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Evaporative Effectiveness & Mass Transfer Coefficient of A U-Shape Brass Tube of an Evaporative Heat Exchanger

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Abstract— The results of this experimental investigations on evaporative effectiveness and mass transfer coefficient of U shape brass tube of an evaporative heat exchanger are offered in this thesis report. The U shape brass tube is subjected to flow of water only & concurrent flows of cooling water from the top; air flows from the underneath and the process fluid are flowing through the tubes. Evaporative effectiveness and mass transfer coefficient are estimated within following range of operating variables Reynolds number of water223 $\leq Re_w \leq$ 1032. Reynolds number of air 2460 $\leq Re_a \leq$ 8059. It is reported that the increase in evaporative effectiveness is found with slight stagnation with increase of Reynolds number of water and Reynolds number of air. Evaporative effectiveness and mass transfer coefficient decreases with increase of Dimensionless enthalpy potential. The percentage increase in Evaporative effectiveness with increase in Reynolds number of water is from 9.23% to 14.72% Mass transfer coefficient increases almost proportional to increment in film Reynolds number of water and Reynolds number of air. The percentage increase in mass transfer coefficient with increase in Film Reynolds number is from 80.94 % to 108.50 %. Based on the experiments correlations derived using the multiple regression analysis. The present empirical results show good agreement with the experimental results. Developed correlations are helpful in improvement of the design of heat transfer devices and many other engineering applications.

***Keywords**— Evaporative effectiveness, mass transfer coefficient, U shape brass tube, heat exchanger*

I. INTRODUCTION

Cooling effect generated by evaporation of water when it comes in contact with blowing air is called evaporative cooling. As air blows and comes in contact with water, some water evaporates and the temperature gets down. Evaporative cooling technique is widely applied in many industries and firms. An evaporative Heat exchanger is a combination of cooling tower and Heat exchanger. The purpose to cool the water and cool the process fluid with the help of cooled water is merged. Researchers aim to improve the effectiveness of heat exchanger which is directly proportional to the heat & mass transfer coefficient. Research work done in the past can provide a good General idea about different aspects of Evaporative cooling process. Erik Karlsson et al [1] performed heat transfer measurements for falling film evaporation up to very high Prandtl numbers. Trilok Singh et al [2] reported the comparative thermal analysis of theoretical and experimental studies of modified indirect evaporative cooler having cross flow heat exchanger. Bilal A. Qureshi [3] investigated the risk based thermal performance of evaporative heat exchangers. B. costelloe et al [4] examined the experimental performance of an open industrial scale cooling tower. Mostafa M. Awad et al [5] studied the heat transfer enhancement of falling film evaporation on a horizontal tube bundle. Rajneesh et al [6] represented experimental investigation on mass transfer coefficient and evaporative effectiveness of evaporative tubular heat exchanger. Seong-YeonYoo at al [7] analyzed thermal performance of heat exchanger for closed wet cooling tower using heat and mass transfer analogy. J.T. Libertya et al [8] reviewed the concept, principle, method and types of

Vol. 2 Issue VIII, August 2014
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INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AND ENGINEERING TECHNOLOGY (IJRASET)

evaporative cooling. Taye S. Mogaji et al [9] developed an evaporative cooling system for the preservation of fresh vegetables for extending the shelf life. AlaHasan et al [10] investigated the performance of plain and finned tube evaporatively cooled heat exchangers. The performance of two evaporatively cooled heat exchangers was also investigated under similar operating conditions. HemantParmar et al [11] examined the potential of a simple desiccant evaporative cooling cycle in five selected cities in Warm and Humid climate zone of India.Ganic et al [12] investigated the mechanism of water film formation over a horizontal tube. Rin Yun at al [13] experimentally investigated the evaporation heat transfer characteristics of carbon dioxide (CO_2) in a horizontal tube. H.-Y. Kim et al [14] studied the effect of hydrophilic surface treatment on evaporation heat transfer at the outside wall of various kinds of copper tubes.

II. TEST SETUP

The schematic diagram of experimental setup is shown in fig.1. The test unit i.e. U shape brass tube is prepared with the following specifications:

