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# of Dropwise Condensation Heat Transfer Enhancement on Silver Coated Copper Surface using n-Heptane as Surfactant Additive

**Ganesh B. Gore[1], N. V. Sali[2], Amrut B. Ghodake[3]**

Student, Mechanical (Heat Power) Engineering Department, Government College of Engineering, Karad, India[1,3]

Associate Professor, Mechanical Engineering Department, Government College of Engineering, Karad, India [2]

**Abstract**: Condensation is one of the most important phenomenons of the heat transfer. A condensation occurs only when a saturated or superheated vapour is brought in contact with surface temperature below the vapour saturated temperature. According to the geometry of appearance, condensation occurred may be either film wise or drop wise. In drop wise condensation, heat transfer coefficient is comparatively higher than that of the film wise condensation. But drop wise condensation is difficult to achieve and sustain over period of long time. It can be achieved by coating the surface and using surfactant additives. So, on the bare copper tube silver coating is done and n-Heptane is used as surfactant additive to enhance the condensation heat transfer coefficient. The additive concentration has been varied from 0 % to 2 % by weight in the steps of 0.4%. Enhancement up to 57% is obtained for the silver coated tube over the bare copper tube.

**Keywords**: dropwise condensation, additive, n-Heptane, coating, condensation heat transfer

## I. INTRODUCTION

Condensation is one of the most important phenomenons of the heat transfer. Condensation has wide range of applications in thermal power plant, refrigeration and air conditioning. A condensation occurs only when a saturated or superheated vapour is brought in contact with surface temperature below the vapour saturated temperature. According to the geometry of appearance, condensation occurred may be either film wise or dropwise.

In film wise condensation (FWC), the condensate forms liquid film on the surface. In this process, latent heat of vaporisation is released by the vapour. The released latent heat has to be conducted through the liquid film to the cooled surface temperature, but this film offers resistance to the heat transfer as it prevents the fresh vapour from coming in contact with the condensing surface. Increase in film thickness increases the resistance offered to the heat transfer which results in reduction in heat transfer coefficient.

In dropwise condensation (DWC), drops formed at the nucleation sites on the condensing vertical surface grow in size by a direct condensation and travel downwards under the gravity forces. The drop slides down and detached from the nucleation site if it is not sustained by the surface tension forces. Now, the nucleation site where the drop forming process initiates is available for the fresh vapour to come in contact with it. Dropwise condensation occurs when the surface is not wetted by the condensate. If the surface is wetted by the condensate then film wise condensation occurs. In dropwise condensation, more amount of vapour in contact with the condensing surface means more amount of heat transferred to the cooled surface. Thus, in dropwise condensation, heat transfer coefficient is comparatively more than that of the film wise condensation.

In order to achieve and sustain DWC, the free surface energy needs to be reduced, which can be achieved practically by using hydrophobic coating. DWC can also be achieved by introducing small amount of the heat transfer additives (surfactants) in the condenser. As the surfactants condense with condensate, an interfacial turbulence will create that result into the loss of hydrodynamic stability, which increases the heat transfer coefficient. The interfacial turbulence also called as ‘Marangoni effect’, is caused by surface tension gradient. This surface tension gradient causes the convective flows that would enhance the heat transfer coefficient.

## II. LITERATURE REVIEW

Many researchers have previously tried to improve the condensation heat transfer coefficient. Aaron Stone et al.[1] investigated the effect of n-octanol as a heat transfer additives in the steam condensation for vertical copper tube. A. Bani Kananeh et al.[2]studied the dropwise condensation on the horizontal plasma-ion implanted stainless steel tubes. Plasma-ion was implanted to achieve stable dropwise condensation. The effect of different steam pressures on the heat

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flux and heat transfer coefficient was studied. M. H. Raush et al.[3] studied dropwise condensation of steam on ion implanted titanium surface. The ion beam implantation of $N^+$ titanium surfaces stabilized by preoxidation procedure was done to achieve stable dropwise condensation. Jorge R. Lara et al.[5] experimentally studied dropwise condensation of steam on the dimpled-sheets. Heat transfer coefficients were measured in vertical dimpled sheet heat exchangers (0.762 mm thick naval brass 464 or 0.203 mm thick copper), some of which were bare and others were coated with a thin layer of passive electrodes Ni-P-PTFE. Also PTFE boiling stones were used on the liquid side as a dynamic nucleation agent. Effect of the differential temperature across the plates on the overall heat transfer coefficient was studied for each of the above surface. Xuehu Ma et al.[7] investigated experimentally, the effect of surface free energy difference on steam-ethanol mixture condensation heat transfer.

