THOMSON REUTERS
ENDNOTE
[Prajapati*, 5(2): February, 2016]
ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785
IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

EXPERIMENTAL STUDY OF COPPER COILS ON EVAPORATIVE TUBULAR HEAT DISSIPATOR TO FIND THE EFFECT OF REYNOLDS NUMBER OF WATER AND INLET TEMPERATURE OF PROCESS FLUID ON DRY OUT HEAT FLUXES WITH ONLY WATER FLOW

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DOI: 10.5281/zenodo.46616

ABSTRACT

The experimental results of a copper coils of an evaporative tubular heat dissipator are investigated in this paper. Effect of Reynolds number of water and inlet temperature of process fluid (hot water) on dry out heat flux with only flow water is determined on different operating conditions. Based on the experiments it is concluded that due to increase in the value of Reynolds number of water (Re_w) & inlet temperature of process fluid (T_{pi}) the dry out heat flux on (Q_{on}) & (Q_{per}) are increased.

KEYWORDS: Reynolds number of water, Dry out Heat flux, Onset heat flux, Permanent heat flux, Heat Dissipation, Evaporative tubular heat dissipator, copper coils.

INTRODUCTION

Evaporative tubular heat dissipator is widely used for cooling of heat process fluids. In an evaporative tubular heat dissipator, fluids viz cold water falls over horizontal tubes in which process fluid (hot water) is passing. For a plant to dissipate the heat energy the temperature of cooling water should not exceed a certain prescribed value. Since air is a poor thermal conductor (to absorb heat from heat surface) hence, for increasing the heat transfer rate of an evaporative tubular heat dissipator, simultaneous flow of both air & water is used.

To obtain an optimum heat transfer rate out of a tubular heat dissipator, there should be an adequate flow of both air and water, across it. The main objective of evaporator is to enhance the efficiency and effectiveness of the process by utilization of heat and energy. The heat transfer coefficient of single copper coil is a function of air-water cross flow arrangement where the water is allowed to shower from top and air rises from underneath. The reduction of inlet water temperature depends upon the humidity, velocity of air and tube spacing. Only few researchers was this worked in this area both analytical and experimental studies have been performed to enhance the performance of Evaporative Tubular Heat Dissipator. Dhar. P.L. et al. [1] conducted experiment with the film is sub cooled and heat transfer from the heated surface is absorbed in the liquid film. The heat transfer coefficient and film break down heat flux data were obtained. The effect of tube spacing and liquid film inlet temperature on the breakdown heat flux and heat transfer coefficient was also studied. Ganic.et al. [2], investigated the mechanism of water film formation over a horizontal tube. They conducted experiment with sub cooled film where heat transfer took place from heated surface to get absorbed by the liquid film. The heat transfer coefficient and film break down heat flux data were obtained. The effect of tube spacing and liquid film inlet temperature on the breakdown heat flux and heat transfer coefficient was also studied by Ganic. Rana et al [3] made investigation without the use of air flow from a single horizontal tube. Here, initially water was used for heat dissipation and then both air and water flow was used simultaneously for dissipation of heat energy. When only water is falling the total energy dissipated by inside hot fluid was compared with both the air and water from the same tube. Rana et al. [4] investigated the mass transfer coefficient experimentally with simultaneous flow of water and air. Mass transfer coefficient was calculated theoretically by applying Lewis relation for both air and water mixture. The mass transfer coefficient with simultaneous flows of air and water is calculated by enthalpy difference. From a design point of view the importance of the effect of Reynolds number of air, cooling water and that of process fluid was studied by Rana & Charan**.** In general, mass transfer coefficient with simultaneous flow of water and air is theoretically calculated and result found from theoretically was compared with only air by using Lewis relation for air water mixture Biyikli et al [5] determined the heat transfer coefficients for a single horizontal tube located above an air fluidized bed and reported increased heat transfer for a gas particle environment. R.S Rana et al [6] studied the additional effect of Re_p passing through the tube & observed that the Nusselt number decreases slightly with Re_p. They have given the empirical relation for Nusselt number in terms of Re_a as negligible. Further, they used their correlation for calculating the heat transfer coefficient with only air flow to predict the theoretical mass transfer coefficient by using Lewis relation. Parez-Blanco et al. [7] has carried out studies on the heat and mass transfer processes of vertical tube evaporative cooler. Murray D.B. [8] made comparison of the heat transfer characteristics of staggered and in-line arrays and found how to increase and decrease the local and overall heat transfer coefficient in each case. Yan and Lin [9] X. Hu et al. [10] Armbruster R. et al. [11] Kumar et al [12] Ali S. Alosaimy [13] Stabat Pascal et al. [14] Danko G. et al. [15] Lin Yuzhen et al. [16] Eashwar Serthuraman et al. [17] Syed Naveed UL Hasan [18] Paul Schausberger[19] Muhammad M.et al. [20] Das P.K. [21] Rajneesh et al. [22]

