International Journal of Scientific Research & Engineering Trends
Volume 5, Issue 3, May-Jun-2019, ISSN (Online): 2395-566X

Review Paper on Determination of Heat Transfer Coefficient through Condensation

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Abstract- **Condensation is the process of conversion of a vapour or gas into liquid, which plays a key role in the system such as air conditioning, power plants, refrigeration, reactor safety, aerospace and desalination. Environmental and economic pressures are driving the need to design increasingly efficient systems. As a result, we need to increase our understanding about condensation. In this paper various research papers have been reviewed, which gives the information about the designing of the condensers and methods to achieve the Condensation Heat Transfer Coefficient and the various factors affecting on it.**

Keywords **- Condensation, Overall Heat Transfer Coefficient, Temperature.**

I. INTRODUCTION

Condensation is defined as the phase change from vapor state to liquid state. When the temperature of vapor goes below its saturation temperature, condensation occurs. A certain amount of sub-cooling is required for condensation. Hence, energy in the latent heat form must be removed from the condensation area during the phase change process. Surface condensation occurs when the vapor contacts with a surface whose temperature is below the saturation temperature of vapor. It is classified as film-wise and drop-wise condensation. PAGE 2 If the condensate tends to wet the surface and thereby forms a liquid film, then the condensation process is known as " Film Condensation". The heat transfer from the vapour to the cooling surface takes place through the film formed on the surface. The heat is transferred from the vapour to the condensate formed on the surface by Convection and it is further transferred from the condensate film to the cooling surface by the Conduction. This combined mode of heat transfer by Conduction Convection reduces the rate of heat transfer considerably (compared with dropwise condensation). In the "Dropwise Condensation", the vapour condenses into small liquid droplets of various sizes, which fall down the surface in random fashion. In this type of condensation a large portion of the area of solid surface is directly exposed to vapour without an insulating film of condensate liquid, consequently higher heat transfer rate are achieved [1].

II. LITERATURE SURVEY

M. Reddy, et al., performed experimentation on "Heat Transfer Coefficient through Dropwise Condensation and Filmwise Condensation Apparatus". In this paper, the Heat transfer coefficient for circular copper tube is determined and result stated is compared with the other correlations. To conduct the experiment, two water cooled condenser tubes of copper (polished) and gold plated (non polished) of 28 mm diameter and 150 mm length are used which are separately enclosed in a steam chamber.

Fig. 1 Experimental Setup.

During the experiment the type of condensation is observed and the heat transfer coefficient is calculated by the LMTD (Log Mean Temperature Difference) Method. The results obtained are :

- Heat transfer coefficient obtained in dropwise condensation is 2 - 10 times more than filmwise condensation, but for a short period of time.
- When a continuous steam pressure is released for a spatial time, the continuous formation of condensation is observed.
- Rate of heat transfer is proportional to the pressure of the steam [2].

D. Kulkarni, et al., did research on " Study of Dropwise Condensation on Teflon Coated Surface". The paper is presented in order to promote the dropwise condensation of water vapors to increase the effectiveness of heat exchanger. For this purpose two tubes are used : one is Teflon coated tube and another is bare iron tube for dropwise and filmwise condensation respectively. The specimen tubes are of following dimensions : 1 inch in diameter, 25 inch in length and 1 mm of thickness. Here the overall heat transfer coefficient is obtained using LMTD method by varying the flow rates of cooling water. After experimentation, it is observed that the quality of dropwise condensation at the top of the tube is better than at bottom of the tube.

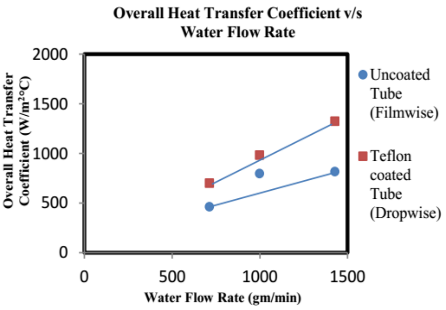

Fig. 2 Overall Heat Transfer Coefficient V/S Water Flow Rate.

