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Heat transfer characteristics of a copper-nickel multi tube with corrugated copper fins in a cross flow heat exchanger

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Abstract

A systematic experimental investigation was conducted to evaluate the heat Transfer characteristics of a copper-nickel multi tube with corrugated copper fins in a cross flow heat exchanger. The heat transfer rate from a tube can be augmented either by increasing the surface area, by number of fins or by creating turbulence in the flow. Experiment was carried out under the copper fin tube type heat exchanger in which no. of fins is mounted along the full length of heat exchanger. The effect of no. of fins on a full length heat exchanger on the heat transfer coefficient was experimentally investigated in case of different mass flow rate of water and air. The performance evaluation of cross flow heat exchanger with copper fins was carried out for water temperature varying from 38^{o}C to 64^{o}C and water velocity 0.07735m/s to 0.271m/s and air velocity 3.194m/s to 14.52m/s. It was found that on the basis of different flow rate of water and air heat transfer coefficient increases constantly on the water and air side respectively.

Keywords: Heat exchanger, turbulence, traverse fins, Temperature variation.

Introduction

Improvement of heat transfer is of major practical importance in all industries. Because of the low heat transfer coefficient of air, it is usually necessary to use extended surface on air side of the heat exchanger to exchange heat with water. Hence, attempt should be made to increase heat transfer rate at lower increase in friction factor. Several approaches had been done to solve this problem. Various works have been done to study the friction and heat transfer characteristics of fluid inside the tube. Most of these experiments were conducted in USA, JAPAN and POLAND in a wide range of fluid flow and heat transfer parameters with the presentation of various empirical correlations. Various designs of heat exchanger with different configuration (Eckel *et al*., 1985; Mueller, 1988; Shah, 1988; Heggs, 1999; Wei-Mon Yan & Pay-Jen Sheen, 2000; Douglas T Crane *et al*., 2004; Somchai Wongwises, 2005; Vaisi *et al.,* 2011) have been proposed to enhance heat transfer co-efficient of cross flow fine tube heat exchanger. Ercan Ataer (2004) has developed a closed, approximate, analytical approach is obtained for transient behavior of finned-tube, liquid cross flow heat exchangers for the step change in the inlet temperature of the hot fluid. The temperature variation of both fluids between inlet and outlet is assumed to be linear.

Aparecido Navarro and luben (2005) has discussed a new numerical methodology for thermal performance calculation in cross-flow heat exchanger is developed. Dong-Keun Yang and Kwan-soo Lee (2006) has developed optimal values of the design parameters for a fin-tube heat exchanger of a household refrigerator under frosting conditions are proposed to improve its thermal performance and extend its operating time. In the optimization procedure, fin spacing's of the heat exchangers are selected as the design parameters. Kaptan and Buyruket (2008) have investigated fouling on heat exchanger and its effects of fouling on heat transfer and flow structures numerically for cross-flow heat exchanger tube geometry. Prabhat Kumar Gupta and Ashesh Tiwari (2008) have investigated heat transfer co-efficient for cryogenic cross counter flow coiled finned tube heat exchangers. Bayram Sahin and Alparsian Demir (2008) have developed optimum design parameter of heat exchanger having perforated pin fins for improving heat transfer co-efficient. Passakorn Vessakosol and Jarwat Charoensuk (2010) have given numerical analysis of heat transfer and flow field around cross flow heat exchanger tube with fouling. Vaisi *et al*. (2011) has investigated transient behavior simulation of fin and tube heat exchanger for the variation of the inlet temperatures of both fluids (hot and cold). The present investigation is taken off with the objective of experimentation on cross flow copper nickel fin tube heat exchanger to collect data on heat transfer co-efficient and fluid flow characteristics. The bi-metallic finned tube which is being investigated is a copper alloy base tube with corrugated copper fins of uniform thickness. The investigation has been carried out for water temperature varying from 38 ^{o}C to 64 ^{o}C and water velocity 0.07735m/s to 0.271m/s and air velocity 3.194m/s to 14.52m/s. These ranges have been selected to suit the conditions prevailing.