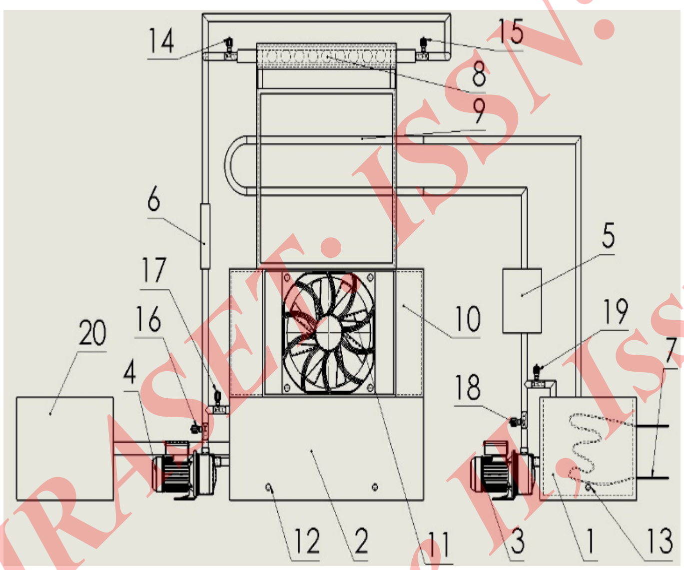

Fig.1 Schematic of Experimental setup

1 Hot fluid reservoir ; 2 Cold fluid reservoir; 3-4 supply pumps; 5-6 Digital flow meter; 7 Heating element ; 8 Cold fluid spray system ; 9 U-shape brass tube;10 Air duct; 11 Blower; 12-13 Sanitations; 14-19 Flow control valves; 20 Feeder chamber.

i) The outer diameter (D_o) of the tube is 0.0254 m.

ii) The inner diameter (Di) of the tube is 0.0234 m.

iii) Active length (l) of the tube is 1.2 m.

iv) The horizontal projection of the U tube is 0.6 m.

v) Outside surface area of the test unit A_o is 0.095755 m^2.

vi) Longitudinal Pitch (P) of the U shaped brass tube is 0.0762 m.

In hot water reservoir water is heated with heating elements and then circulated through U shape tube with help of pump. Cooling water from the reservoir is supplied to spray pipe system with the help of pump. Air is supplied from an axil flowers and flows form bottom to top in the duct. RTD PT 100 sensors are used to measure temperatures at different stages in combination with data logger with resolution of 0.1^oC. Flow rates of cooling and hot water are measured with digital flow meters and flow control valves are used to adjust the flow rate. Velocity of air is measured at top of the section with the help of anemometer.

III. METHODOLOGY

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A. Heat transfer rate (With water only)

The cold water was made to flow over a U shaped horizontal brass tube. The flow rate of cooling water was taken initially fixed at 0.05219 kg/s and gradually increased up to 0.24310 kg/s in 6 equal intervals. The hot water then made to flow through the tube at 58.96 ±.0.44 ^oC at 0.6256 kg/s to provide the heat load and the steady state was achieved in each step. Then, Hot water temperature at inlet and outlet, Tube surface temperature, cooling water temperature at inlet and outlet and flow rate of hot & cold water are measured in each reading.

B. Heat transfer rate (with simultaneous flow of water and air)

The above experiment was repeated for first, second, third, fourth, fifth & sixth set of readings at air velocities at the top of test section as 1.5 m/s, 3.4 m/s, 4.2 m/s, and 4.9 m/s. Each set of observation contain four readings. The temperature of air (dry bulb temperature and wet bulb temperature) at inlet and outlet of the test section were measured in addition to the

Vol. 2 Issue VIII, August 2014

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INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AND ENGINEERING TECHNOLOGY (IJRASET)

all the parameters measured in previous experiment with water only.

IV. RANGE OF OPERATING VARIABLES

The flow rate of process fluid (hot water) in the experiment is taken constant at 0.6256 kg/s and the flow rate of cooling water is taken in the range of 0.05219 kg/s to 0.2431 kg/s. The temperature of the process fluid is taken as 60. ±2^{o}C and the temperature of the cooling water is taken as 29.5±0.5^{o}C. The temperature of the air is taken as 30±1^{o}C and the velocity of the air is controlled in the range of 1.5 m/s to 4.9 m/s. Reynolds Number of cooling water is taken in the range of 223 to 1032 and the Reynolds Number for air is taken in the range of 2460 to 8059.

V. MATHEMATICAL EQUATIONS

Evaporative effectiveness and mass transfer coefficient are the parameters which controls the performance of a tube of evaporative heat exchanger for the present investigation. The mass transfer coefficient is determined as:

$$K = \frac{Q}{A_o(i_s - i_a)} \quad \text{(i)}$$

Mass transfer coefficient ratio is the ratio of mass transfer coefficient and maximum value of mass transfer coefficient when tube is subjected to simultaneous flow of water and air was determined by following equation:

$$\overline{K} = \frac{K}{K_{\max}} \quad \text{(ii)}$$

The evaporative effectiveness is defined as the ratio of heat transfer rate in a given evaporative cooler to that of a simple water cooler and is expressed as:

$$EE = \frac{Q_{wa}}{Q_w} \quad \text{(iii)}$$

where, 'Q_{wa}'is the heat transfer rate from a U shaped brass tube, when both air and cooling water flowing simultaneously can be written as:

