EXPERIMENTAL STUDY OF CONDENSATION USING ADDITIVES ON COPPER SURFACES FOR HEAT TRANSFER ENHANCEMENT

V.G.Choudhari[1], A.R. Acharya[2], A.T.Pise[3]

[1,] PG Student, [2,] Associate Professor, Department of Mechanical Engineering,
Government College of Engineering, Karad, (India)
[3,] Deputy Director of DTE, Maharashtra, (India)

ABSTRACT

Visual experiments were employed to investigate heat transfer characteristics of steam on vertical copper plates with one is polished and other is chromium plated copper surface. Filmwise condensation and Dropwise condensation were achieved on two surfaces. But the stability of dropwise condensation achieved is less. Use of certain additives with water leads to decrease in surface tension which results in providing more stable surface and helps in achieving dropwise condensation. So experimental investigation is done by use of effective additives for enhancing heat transfer coefficient in condensation of steam over a copper surface and observing various fluid characteristics over a surface.

Keywords*: *Surface Tension, Additive Concentration, Heat Transfer Enhancement, Surface Age, Pressure, Flow Rate of Water.

I INTRODUCTION

Condensation heat transfer has important practical applications, for example, in thermal power plant, in vapour compression refrigeration and in air conditioning systems. Whenever a saturated vapour at a temperature Tsat is brought in contact with a surface maintained at temperature Ts such that Ts is less than Tsat, vapours condense on a surface. Thus condensation is the reverse of boiling process. The vapours may condense on a surface in one of the two modes: filmwise condensation or dropwise condensation. In Filmwise condensation, say on a vertical surface, vapours condense on a surface and drip down forming a continuous liquid film on the surface. Thickness of the condensate film increases as it travels down the plate. During the condensation process, latent heat of vaporization is released by the vapours. For further condensation to occur, the released latent heat has to be conducted through this liquid film to the cooled surface at temperature Ts. However the liquid film offers resistance to the flow of heat and this resistance increases as the thickness of the film increases.

In Dropwise condensation, the vapours condense on a surface in the form of drops, which drip down the surface. A continuous film of liquid is not formed on a surface. Thus more of the base area is at Ts is always exposed to the vapours. Therefore heat transfer rate is higher in dropwise Condensation as compared to filmwise condensation. Generally, dropwise condensation occurs on smooth surfaces which do not get wetted. But it is difficult to maintain dropwise condensation since with time all surfaces tends to get wetted due to oxidation effect.Thus it is very difficult to maintain the stability of a surface.

Nomenclature

Di	Inner diameter of tube
Do	Outer diameter of tube
g	Accelaration due to gravity
hi	Inner heat transfer coefficient
ho	Outer heat transfer coefficient
ho-c	Outer heat transfer coefficient of chromium plated copper surface
ho-p	Outer heat transfer coefficient Polished copper surface
k_w	Thermal conductivity of water
L	Length of tube
m_w	Mass flow rate of water
Nu	Nusselt number
Pr	Prandlt number
Re	Raynold number
T_s	Steam temperature
T_w	Wall temperature
U	Overall heat transfer coefficient
U-c	Overall heat transfer coefficient of chromium plated copper surface
U-p	Overall heat transfer coefficient of chromium plated copper surface
μ	Dynamic viscosity of water
ρ_w	Density of water
v_w	Kinematic viscosity of water
λ	Latent heat of vapourisation

Due to the addition of a certain additives like Ammonium Chloride (NH_4Cl), dynamic surface tension of the solution changes. Surface tension of a solution decreases as the temperature increases. Wettability also affects heat transfer enhancement in condensation. Fig. 1 shows the magnitude of surface tension as a function of the temperature for various concentrations ammonium chloride.

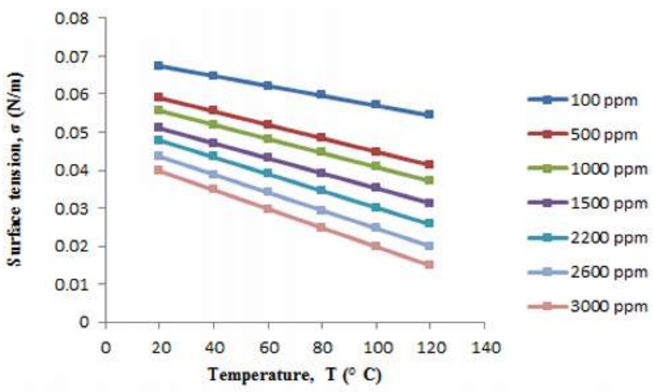

Fig 1: The surface tension as a function of temperature at various ammonium chloride concentration concentrations

II LITERATURE REVIEW

Condensation is still one of the most important heattransfer processes in many energy conversation systems. Condensers used in most of the real world applications are huge in size and are very expensive to manufacture. Any progress made in enhancing the condensation heat transfer rate would greatly reduce the driving potential or reduced pumping power required for desired output and finally the possibility of size reduction for the particular heat exchanger. Dropwise condensation (DWC) exhibits a significantly higher heat transfer coefficient than filmwise condensation (FWC) when properly promoted. However, long term DWC conditions are usually difficult to maintain. Over the years many researchers have used, some of them are discussed below.