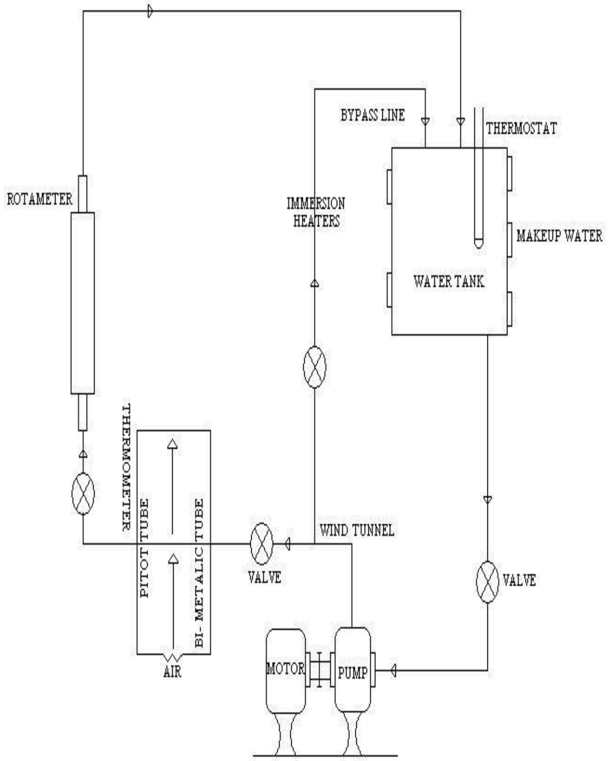
Experimental setup

The experimental setup use in the present investigation is shown in Fig.1 & 2. The heat exchanger is fitted in the wind tunnel with the help of rubber pipes clamped with clips. Also the heat exchanger pipe is supported by an angle iron frame resting on a vibration damped foundation. The heat exchanger is single flow type for both air and water side. It is found by approximate heat balances expected that the decrease in temperature on the water side even with sufficiently high

Fig.1. Photograph of experimental setup and cross flow multi tube heat exchanger

turbulent flow of air was very small. Hence the experimental accuracy is very much curtailed in spite of using accurate instruments for measuring temperature. The arrangement of experiment setup consists of: (a) An overhead water tank (3' x 2' x 2') and 5meter long is used to store the water. (b) An immersion rod is used for heating the water. Its capacity is 1.5 KW and use 7 no. (c) A wind tunnel used for flow of air. (d) Measuring device like Rota meter, Thermometer, Inclined manometer, Pitot tube. (e) A 5 h.p. induction motor.

Fig.2. Block diagram of experimental setup



The water passing through the tubes of heat exchanger was supplied by a 5 h.p. motor pump set. The hot water which is heated with the help of immersion rods is circulated at a particular temperature from a water tank. The section line is about 5 m. long and the delivery is about 1.5 m and 6m back from the heat exchanger to the tank. Appliances for providing a more-or-less constant supply of hot water are generally known as water heaters, boilers, or geysers depending on whether they are heating potable or non-potable water. The atmospheric air was made to flow through the wind tunnel 15" x 6' by a blower being driven by a 5 h.p. induction motor. The air flow is varied by a varying the speed of the blower by means of a reversible input CATER gear. The air from the blower passes through a mesh before it reaches to the heat exchanger pipe to ensure that it has been thoroughly mixed and cleaned. A Rota meter is a device that measures the flow rate of liquid in a closed tube.

Fig. 3. Arrangement of rota meter and inclined manometer

A rota meter shown in Fig. 3 consists of a tapered tube, typically made of glass, with a float inside that is pushed up by flow and pulled down by gravity. A rota meter requires no external power it uses only the inherent properties of the fluid, along with gravity, to measure flow rate. The thermometer is a device that measures temperature or temperature gradient. Inclined manometer is a device is shown in Fig.3 to measure a minimum differential head of the order of 0.01m of water, and in its simplest form is a vertical glass U tube half filled with water. A Pitot tube is a measuring instrument which is used to measure fluid flow.