From the graph it is seen that

- The overall heat transfer coefficient increases with the increase in mass flow rate and viceversa.
- The overall heat transfer coefficient obtained on teflon coated tube is 20- 60 % more than on bare iron tube [3].

M. Farhami, et al., studied on "Factors Affecting Selection of Tubes of Heat Exchanger". The paper basically stated how to select the tube material for condensers, taken into account the various alloys for the tubes of heat exchangers and the effects of water on them. Further, the selection of tube material and sheet is obtained with the operation and maintenance effects on the tubes.

Table 1 Water Contaminant And Its Effects.

Table 1-Water contents	
contents	resultant problems
Hardness	main Sedimentary materials are in thermal converters and boilers
Free and mineral acids	corrosion
bicarbonate Oxide	Corrosion occurrence especially in condensers and steam lines
PH	shows acidity or alkalinity level of water
Sulfate ion	It combines with calcium and makes calcium sulfate sediment
Chloride ion	Increases water corrosion
Na	It combines with OH and causes corrosion
Silicate	It causes deposition in boilers and cooler systems
Oxygen	It involves in deposition occurence in boilers
Hydrogen sulfide	It causes bad smell (rotten eggs) and corrosion

The factors like water quality, operation and maintenance, heat exchanger design are considered independently and without interaction to study the tubes of copper alloy, type 304 and 316 stainless steel, 6 percent molybdenum alloy, Super Ferritics and titanium. After studying the all above parameters, the author reached to the conclusion that

- Fluids used in condenser should be thoroughly analyzed and factors affecting it such as creating probable sediments, PH, acidity, etc. Should be specified.
- To prevent the tube from particles deposition, the fluid velocity should be high, but on other hand it should resist the tube from corrosion. Therefore the tube lifetime can be achieved with speed of 4 m/s.
- Copper and stainless steel alloys, stainless steel with 6 percent molybdenum, super-freak or titanium alloys shows high resistance against corrosion.
- For U shape tube, water should be very smooth and clean water [4].

S. Hossain, et al., did research paper on "Effect of different working fluids on shell and tube heat exchanger to recover heat from exhaust of an automotive diesel engine". The author has done an experiment to measure the exhaust waste heat available from a 60 kW automobile engine, using two heat exchangers one to generate saturated and other to generate super heated vapors.

The working fluid first passed through saturated heat exchanger and then through superheated heat exchanger. The proposed heat exchanger effectiveness is measured by computer simulation using different working fluid like water, ammonia, and HFC-134a. The proposed model is investigated by considering, the effect of radius of the shell, no of tubes, length of the heat exchanger, pressure drop etc.

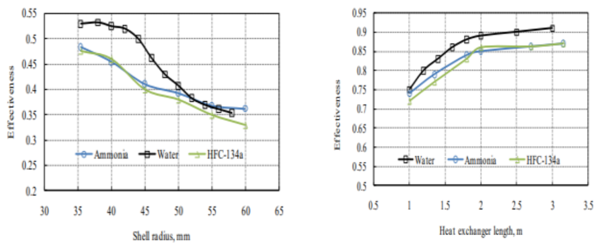

Fig. 4 effectiveness v/s shell radius and condenser length.

- Use of larger shell diameter and length of the heat exchanger, reduces the effectiveness of heat exchanger for all three working fluids.
- Water can works more efficiently to recover the heat from the exhaust of the engine than the other organic fluids, since it has very high enthalpy drop across the turbine.
- With the exhaust heat available from the diesel additional 15%, engine 13% and 8% power can be achieved by using water, HFC-134a and ammonia as working fluid respectively [5].

S. Pawar, et al., proposed a paper on "Determination of Experimental Overall Heat Transfer Coefficient for U-tube, Helical and Spiral Coils of Same Length Under Isothermal Condition".