Fatica [1] were first to propose a model to compute the rate of heat transfer. They assumed that on a given area all drops are of same size, uniformly spaced and grow by direct condensation. In later attempts, different researchers have dealt with the problem of drop size distribution in a variety of ways.Maa [2] used the population balance method to derive the drop size distribution of small drops which grow mainly by direct condensation. The number of nucleation sites was varied so that the result would fit the experimental data. Wu [3] used the population balance method to derive the drop size distribution of small drops which grow mainly by direct condensation based on the assumption of steady size distribution. They estimated a vapour side heat transfer coefficient of dropwise condensation by assuming heat conduction through the drop as the only resistance to drop growth.Mousa [4] has derived a theoretical derivation for the sweeping period in his model but, actually the sweeping period could be determined experimentally by knowing the maximum drop radius and the contact angle it made with the condensing surface. Mousa also assumed a radius slightly greater than that of the minimum radius which was not clearly explained. S.Vemuri [5] studied experimental and theoretical concept of drop-wise condensation. In this Hydrophobic coatings have been created through self-assembled mono layers (SAMs) of n-octadecyl mercaptan (SAM-1) and stearic acid (SAM-2) on copper alloy (99.9% Cu, 0.1% P) surfaces to enhance steam condensation through drop-wise condensation.

III EXPERIMENTAL METHOD

3.1. Experimental Set-up

The experimental apparatus, shown schematically in Fig. 1, consist of two hollow copper tubes one is polished and other is chromium plated fitted in a cylindrical glass body by brazing. Boiler for producing steam. Reservoir is for providing water continuously through two hollow copper tubes and collecting outlet water. Water in the Reservoir is continuously cooled by Radiator. Ratameter is used to measure mass flow rate of water. K-type thermocouples are attached on two copper surfaces to measure its surface temperature i.e. T1 and T2. One thermocouple is provided in cylindrical glass to measure steam temperature T3. T4 and T5 measures outlet water temperature. T6 measures inlet water temperature. Control valves are used to vary mass flow rate of water in two tubes.

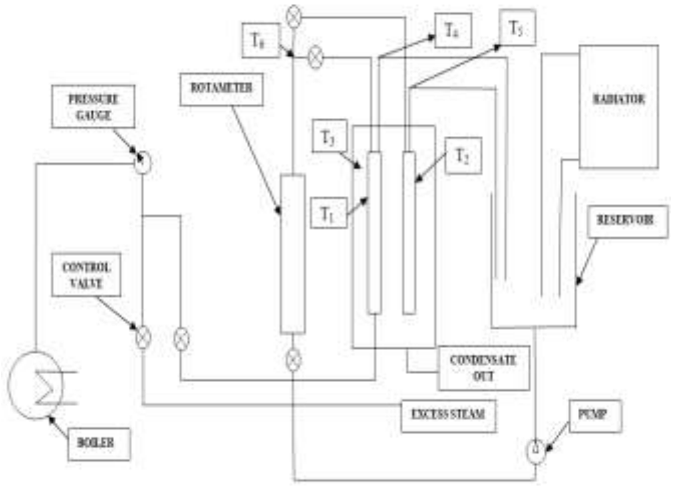

Fig. 2 Schematic diagram of experimental set-up

3.2. Experimental Specification

Steam from boiler is flowing outside the two tubes. The tubes sizes are given in Table 1.