EXPERIMENTAL TEST RIG
The schematic of experimental test rig fabricated for present investigation is shown in Figure 1.

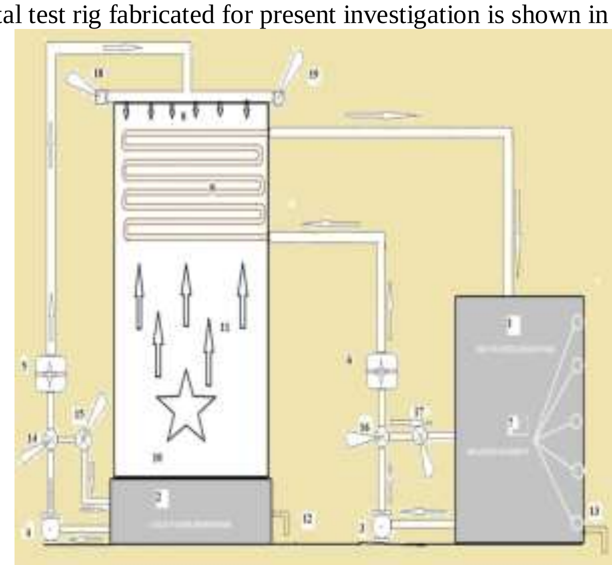

Figure 1. Schematic of experimental test rig

The experimental set-up consists of following parts which are explained as follows:-

1. Hot water reservoir.
2. Cold water reservoir.
3. Process fluid supply pump.
4. Cold water supply pump.
5. Cold water digital flow meter.
6. Hot water digital flow meter.
7. Heating coil.
8. Shower pipe.
9. Test unit.
10. Air duct.
11. Air blower
12-13. Water drain valve
14-19. control valves

The process fluid (water) is heated at a constant temperature in reservoir (1) and heated process fluid is directed to the test section (9) by means of process fluid supply pump (3). The reservoir (2) in which cold water is stored which is directed to the shower pipe (8) by means of cooling water supply pump (4) & the flow rate of both fluids is measured by digital flow meter (5,6). The fluid leaving the test section is collected in reservoir (2).The test section (9) consists of a smooth copper coil (1×8) which is 0.610 m long with a 0.0254 m outer and 0.234 m inner diameter. The temperature of outside cooling water and the hot water flowing inside the tube are detected by Platinum resistance temperature detector (RTD) pt100 sensors. The test section surface temperature is also measured by means of (RTD) pt-100 sensors embedded beneath the surface, around its circumference, and at three different locations, along its length.

DESCRIPTION OF EXPERIMENTAL PARTS

The specification of the test tube and test section are as under.