Most of the experiments were focused on the either on condenser surface modification or on addition of the surfactant alone. So in present work is focused on surface modification as well as addition of the surfactants.

## III. EXPERIMENTATION

The schematic of the experimental set-up to study the dropwise condensation is as shown in fig. It consists of condenser, Boiler (Steam Pressure Cooker) with valve arrangement, water reservoir, radiator, fixed displacement with valve. The condenser surface is made up of copper tubes with silver coating in which cooling water is circulated through water reservoir. This tube is enclosed in a glass cylinder to observe the phenomenon of condensation. Steam from the boiler enters into the glass cylinder and flows around the copper tubes. A Bourdon tube pressure gauge is used to indicate steam pressure entering into the cylinder. A Rotameter is used to measure the flow rate of circulating cooling water flowing through the copper tubes. A several thermocouples are provided to measure the temperature of entering steam, surface temperature of condensing tubes and circulating cooling water temperature entering and leaving through condensing tubes. The pressure and flow control valves are incorporated in set up to control the steam and circulating water flow.

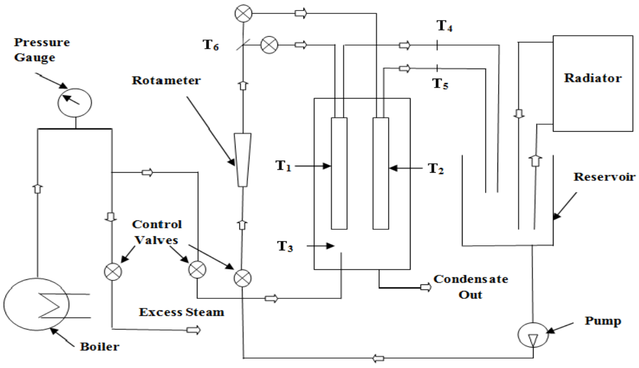


Figure 1 Proposed Experimental Set up

The steam is generated in the boiler. The generated steam is then passed on the condensing tubes. The condensing tube is cooled by circulating cooling water from reservoir. The water in reservoir is cooled by circulating it through the radiator. The condenser is prepared by coating the tube of copper with a coating of silver. External diameter of the tube is 16mm and length of the tube is 170mm. The silver coating is done by electroplating.

Figure 2 Silver Coated Condenser

The experiments were conducted at constant flow rate of water of 100 lph. The additive used was n-Heptane. The concentration used was 0.0%, 0.4%, 0.8%, 1.2%, 1.6%, 2.0% by weight. The properties at the mean surface temperature are computed and the heat transfer coefficient is calculated by the following relation:

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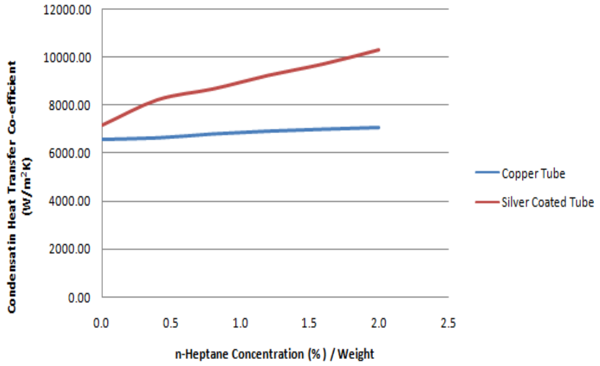
$$ho = 0.943\left(\frac{\lambda\, \varrho^{2}\, g\, k^{3}}{(T_s - T_w)\mu\, L}\right)^{0.25}$$

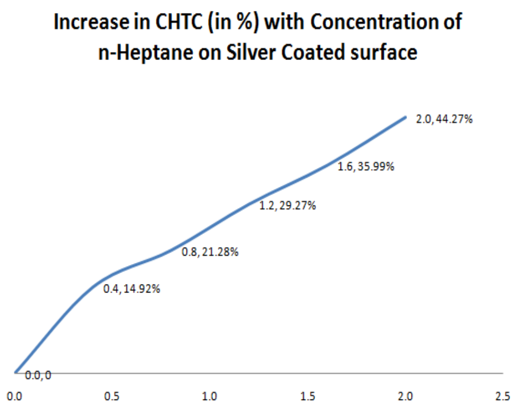
## IV. RESULT AND DISCUSSION

The results obtained are as below:




From this it is clear that the silver coated tube will give the substantial higher condensation heat transfer co-efficient than that of the bare copper tube.