Tubes	Inner Diameter(mm)	Outer Diameter(mm)	Length (mm)
Polished copper surface	17	20	150
Chromium plated copper surface	17	20	150

Table 1 Tube Size

3.3. Procedure

Obtain the steam in a boiler. This steam is supplied inside a glass cylinder over the two copper tubes. Water from reservoir is flowing inside two copper tubes which maintain the temperature of surfaces. As the temperature of surfaces is below saturation temperature, steam gets condensed on surface .After achieving a steady state note down temperatures T1 to T6 and mass flow rate of water measured by rotameter

On the basis of above obtain temperature, obtaining inner and outer heat transfer coefficient and thus the overall heat transfer coefficient,

$$Re = \frac{4\, m_w}{\pi\, Di\, \varrho_w v_w}$$

For a laminar flow with L/D<60, Pr>0.7, constant wall temperature, Nusseltnumber is given by Hausen as:

$$Nu = 3.66 + \frac{0.0668\ \frac{Di}{L}\ Re\ Pr}{1 + 0.04\,(\frac{Di}{L}\ Re\ \mathrm{Pr})^{2/3}}$$

$$hi = \frac{Nu\ k_w}{L}$$

$$ho = 0.943\left(\frac{\lambda\, g^2\, g\, k^3}{(T_s - T_w)\,\mu\, L}\right)^{0.25}$$

$$\frac{1}{U} = \frac{1}{hi} + \frac{Di}{Do\, ho}$$

IV RESULTS AND DISCUSSION

In the present study two different types of copper surface have been used for experimentation. Out of that one is polished copper surface and other is chromium plated copper surface. Experimentation were carried out at pressure 1 bar and 1.4 bar and it is kept operated at these pressure until steady state is reached. Again experiment were repeated by varying the mass flow rate of water. Filmwise and dropwise condensation is found to occure on a polished and chromium plated copper surface respectively. But the stability of dropwise condensation occurring on a chromium plated copper surface is very less i.e. the surface leads to filmwise condensation after some time. At steady state both surface leads to filmwise condensation.

Results which were observed by varying pressure and mass flow rate of water are as follows:

Figure 3 shows the magnitude of outer heat transfer coefficient as a function of pressure at a flow rate of 70 (LPH) on both copper surfaces.

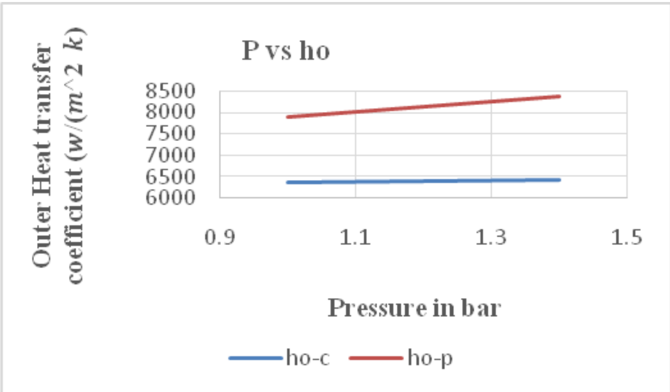

Fig 3 Magnitude of outer heat transfer coefficient as a function of pressure

Figure 4 shows magnitude of outer heat transfer coefficient as a function of flow rate of water at pressure 1.4 bar on both copper surfaces.

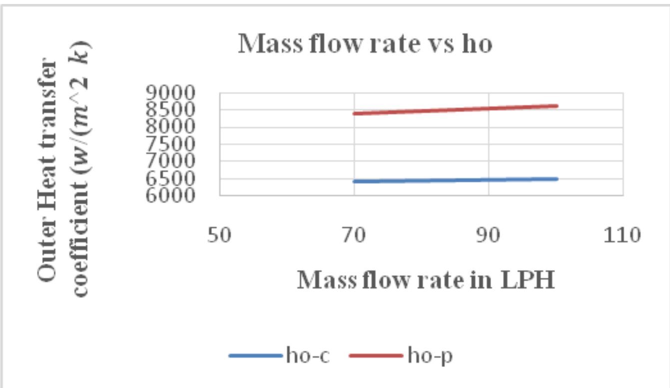

Fig 4 Magnitude of outer heat transfer coefficient as a function of mass flow rate of water

Figure 5 shows magnitude of overall heat transfer coefficient as a function of pressure at a flow rate of 70 (LPH) on both copper surface

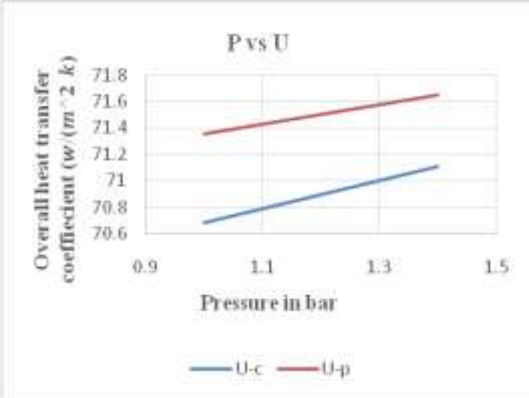

Fig 5 Magnitude of overall heat transfer coefficient as a function of pressure

Figure 6 shows magnitude of overall heat transfer coefficient as a function of flow rate of water at pressure 1.4 bar on two copper surfaces.