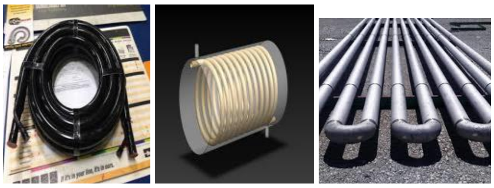

Fig. 5 Types of Condenser Tubes.

The aim of this experiment to predict the Overall Heat Transfer Coefficients under isothermal and turbulent conditions for different mass flow rates. Mild steel material is used for all the coils of the condensing tube, which are of 5.2 m in length and water as the working fluid with the turbulent flow keeping the Reynolds number within 2000<Re<12000.

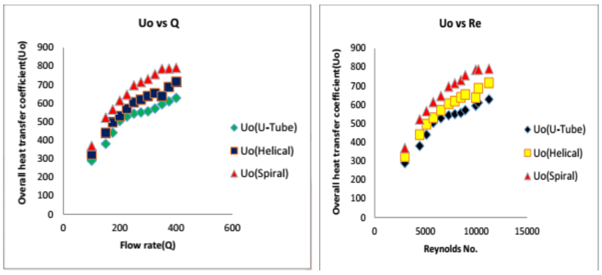

Fig. 6 Overall Heat Transfer Coefficient V/S Mass Flow Rate and Reynolds Number.

From the experiment it is found that

- Spiral coil gives high nusselt number, convective heat transfer coefficient and Overall heat transfer coefficient than Helical coil and U-tube coil of same length under isothermal conditions.
- Average percentage increase in heat transfer for Spiral coil with respect to U-Tube coil is 28.75% and to helical coil is 15.25%.
- Spiral coil requires less space compared to the other two coils [6].

D. Maheshwari, et al., studied the "Experimental Investigation of U-tube heat exchanger using Plain tube and Corrugated tube" has done in this article.

The TEMA [Tubular Exchanger Manufacturer Association] Standard is used for analysis of U-tube Heat Exchanger with Plain tube and Corrugated tube by thermal designing calculation. To compare the Plain tube compare with Corrugated tube in order to increase heat transfer rate, efficiency, heat transfer area, the different characteristic parameters like mass flow rate, pressure drop , effectiveness, etc. are considered

The specimens used are plain and corrugated copper tube which are arranged in counter flow having total heat transfer area as 0.260 m2 and 1.041 m2 respectively, and the thickness of 1.244 mm, length 700 mm and shell length is 300 mm. The water is used as fluid as both cooling and heating medium for the process of heat transfer. Then the following results obtained by investigations are based on different parameters such as overall heat transfer coefficient, exchanger effectiveness, NTU, heat capacity ratio, Reynolds number

Experimental result for plain tube heat exchanger	
Hot Fluid	Hot water
Hot water inlet temperature	327.6 K
Hot water outlet temperature	324.1 K
Hot water mass flow rate	0.120 kg/s
Cold fluid	Cold water
Cold water inlet temperature	306.8 K
Cold water outlet temperature	309.3 K
Cold water mass flow rate	0.112 kg/s

Experimental result for corrugated tube heat exchanger	
Hot Fluid	Hot water
Hot water inlet temperature	327.6 K
Hot water outlet temperature	322.9 K
Hot water mass flow rate	0.127 kg/s
Cold fluid	Cold water
Cold water inlet temperature	306.8 K
Cold water outlet temperature	310.1 K
Cold water mass flow rate	0.119 kg/s

Fig. 7 Experimental Results For Plain Tube And Corrugated Tube.

- The Plain U-Tube Heat Exchanger Has Lower Efficiency And Effectiveness Compared To Corrugated U-Tube Heat Exchanger.
- The influence of corrugation is more on tube side than shell side, with higher value of pressure drop.
- The increase in Reynolds number and Nusselt number causes the increase in Overall heat transfer coefficient [7].