Experimental procedure and data reduction

Firstly, the measuring instruments were calibrated. Then the heat exchanger was calibrated and tested for heat balance. Approx. 2 to 5% error was found in heat load of hot fluid and cold fluid side of heat exchanger due to temperature variation and surface roughness on water and air side. There are seven holes drilled on air tunnel to put thermometers and pitot tube which were arranged along rubber cork before the heat exchanger tube and three thermometers are after it. Pitot tube is connected to the water column so as to find the velocity of air in the tunnel. In the air tunnel one mesh is provided to get proper mixing of air before it passed over the heat exchanger pipe. There is an arrangement of gearing system in order to vary the amount of air flow. In the water side amount of flow is measure with the help of rota meter. Its capacity is 20 to 200 lit./ Min. and accuracy of 5 lit/min. Here also two thermometer pockets are provided just after the delivery of the pump one by pass line is fitted with a control valve so as to decrease the amount of water pressure in the heat exchanger pipe. Amount of flow can be controlled with the help of valves. After passing through heat exchanger pipe the water is taken back into the water tank. Experiments were conducted over the following range of inputs parameters and dimensions of cross flow copper fins and copper nickel tube heat exchanger is given in Table 1.

Table 1. Dimensions of cross flow copper fins and copper nickel tube heat exchanger

Outer dia of base tube	Do	16 mm
Thickness of tube (Do- Di) / 2 = 1 mm.	t	1 mm
Outer dia of tube with fins	D_f	38 mm
Hheight of fin (D_f - Do) / 2 = 11 mm.	h	11mm
Length of tube	L	600 mm
Thickness of fin	W	0.12 mm
Total No: of fins per unit length of tube		394 /ft.
Total No: of fins	N	788 for one tube
Total No: of tubes	n	14
Spacing between fins	S_f	1.313 mm
Air flow area	A_1	49343.18 mm^2
Surface area of fin	A_f	2069580.709 mm^2

Range of input parameters

(i) Air velocity : 3.194m/s to 14.53m/s
(ii) Water velocity : 0.078m/s to 0.27m/s
(iii)Avg. air inlet temp. : 38^oc to 65^oc
(iv)Water inlet temperature: 58^oc to 63^oc

The no. of formulas had been used for detailed calculation of convective heat transfer coefficient, water velocity and air velocity which are given below:

(i) Convective heat transfer coefficient on air side:

$$h_a = J_a (K / d_e)(C_p \mu / K)^{1/3}$$

(ii) Convective heat transfer coefficient on water side:

$$h_w = J_w (K/ D_i) (Cp_w \mu / K)^{1/3}$$

(iii) Convective heat transfer coefficient on air side with fin efficiency

$$h_a'' =(\Omega \times A_f \times A_o) \ h_a / A_i$$

(iv) Water velocity:

$$V_w = v_w / A_{ct}$$

(v) Air velocity:

$$V_a = \sqrt{} (2000 \, g \, \Delta h \sin \theta$$

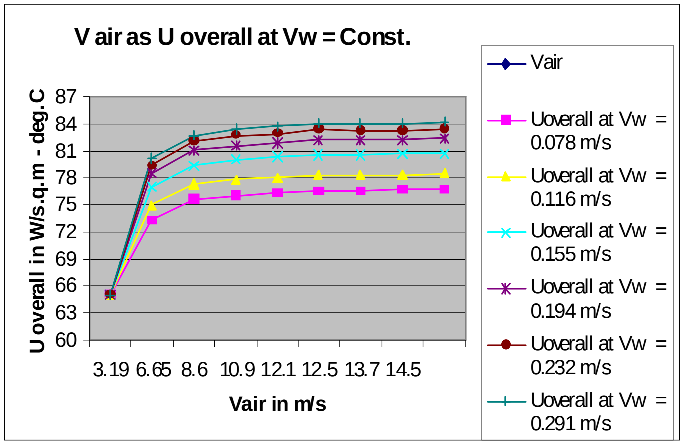
Result and discussion

After having studied the heat transfer and fluid flow characteristic, it becomes necessary to combine these to evaluate the performance of cross flow fin tube type heat exchanger for this purpose, their performance was studied for each heat flux separately for variation of heat transfer on water and air side with respect to flow rate on water and air side with respect to water velocity and air velocity respectively. The overall heat transfer coefficient and heat transfer coefficient increases as the air velocity increases at constant water velocity in all cases. And on equal mass flow rate of water basis heat transfer on water and air side first increases from 10-15 lit/min. then after 15-35lit/min decreases.