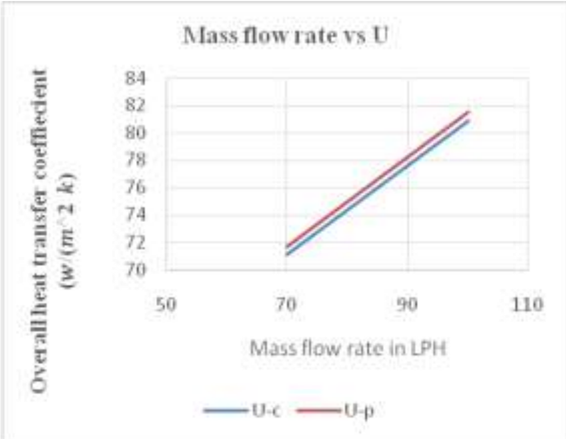

Fig 6 Magnitude of overall heat transfer coefficient as a function of mass flow rate

Figure 7 shows the magnitude of heat transfer coefficient as a function of %wt of Ammonium Chloride (NH_4Cl) at pressure 1 and 1.4 bar on two copper surfaces.

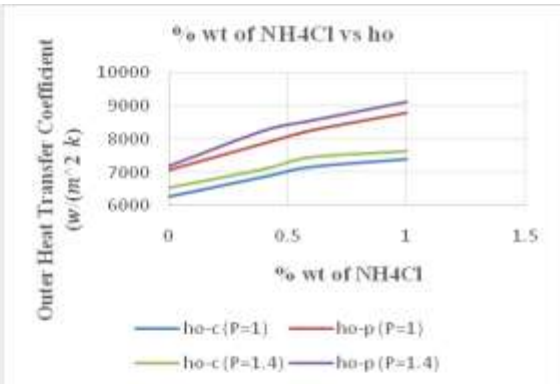

Fig 7 Magnitude of overall heat transfer coefficient as a function of pressure

Figure 8 shows the magnitude of heat transfer coefficient as a function of %wt of Ammonium Chloride (NH_4 Cl) at flow rate of 70 and 100 (LPH) on two copper surfaces.

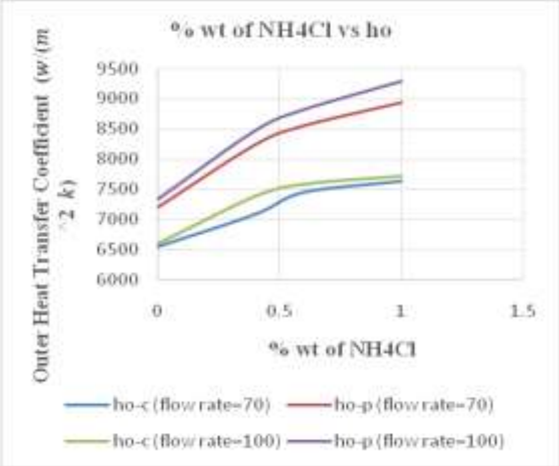

Fig 8 Magnitude of overall heat transfer coefficient as a function of flow rate

Figure 9 shows the magnitude of heat transfer coefficient as a function of %wt of 2-Ethoxy Ethanol at pressure 1 and 1.4 bar on two copper surfaces.

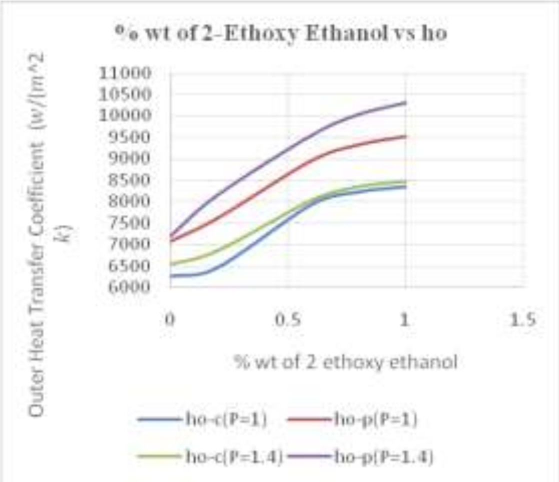

Fig 9 Magnitude of overall heat transfer coefficient as a function of pressure

Figure 10 shows the magnitude of heat transfer coefficient as a function of %wt of 2-Ethoxy Ethanol at flow rate of 70 and 100 (LPH) on two copper surfaces.