D. Waikar, et al., did research on "Condensation of steam on multiple horizontal tubes". The research is done by using two model one is physical and other is theoretical. In analytical method, a computer program

International Journal of Scientific Research & Engineering Trends
Volume 5, Issue 3, May-Jun-2019, ISSN (Online): 2395-566X

has been implemented using theoretical model which is developed to calculate film thickness ans velocity distribution in the condensate film. The results obtained are considering two phenomenon are as follows :

- Film thickness of condensate and velocity of condensate film increase as the diameter of tube increases for the same angular position.
- The average values of heat flux and heat transfer coefficient decreases as the tube diameter increases.
- As the temperature difference between steam and wall increases, film thickness and velocity of condensate increases, the mean heat flux increases and mean heat transfer coefficient decreases

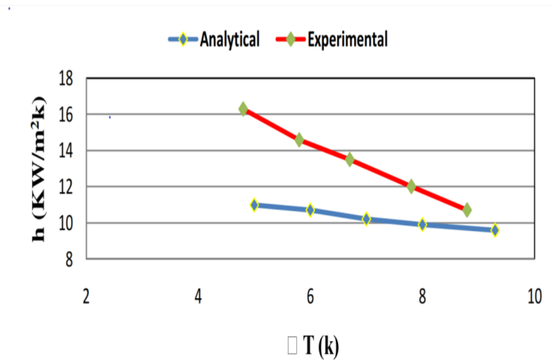

Fig. 8 Convective Heat Transfer Coefficient V/S Temperature

A physical model is developed for experimental investigation. The experiments are performed by inclining the setup at 5 different angles from 0o to 15o , which give the following result.

- The rate of heat transfer increases and heat transfer coefficient decreases as the difference between temperature increases, for 0o inclination in the both the lower tubes.
- Heat transfer rate and heat transfer coefficient for all tubes nearly same for 15o inclination, since the both lower tubes are free from condensate fall over them.
- The sweep effect of steam increases heat transfer rate and decreases heat transfer coefficient [8].

R. Mathurkar, et al., carried out experimentation on "Steam Condensation heat transfer coefficient in vertical mini diameter tube". In this paper the review of condensation of steam inside the vertical tube has been taken. Here the tube containing steam surrounded by water. The condensation heat transfer coefficient is calculated by varying saturation temperature and mass flow of water steam and cooling water. And the result obtained are compared with the thermal resistance method and with different correlations such as Nusselt theory, Bromley and Rohsenow theory, Kapitsa and Mc-Adams theory, Kutateladze theory, Hobler theory, Jack H. Goodykoontz and Robert G. Dorsch theory, etc. The author made the following conclusions as :

- As Nusselt's correlation doesn't considered the steam velocity, it gives less heat transfer coefficient compared to others. Further it it is see that increase in vapour velocity increases the heat transfer coefficient, because presence of vapour velocity tends to more shear action and disturbances to the condensate film, which makes the film thinner.
- The another parameter which increases the Condensation heat transfer is the increase in vapour pressure. This is possible under the influence of gravity [9].

R. Laskowski, et al., has done investigation on "Determining the Optimum Inner Diameter of Condenser Tubes Based on Thermodynamic Objective Functions and an Economic Analysis". In this paper the tube diameters of power condensers in a 200 MW and 500 MW units, are verified by technically and economically by considering the performance of a condenser, the low-pressure part of a turbine, and a cooling-water pump as well as the profit from electric power generation and costs of building the condenser and pumping cooling water. According to 2nd law of thermodynamics, the simultaneous effects of heat transfer and flow resistance are considered

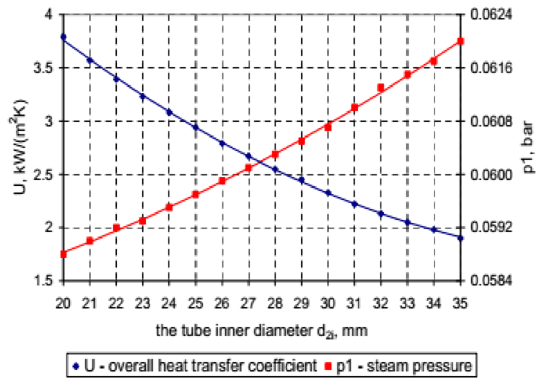

Fig.9 Overall Heat Transfer Coefficient and Steam Pressure As A Function of Tube Inner Diameter.