Outer diameter of the test tube (D_0)	$= 0.0254\,m$
Inner diameter of the test tube (D_i)	$= 0.0234\,m$
Effective length of the test tube (L)	$= 0.610\,m$
Horizontal projection of the effective length (1×8) of coil (L_1)	$= 4.88\,m$
Outside surface area of the test tube (A_0)	$= 0.3892093\,m^2$

EXPERIMENTAL PROCEDURE

In a tubular heat dissipator the process fluid (hot water) passes inside the horizontal copper coil and the cooling water in the form of spray is distributed uniformly over test coil by means of shower arrangement at the top of the section. For heat dissipation forced draught is produced in counter as well as cross-flow mode with respect to process fluid. The cold water (stored in cold reservoir) flows in the form of thin film around the periphery of coils of tubes and falls in the same reservoir. Some of the cooling water is evaporated when heat exchange between hot water and cooling water takes place inside gravity driven water film. During evaporation the water vapours thus formed get migrated into air at the water-air interface and picks-up sensible heat also from water at the interface.

For proper functioning of evaporative tubular heat dissipator, one of the major conditions is that the surface of the tubes must remain completely wet during the experiment. A continuously water supplying system is arranged for this purpose. If the quantity of cooling water is less than the requirement during the operation the water film breakdown occurs at this stage and the dry patches appear on the tube surface. These dry patches can be rewetted by upstream disturbance at low heat flux, but on the other side at high fluxes, the dry patches eventually persist. Due to this an abrupt decrease in heat transfer coefficient occurs. The given flow rate of the cooling water at which dry patches just appear on the tube surface is known as onset dry out heat flux and when the dry patches are permanently settled, corresponding this heat flux is known as permanent dry out heat flux. Prior to running the fluid through the loop, the test section was thoroughly cleaned. When the cleaning was completed, the test fluid (water) was heated in reservoir 1 at a constant temperature and the cooling water was run through the system for several hours to all steady state.

EXPERIMENTAL PROCEDURE FOR DRY OUT HEAT FLUX WITH ONLY WATER FLOW

Current work utilizes various operating conditions in which experiments have been conducted to evaluate dry out heat flux related to onset and permanent dry patches on a copper coil over which the cooling water was showered. The process fluid flow is initiated over test coil with variation in Reynolds number of water, the inlet temperature of process fluid gets effected and film Reynolds number of dry out heat fluxes have been determined.

Just before conducting experiments it was necessary to find out the minimum wetting rate for the copper coil. The minimum wetting rate is the condition at which effective length of test coil becomes completely wet, but at this state, test coil does not subject to any process fluid. When the effective length of test coil is completely wet the value of flow rate of cooling water at steady state is known as minimum wetting rate. For this purpose, the cooling water was allowed to flow over the test coil. The major condition of minimum wetting rate is that the test coil becomes completely wet throughout the effective length at minimum flow rate. After obtaining the minimum wetting rate, the cold water was showered over the test coil for about 1/2 hour until the saturated of tube to its entirety. For the first set of readings the flow rate of cooling water was fixed at 0.020 kg/s which were just above the minimum wetting rate. At the same time the process fluid (hot water) from hot water reservoir at a constant temperature of 65±1 ^{0}C was allowed to flow inside the coil of tube. When the steady state condition of process fluid was achieved the value of process fluid at that stage was noted down with the help of digital flow meter.

The value of process fluid was then increased in small and equal steps (a steady state condition was achieved between consecutive steps) during that stage dry patches seem for the very first time on the surface of the test coil. The stage hence attained for dry patches is termed as onset dry patches formation and corresponding to these onset dry patches the heat load so obtained is known as dry out heat fluxes. These dry patches were observed with the help of highly magnifying glass. After the onset dry out patches disappeared the flow rate of process fluid increased in small increment and steady state condition was achieved in each increment. This process was continued until it was found that droplets of water over dry patches got disappeared. This condition is referred as state of permanent dry patch formation and corresponding to permanent dry patch heat fluxes hence obtained is referred as permanent dry out heat flux. At the same time inlet temperature of cooling water and inlet and outlet temperature of process fluid were sensed by (RTD) pt100 sensors at both the onset and permanent dry patch stages.