$$Q_{wa} = W_h C_p (T_{hi} - T_{ho}) \quad \text{(iv)}$$

and 'Q_w'is the heat transfer rate from a U shaped brass tube, when only cooling water flowing at same operating conditions and is calculated as:

$$Q_w = W_h C_p (T_{hi} - T_{ho}) \quad \text{(v)}$$

Reynolds number of air and Reynolds number of cooling water were determined as:

$$\text{Re}_a = \frac{\rho_a V_{t,s} D_o}{\mu_a} \quad \text{(vi)}$$

$$\text{Re}_w = \frac{4\Gamma}{\mu_w} \quad \text{(vii)}$$

Liquid film flow rate per unit length of cooling water, Γ found as:

$$\Gamma = \frac{W_w}{2l} \quad \text{(viii)}$$

Where, l is horizontal projection length of a tube and its value used here as 0.6 m.

Dimensionless enthalpy potential was calculated as:

$$(\overline{EP}) = \frac{(i_s - i_a)}{i_{fg}} \quad \text{(ix)}$$

where, (i_s-i_a) is enthalpy potential, the difference of enthalpy of saturated air at the average tube surface temperature and the enthalpy of air at the inlet of heat exchanger and 'i_{fg}'is the latent heat of vaporization of water at inlet at the mean temperature of cooling water.

VI. RESULTS AND DISCUSSIONS

In order to study the qualitative effects of film Reynolds number of water (Re_w), Reynolds number of air (Re_a) and dimensionless enthalpy potential $\overline{EP}$ on Evaporative effectiveness & mass transfer coefficient , the computed results are shown in the graphical form in Fig. 2 to 5.

Vol. 2 Issue VIII, August 2014

ISSN: 2321-9653

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AND ENGINEERING TECHNOLOGY (IJRASET)

A. Effect of film Reynolds number on Evaporative Effectiveness.

The effect of Reynolds number of cooling water on the Evaporative effectiveness is shown in fig 2 for some selected value of Reynolds number of air. It is observed from fig that Evaporative effectiveness increase with Reynolds number of water up to the value of 385 then it slightly drops and again increases.

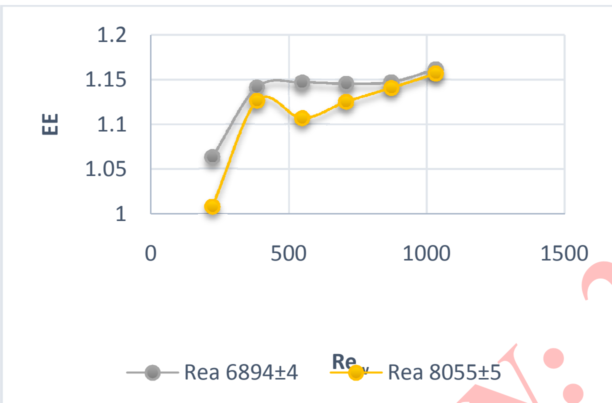


Fig.2 Effect of film Reynolds number on Evaporative effectiveness

Effect of film Reynolds number on masstransfer Coefficient

The effect of Reynolds number of water on Mass transfer coefficient for some selected value of Reynolds number of air is shown in fig 3. It is observed from fig that Mass transfer coefficient increases with Reynolds number of water.

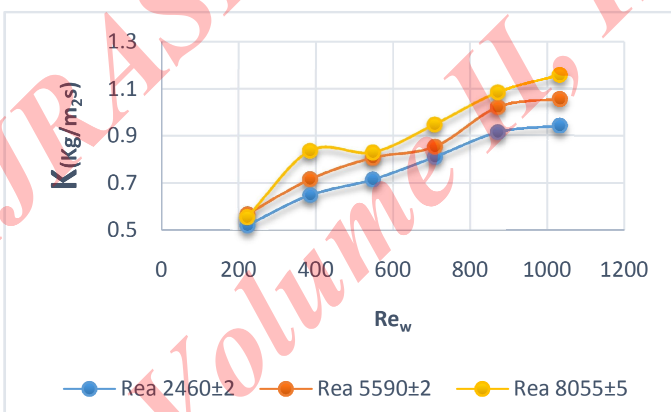


Fig.3 Effect of film Reynolds number on mass transfer coefficient

B. Effect of Enthalpy potential an EvaporativeEffectiveness

The effect of Enthalpy potential on Evaporative Effectiveness for some selected values of Reynolds number of air is shown in fig 4. It is observed from fig that Evaporative Effectiveness decreases with increase in Enthalpy potential.

