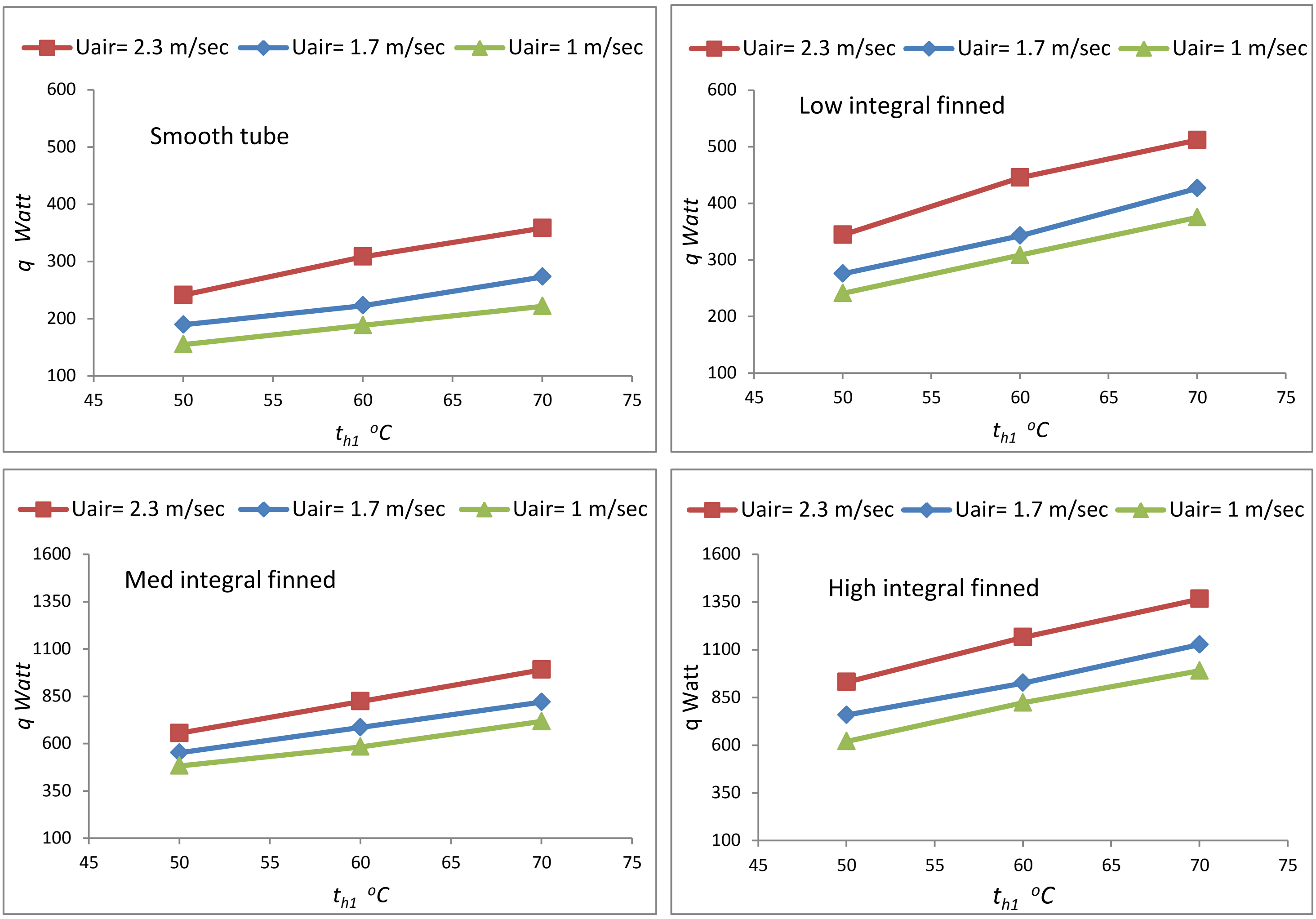

Fig. (4) Heat transfer rate against inlet water temperature and various air velocities at the water flow rate 5L/min