For the second and third sets of reading at constant temperature 60 $\pm 1\,^0C$ and 55 $\pm\,^0C$ respectively the above experimental procedure was repeated. The cooling water flow rate was varied in the range from 0.020 kg/sec. to 0.190 kg/sec. The experimental data were recorded with the help of data logger and then this data was fed in to the memory of computer for computational purpose. The ranges of variables which have been selected for the investigation are given in table.

GOVERNING EQUATIONS FOR DRY OUT HEAT FLUX WITH ONLY WATER FLOW

Dry out heat flux which causes onset and permanent dry patch is governed by the following equation:

$$Q_{on} \text{ or } Q_{per} = \frac{Q_w}{A_0} \tag{1}$$

Where, Q_w is the heat dissipation rate from the process fluid to water, and is found from the following equation.

$$Q_w = M_p C_p \left(T_{pi} - T_{po}\right) \tag{2}$$

Where, M_p mass flow rate of process fluid.

The Reynolds number of cooling water $\left(\mathrm{Re}_w\right)$ is calculated from the following equation:

$$\mathrm{Re}_w = \frac{4\Gamma}{\mu_w} \tag{3}$$

Where, Γ Mass flow rate of water per side per unit axial length of the tube [kg /m/s]

$$\Gamma = \frac{\mu_w}{2L} \tag{4}$$

Where, μ_w is the dynamic viscosity of water and is calculated from the linear equation.

$$\mu_w = \frac{\left[6.5380 - 0.1044\left(T_{afw} - 40\right)\right]}{10^4}, \text{ When} 40 \le T_{afw} \le 50 \tag{5}$$

$$\mu_w = \frac{\left[5.4940 - 0.0874\left(T_{afw} - 50\right)\right]}{10^4}, \text{When} 50 \le T_{afw} \le 60 \tag{6}$$

Table 1 Range of operating variable for dry out heat fluxes for tube with only water flow.

T_{pi} (^oC)	M_w (kg/s)	T_{wi} (^oC)	Re_w
65±1	0.020 to 0.190	34.8 to 36	14.87 to 141.73
60±1	0.020 to 0.190	34.8 to 36	14.37 to 137.30
55±1	0.020 to 0.190	34.8 to 36	13.60 to 129.77

RESULTS & DISCUSSION

EFFECT OF REYNOLDS NUMBER OF WATER AND INLET TEMPERATURE OF PROCESS FLUID ON DRY OUT HEAT FLUXES WITH ONLY WATER FLOW:

The computed results from experiment are represented in graphical form in Figure 2 & 3 shows that the effect of Reynolds number of water (Re_w) on the onset dry out heat flux (Q_{on}) and permanent dry out heat fluxes (Q_{per}) for a few inlet temperature levels of process fluid. It is concluded that due to increase in the value of Reynolds number of water & inlet temperature of process fluid (T_{pi}) the dry out heat flux on (Q_{on}) & (Q_{per}) are increased.

In Figure 3 it is also observed that, at inlet temperature of process fluid i.e 60 ^0C the permanent dry out heat flux gets decreased with inlet temperature of process fluid. It is because of the fact that slight unsteadiness of liquid flow patterns were observed during experimentation results involving scattering of the experimental data. The experiments values shows the percentage in dry out heat flux on onset (Q_{on}) increases by 57% to 494% and dry out heat flux on permanent (Q_{per}) by 61% to 497%, when flow rate of cooling water and temperature of process fluid were varied in the range as given Table 1 keeping the temperature of cooling water fixed at a certain value for a given set of observation.

An significant observation drawn out after studying the trends of the graphs plotted between Reynolds number of water, onset and permanent dry out heat fluxes was that, at a certain specific value of Reynolds number of water i.e 14.87 the values of onset and permanent dry out heat fluxes approximately same.