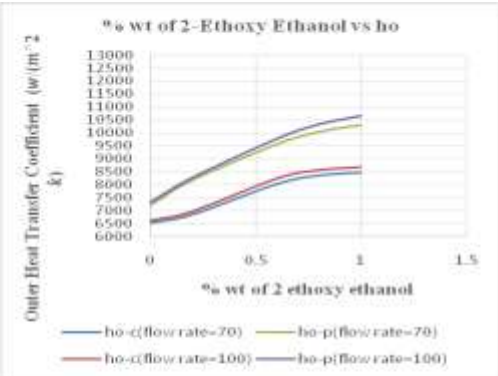

Fig 10 Magnitude of overall heat transfer coefficient as a function of flow rate

Figure 11 shows % Enhancement in heat transfer coefficient as a function of %wt of Ammonium Chloride (NH_4Cl) on two copper surfaces.

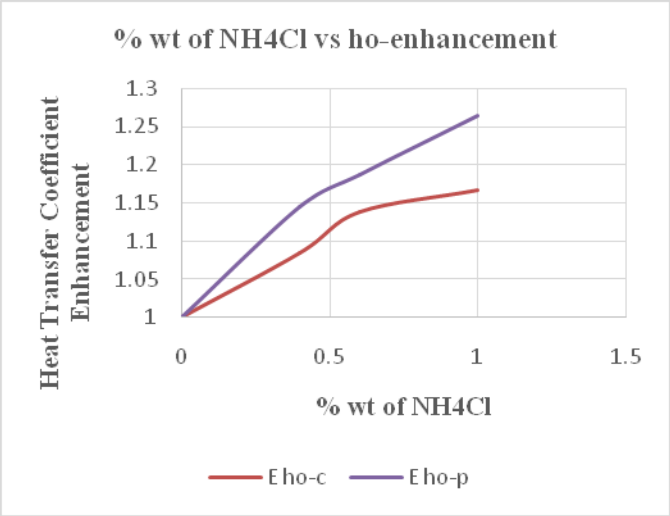

Fig 11 Magnitude of overall heat transfer coefficient as a function of flow rate

Figure 12 shows % Enhancement in heat transfer coefficient as a function of %wt of 2-Ethoxy Ethanol on two copper surfaces.

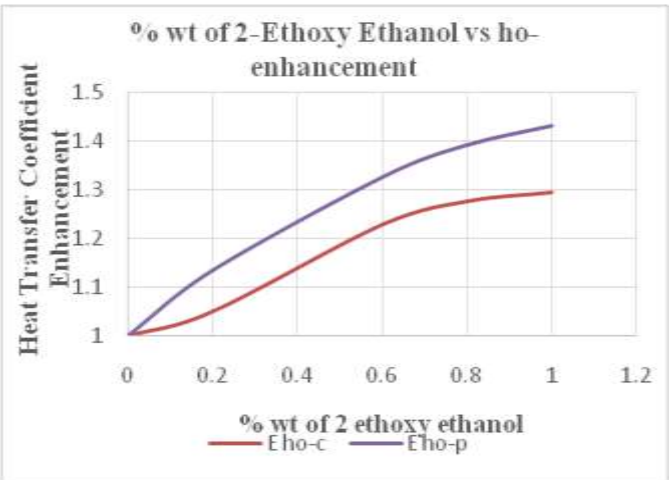

Fig 12 Magnitude of overall heat transfer coefficient as a function of flow rate

V CONCLUSION

The effects of variation in pressure and mass flow rate of water on the condensation heat transfer characteristics were investigated experimentally on polished copper surface and chromium plated copper surface. The conclusions of this study can be summarized as follows:

1. In the current research experiments were carried out on polished copper surface and chromium plated copper surface. Initially as condensation starts dropwise condensation is found to occur on chromium plated copper surface and filmwise condensation on polished copper surface. But the stability of dropwise condensation is very less and which leads to filmwise condensation at steady state.

2.It is evident that from the results that at pressure 1 to 1.4 bar magnitudes of heat transfer coefficient obtained on polished copper surface is higher as compared to chromium plated copper surface. Again heat transfer coefficient increases as pressure increases.

3. Also at mass flow rate of 70 and 100 (LPH) magnitudes of heat transfer coefficient obtained on polished copper surface is higher as compared to chromium plated copper surface. Again heat transfer coefficient increases as flow rate increases.

4. Form the experimental data obtained it has been proven that by using effectiveadditives like Ammonium Chloride(NH4Cl) and 2-Ethoxy Ethanol heat transfer coefficientis enhanced by 1.26 and 1.43 on polished copper surface respectively.

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