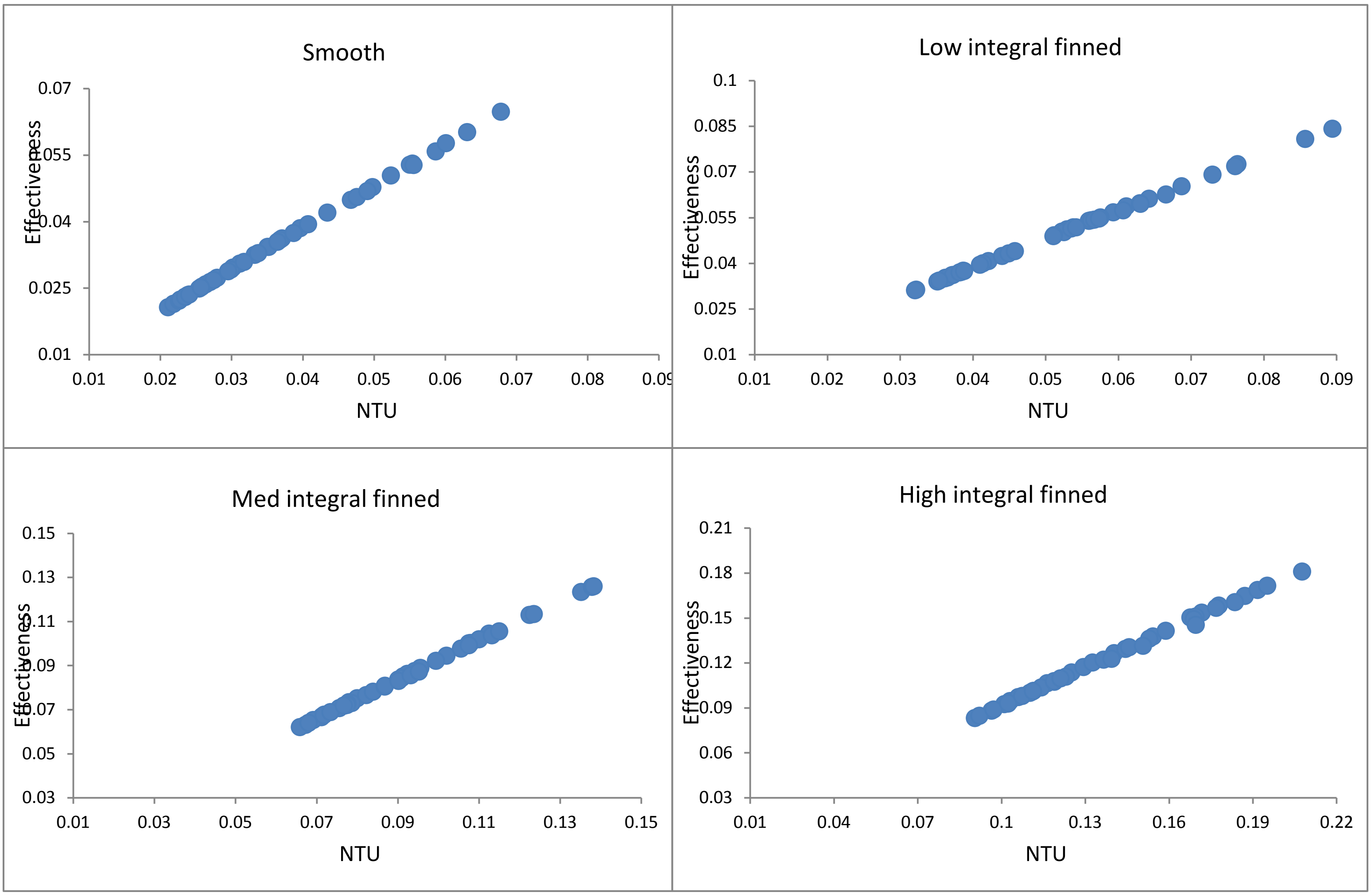

Fig. (5) Effectiveness for all cases against the (NTU)