The author has reached to the conclusion that :

- For determining the optimum condenser tube diameter, the entropy generation minimization and the method of the unit's power output maximization are approximate methods. The result indicates the minimum total entropy generation for any diameter matches the maximum power.
- The higher the temperature of cooling water at the condenser inlet is, the condensing steam becomes more pressurized, when the temperature of the cooling water at the condenser inlet is more.
- Pressure of condensing steam decreases, as the mass flow rate of cooling water increases, while the resistance to flow and power supplied to the cooling-water pump increase [10].

S. Zhang, et al., performed experimentation on "Condensation Heat Transfer with Non-Condensable Gas on a Vertical Tube". To analyse the effect of different parameters on HTC a diffusion layer is modeled on vertical tube, by simulation of the heat transfer process. In this investigation, the author has presented an improved model of PCCS and a correlation is presented by considering liquid film conduction the interface temperature is solved by iteration to compare with the Dehibi's model. The experimental study is conducted with a vertical tube of 2 m in length and 0.38m in diameter, by correlating enhanced factor φ due to suction effect to determine the variation of condensation heat transfer coefficients with pressure, mass fraction of air, wall sub cooling.

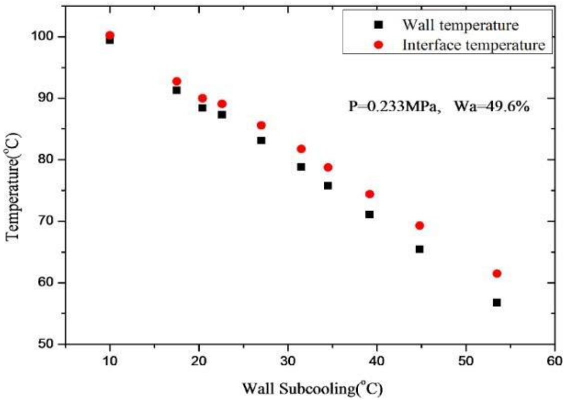

Fig. 10 Wall Subcooling V/S Temperature Graph.

Presented experiment gives less Heat Transfer Coefficient. When the steam mass fraction is less than 70%, the effect of conduction is small through condensate. As the wall subcooling temperature increases, the interface temperature decreases, because the increased wall subcooling temperature enhances the heat transfer rate. Then the condensation film thickness increases, which increases film conductivity resistance results in the increase of interface subcooling temperature. The HTC decreases with the increase of wall subcooling, which inhibits the mass transfer [11].

IV. CONCLUSION

- Heat transfer coefficient in Dropwise Condensation is 2 - 10 times higher than Filmwise Condensation.
- Dropwise condensation occurs for some period of time than filmwise condensation for the same surface finish.
- The heat transfer coefficient is proportional to the pressure of steam, velocity of the steam, and the mass flow rate of the cooling water.
- The rate of heat transfer can be increased by the application of coating, by increasing the surface area with increasing the length of the tube, The lesser the diameter of tube, higher the heat transfer coefficient can be obtained.
- Use of spiral or helical coiled tubes (with or without fins) can be the alternative for the straight tube
- Effectiveness of heat exchanger can be reduced by increase in the diameter of shell.
- Alloys of stainless steel and copper can be used to resist the corrosion.
- The influence of corrugation is more on tube side than shell side, with higher value of pressure drop.
- Water recovers more heat than other organic fluid, but it should be clean and smooth to increase the tube life.
- Angle of inclination for horizontal tubes causes to achieve high heat transfer coefficient under influence of gravity.
- The increase in Reynolds number and Nusselt number causes the increase in Overall heat transfer coefficient.
- The sweep effect of steam increases heat transfer rate and decreases heat transfer coefficient

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