Variation of overall heat transfer co-efficient with air velocity at constant water velocity

Fig. 4 indicates if the air velocity (V_a) increases from 3.194 m/s to 6.65 m/s. overall heat transfer co- efficient ($U_{overall}$) increases gradually. The reason for this it could be that the air flow is laminar at 3.194 m/s of air velocity and it may become turbulent at 6.65 m/s of air velocity due to this turbulence the $U_{overall}$ increases suddenly. But as the air velocity increases after 6.65 m/s and further the air flow remains turbulence that's why $U_{overall}$ increases gradually. Further it has been noticed that as the air velocity increases over all heat transfer co-efficient is also increased in all cases i.e. for water velocity of 0.07735, 0.1160308, 0.1547, 0.194, 0.23206, 0.271 m/s respectively.

Fig .4. Variation of $U_{overall}$ with V_{air} at constant V_w



Variation of air side heat transfer co -efficient with air velocity at constant water velocity

Fig. 5 indicates if air side heat transfer co-efficient increases suddenly when air velocity changes from 3.194 m/s to 6.65 m/s and after 6.65 m/s, it increases gradually. Since the water side heat transfer co - efficient is constant for different air velocities at constant water velocity in all cases therefore the air side heat transfer co - efficient mainly affects the overall heat transfer co - efficient of the given heat exchanger. As $U_{overall} = h''_a . h'_a h'_w / (h''_a + h'_w)$ so value of $U_{overall}$ changes proportionally as the air side heat transfer co - efficient

Fig.5. Variation of h" of air with V_{air} at constant V_w at constant water velocity

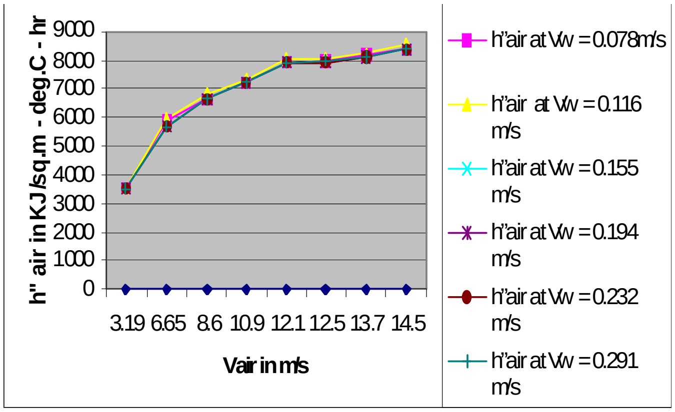


Fig. 7. Variation of heat transfer on air side at different water flow rate

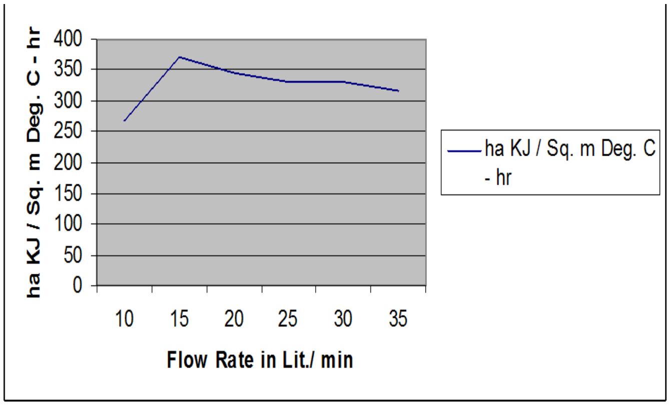
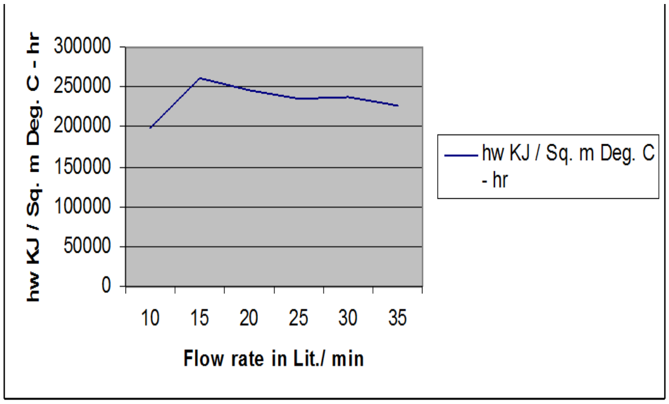


Fig. 6. Variation of heat transfer on water side at different water at constant water velocity



increases with respect to air velocity from 3.194 m/s to 6.65 m/s at constant water velocity in all cases i.e. V_w = 0.07735, 0.1160308, 0.1547, 0.194, 0.23206, 0.271 m/s.