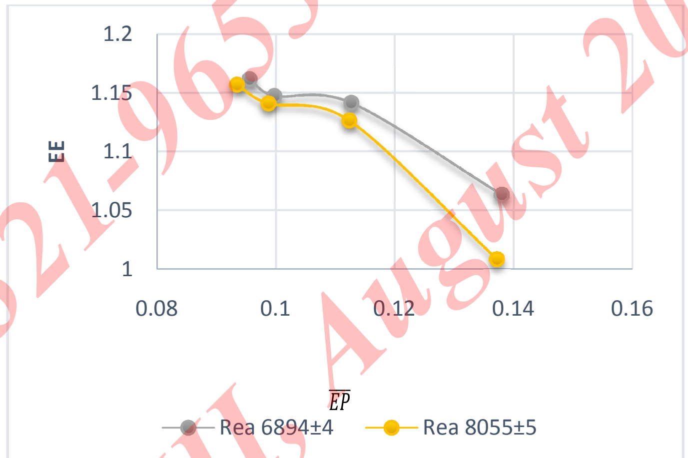
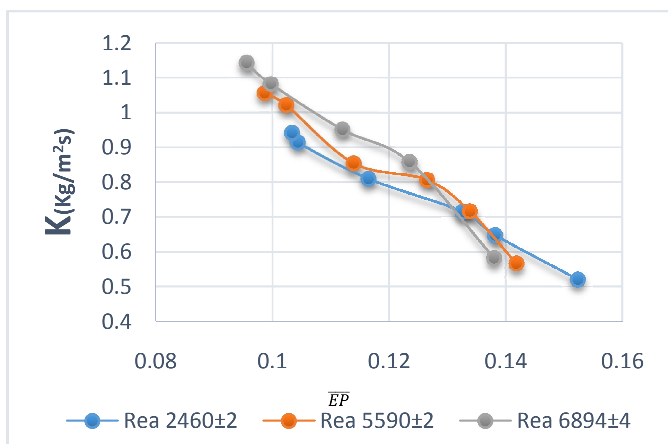


Fig.4 Effect of Dimensionless Enthalpy potential on Evaporative Effectiveness

C. Effect of Enthalpy potential on Mass transfer Coefficient

The effect of Enthalpy potential on mass transfer coefficient for some selected values of Reynolds number of air is shown in fig 5. It is observed from fig that the mass transfer coefficient decreases with increase in enthalpy potential.



ISSN: 2321-9653

Fig.5 Effect of Dimensionless Enthalpy potential on Mass transfer coefficient

VII. CORRELATIONS DEVELOPED

A multiple regression analysis of the experimental data collected on U shape brass tube is used to find the correlations and to improve the system performance. The computed results are used to develop the correlations of Evaporative effectiveness & mass transfer coefficient in terms of dimensionless numbers.

These relations provide effective results within the specified operating variable range specified

A. For Evaporative effectiveness

$$EE = 0.39(Re_w)^{0.028} (Re_a)^{0.09} (\overline{EP})^{-0.029} \qquad (x)$$

This correlation shows percentage error in between experimental values and predicted values is ±7 %

B. For Mass transfer coefficient

$$\overline{K} = 0.014(Re_w)^{0.27} (Re_a)^{0.10} (\overline{EP})^{-0.60} \qquad (xi)$$

This correlation shows percentage error in between experimental values and predicted values is ±10.35 %

VIII. CONCLUSIONS

In this investigation, experiments have been conducted on a U tube evaporative heat exchanger with water only and also with simultaneous flows of water and air. Cooling water from cooling water spray system is distributed uniformly over the U tube. Experiment has been operated under various operating conditions to determine Evaporative Effectiveness and mass transfer coefficient for a U shape brass tube.

Following major conclusions are drawn from the Evaporative effectiveness and mass transfer coefficient studies being carried out on the U shaped brass tube of the heat dissipater which was subjected to water flow and also with simultaneous flows of water and air in the form of sprays from the top:

1. The increase in evaporative effectiveness is found with slight stagnation with increase of Reynolds number of water and Reynolds number of air.

2. Evaporative effectiveness and mass transfer coefficient decreases with increase of Dimensionless enthalpy potential.

3. The percentage increase in Evaporative effectiveness with increase in Reynolds number of water from 223 to 1035 is from 9.23% to 14.72% when Reynolds number of air is varied from 2460 to 8060.

4. Mass transfer coefficient increases almost proportional to increment in Reynolds number of water and Reynolds number of air.

5. The percentage increase in mass transfer coefficient with increase in Reynolds number of water from 223 to 1035 is from 80.94 % to 108.50 % when Reynolds number of air is varied from 2460 to 8060.

6. The effects of Reynolds number of air on both the parameters Evaporative Effectiveness and Mass transfer coefficient are less pronounced than that of Reynolds number of water.

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