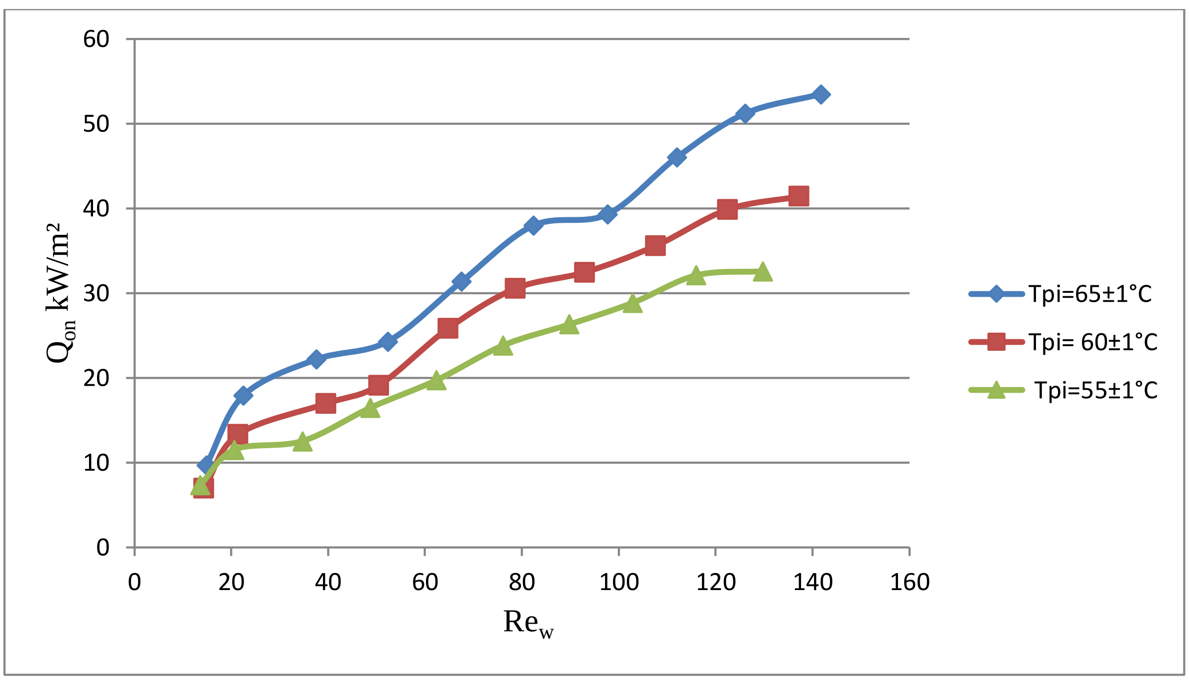

Figure 2. Effect of film Reynolds number of water on the onset dry out heat flux of a tube with only water.

ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785

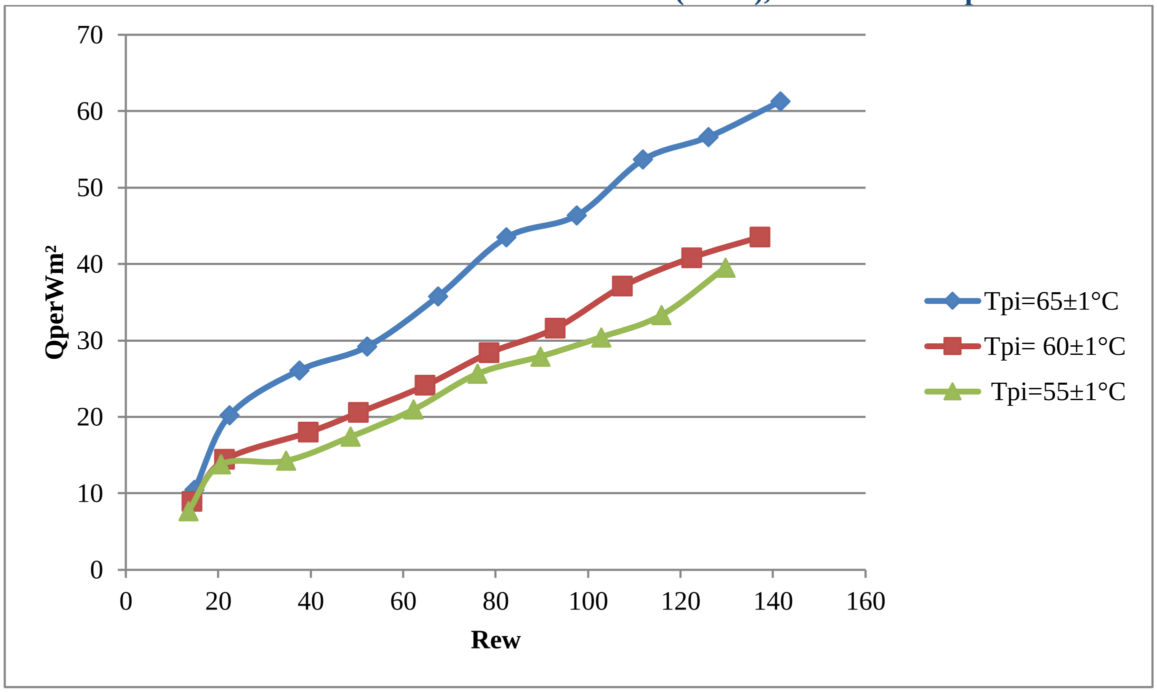

Figure 3. Effect of film Reynolds number on the permanent dry out heat flux of a tube with only water

CONCLUSIONS

DRY OUT HEAT FLUX FOR COPPER COIL SUBJECTED TO ONLY WATER FLOW.

On the basis of current study major conclusions are drawn from the dry out heat transfer studies being carried out on a copper coil of the heat dissipator which was subject only water flow in the form of sprays from the top. The values of onset and permanent dry out heat fluxes get enhanced with Reynolds number of water. It is because of fact that the greater heat fluxes required to evaporate water at a faster rate from the tube surface to form the dry patches on the coil. At higher flow rate of cooling water a comparatively thicker water film is generated over the test coil, consequently maintaining the tube surface in wet condition if this thick water film is intended to break the mass flow rate of process fluid is increased. This whole phenomenon leads to augmentation of onset and permanent dry out heat fluxes with Reynolds number of water.

NOMENCLATURE

D_O	Outer diameter of test tube (m)	D_i	Inner diameter of test tube (m)
D_1	Spacing between neighbouring jets or droplet (m)	L	Effective length of test tube (m)
L_1	Horizontal projection of the effective length (m)	A_O	Outer surface area of test tube (m^2)
Q	Heat flow rate (W)	Q_{on}	Onset heat fluxes (W/m^2)
Q_{per}	Permanent heat fluxes (W/m^2)	Q_w	Heat dissipation rate with water (W)
h_w	Heat transfer coefficient for water (W/m^2 ^oC)	Re_w	Reynolds number of water
M_w	Mass flow rate of cooling water (m/s)	M_p	Mass flow rate of process fluid (m/s)
T_{wi}	Temperature of water at inlet (^oC)	T_{pi}	Temperature of process fluid at inlet (^oC)
T_{po}	Temperature of process fluid at outlet (^oC)	$T_{a,fw}$	Average film temperature of water (^oC)
C_p	Specific heat of water at constant temperature (kJ/kgK)		

 ISSN: 2277-9655
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μ_w Dynamic viscosity of water at inlet temperature $\left(Ns/m^2\right)$

Subscripts

i	Inner	o	Outer
on	Onset	per	Permanent
w	Water	p	Process fluid
d	Dry	pi	Inlet process
po	Outlet process	a, wf	Average water film

Greek Symbols

Γ Mass flow rate cooling water per side per unit axial length of tube (kg/m/s)

μ Dynamic viscosity

Abbreviations

RTD Resistance temperature detectors

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