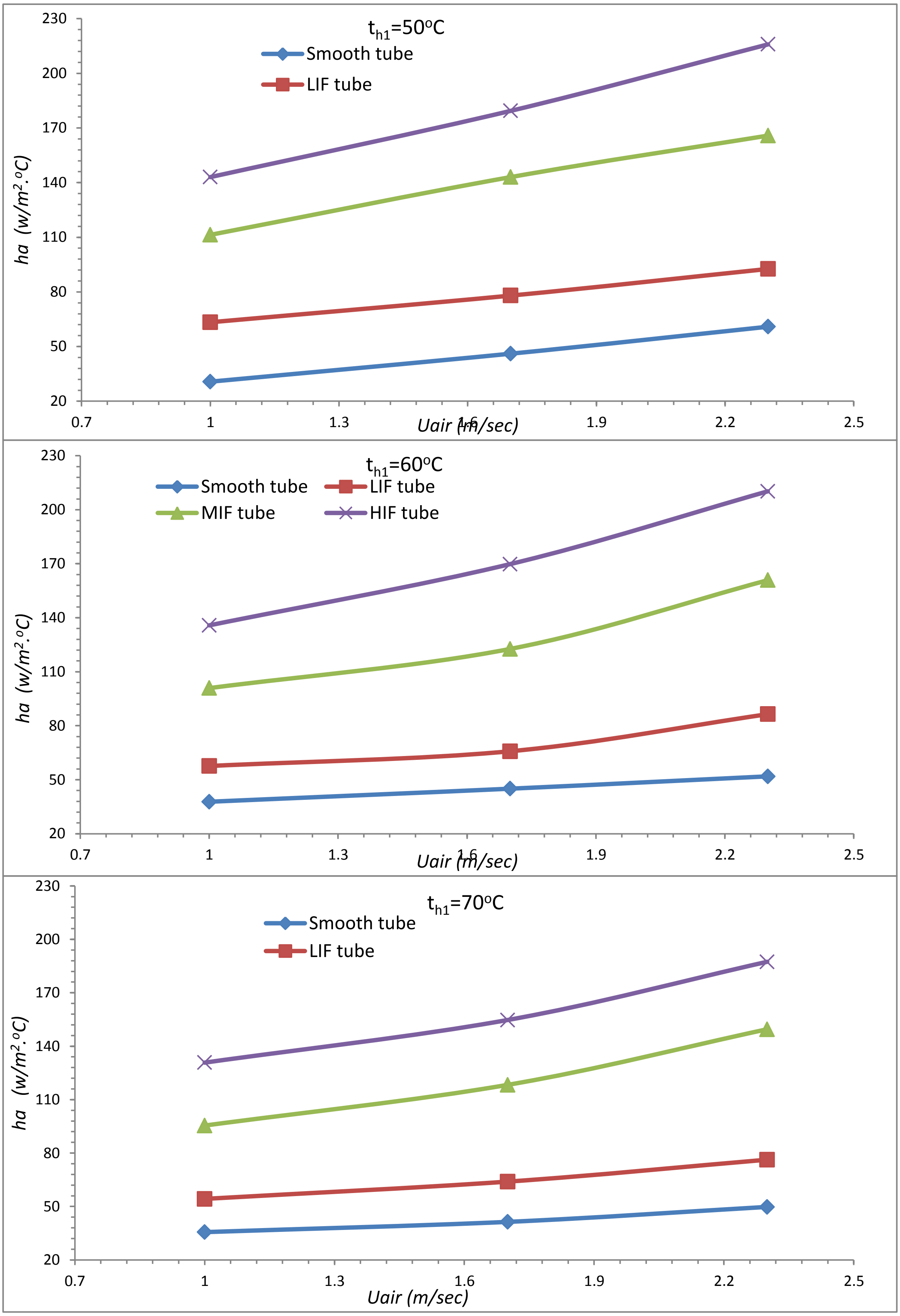

Fig. (6) Comparison the air side heat transfer coefficient against air velocity and various inlet water temperatures for all cases at 6L/min