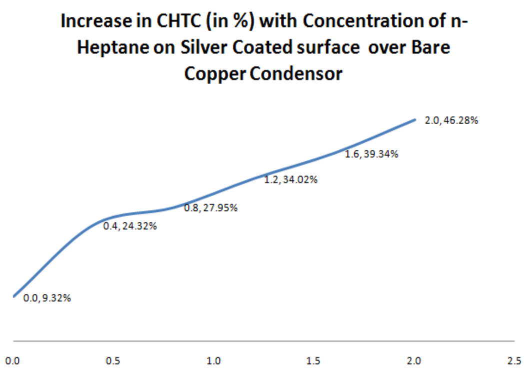
*A.* Effect of n-Heptane on condensation heat transfer co-efficient:




The condensation heat transfer co-efficient increases with increase in n-Heptane concentration. An increase of 44.27% is obtained at 2.0% concentration of n-Heptane as that of 0.0% concentration. Also it can be seen as the additive concentration increases the heat transfer co-efficient increases.

*B.* Effect of silver coating on condensation heat transfer co-efficient:

The condensation heat transfer obtained is higher for the silver coated tube than that for the bare copper tube. The increase in condensation heat co-efficient is 9.32%, 24.32%, 27.95%, 34.02%, 39.34% and 46.28% for 0.0%, 0.4%, 0.8%, 1.2%, 1.6%, 2.0% respectively.




*C.* Combined effect of surface coating and n-Heptane:

The addition of n-Heptane and coating of silver gives overall increase of 57.72% in condensation heat transfer co-efficient for 2.0% addition of n-Heptane for the silver coated tube. The stable dropwise condensation is obtained on the silver coated tube.

## V. CONCLUSION

It can be concluded that the silver coating on the condensers can increases the condensation heat transfer coefficient up to 50 %. It also helps to achieve and sustain dropwise condensation for a long time. The Marangoni effect plays an important role in condensation when the surfactant is added to the steam. As concentration of n-Heptane increased up to 2.0% the condensation heat transfer goes on increasing.

## ACKNOWLEDGMENT

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## REFERENCES

[1]. Aaron Stone, Arslan Razani and Kwang J Kim, and Jason Paquette, "Enhanced Steam Condensation as a Result Of Heat transfer Additives", International Journal of Environmentally Conscious Design & Manufacturing, vol. 10, No. 4, 2001.

[2]. A. Bani Kananeh, M. H. Rausch, A. P. Froba, A. Leipertz, "Experimental study of dropwise condensation on plasma-ion implanted stainless steel tubes", International Journal of Heat and Mass Transfer 49 (2006) 5018-5026.

[3]. M. H. Rausch, A. Leipertz, A. P. Froba, "Dropwise condensation of steam on ion implanted titanium surface", International Journal of Heat and Mass Transfer 53 (2010) 423-430.

[4]. Jorge R. Lara, Mark T. Holtzapple, "Experimental investigation of dropwise condensation on hydrophobic heat exchangers part I: Dimpled-sheets", Desalination 278 (2011) 165-172.

[5]. Jorge R. Lara, Mark T. Holtzapple, "Experimental investigation of dropwise condensation on hydrophobic heat exchangers Part-II: Effect of coating and surface geometry", Desalination 280 (2011) 363-369.

[6]. Yong- Du Jun, Kwang J. Kim, John M. Kennedy, "Dynamic surface tension of heat transfer additives suitable for use in steam condensers and absorbers", International Journal of Refrigeration 33 (2010) 428-434

[7]. Xuehu Ma, Zhong Lan, Wei Xu, Mingzhe Wang, Sifang Wang, "Effect of surface free energy difference on steam-ethanol mixture condensation heat transfer", International Journal of Heat and Mass Transfer 55 (2012) 531-537

[8]. Ding- Jun Huang, Tzong-Shyng Leu, "Condensation heat transfer enhancement by surface modification on a monolithic copper heat sink", Applied Thermal Engineering 75 (2015) 908-917

[9]. Benli Peng, Xuehu Ma, Zhong Lan, Wei Xu, Rongfu Wen, "Experimental investigation on steam condensation heat transfer enhancement with vertically patterned hydrophobic-hydrophilic hybrid surfaces", International Journal of Heat and Mass transfer 83 (2015) 27-38

[10]. Bong June Zhang, Cheng Kuok, Kwang Jin Kim, Taeseon Hwang, Hyungkee Yoon, "Dropwise steam condensation on various hydrophobic surfaces: Polyphenyl sulphide (PPS), polytetrafluoroethylene (PTFE) and self assembled nano silver (SAMS)", International Journal of Heat and Mass Transfer 89 (2015) 353-358