Variation of heat transfer on water side at different water flow rate

Fig. 6 shows that as the flow rate 10 to 15 Lit. / min. Increases, heat transfer also increases but after 15 Lit./ min to 35 Lit. / min the heat transfer rate decreases in permissible limit due to variation of heat flux at temperature difference at water side

Variation of heat transfer on air side at different water flow rate

Fig. 7 shows that as the flow rate 10 to 15 Lit. / min. increases, heat transfer also increases. But after 15 Lit./ min to 35 Lit. / min the heat transfer rate decreases in permissible limit due to variation of heat flux at temperature difference at water side. The air side and the

Table 2.Variation of $U_{overall}$ heat transfer co-efficient with air velocity at constant water velocity

V_{air}	$U_{overall}$ atV_w = 0.078m/s	$U_{overall}$ atV_{wa} = 0.116m/s	$U_{overall}$ atV_w = 0.155 m/s	$U_{overall}$ atV_w = 0.194 m/s	$U_{overall}$ atV_w = 0.232 m/s	$U_{overall}$ atV_w = 0.291 m/s
3.194	73.36	74.96	77.03	78.51	79.49	80.19
6.65	75.69	77.34	79.48	81.06	82.10	82.85
8.60	76.08	77.83	80.04	81.65	82.70	83.46
10.90	76.35	78.05	80.34	81.96	83.02	83.78
12.1	76.60	78.31	80.625	82.25	82.32	84.09
12.52	76.61	78.32	80.63	52.26	83.30	84.07
13.68	76.68	78.39	80.71	52.34	83.37	84.15
14.53	76.75	78.48	80.77	82.41	83.48	84.26

Table 3. Variation of air side film co-efficient with air velocity

V_{air}	h"$_{air}$ata V_w =0.078m/s	h"$_{air}$ atV_w =0.116m/s	h"$_{air}$ atV_w =0.155m/s	h"$_{air}$ atV_w =0.194m/s	h"$_{air}$ atV_w =0.232m/s	h"$_{air}$ atV_w =0.291m/s
3.194	3487.2	3532.6	3487.2	3487.2	3487.2	3487.2
6.65	5898.9	5907.5	5699.7	5699.7	5699.7	5699.7
8.60	6625.4	6811.7	6625.4	6625.4	6625.4	6625.4
10.90	7244.4	7331.9	7244.4	7244.4	7244.4	7244.4
12.1	7938.9	8023.6	7938.9	7938.9	7938.9	7938.9
12.52	7955.6	8038.2	7891.4	7891.4	7891.4	7891.4
13.68	8171.2	8251.5	8089.9	8089.9	8089.9	8089.9
14.53	8373.5	8536.9	8373.5	8373.5	8373.5	8373.5

water side pressure drop both increase with air velocity and water velocity respectively within the permissible limit (Table 2 to 5).

Table 4. Variation of heat transfer on water side with respect to flow rate

hw KJ / Sq. m Deg. C - hr	Flow Rate Lit. / min
198010.88	10
261855.18	15
245801.59	20
236153.92	25
237359.06	30
226013.32	35

Table 5. Variation of heat transfer on water side with respect to flow rate

ha KJ / Sq. m Dieg. C - hr	Flow Rate Lit. / min
268.59	10
371.41	15
345.78	20
329.63	25
331.72	30
315.47	35

Conclusion

From the present investigation on heat transfer characteristics on water and air side at different mass flow rate of water and air & their velocity on cross flow fin tube heat exchanger, it is concluded that: The min. $U_{overall}$ is 73.36w/m^2-^{o}c (at Va=3.194 m/s & Vw=0.078m/s) and max. h"a is 8373.49 KJ/m^2-^{o}c-hr(at Va=14.53m/s & Vw=0.27m/s.); and max. $U_{overall}$ is 84.26w/m^2-^{o}c (at Va=14.53m/s & Vw=0.27m/s).& min. h"a is 3487.15 KJ/m^2-oc-hr (at Va=3.194 m/s & Vw=0.078m/s).

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