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Experimental Investigation on the Effect of Various Process Parameters of Impacting Liquid Sprays on Cooling Characteristics of Enhanced Surfaces

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Abstract: Different Industrial applications required high heat removal rats in order to provide efficient cooling for reliable working and its operational life. There are different ways to achieve uniform cooling .1.Microchanel Cooling, 2. Jet impingement cooling, 3. Spray impingement cooling. Out of these three methods Spray cooling have some advantages like low fluid inventory, Compact in size, light weight with few moving components, uniformity of cooling and isothermally. Due to the above mentioned advantages spray finds their use for cooling in number of industrial applications for example: HVAC, Laser guided weapons, Supersonic Flights, Agriculture, Cooling of super computers and many others. In the spray cooling properties under consideration are the different nozzle operating pressure, effect of mass flux, effect of surface enhancement, cooling effect, optimisation of various enhance surface with respect to nozzle diameter fluid properties under consideration and experimental investigations are thermal conductivity of liquid, surface tension of liquid, specific heat of liquid, latent heat of vaporization and lastly Calorimeter design properties are: super heat of heater, surface wet ability surface size, thermal diffusivity of subtract. It can be concluded that parameter which are the most significant parameter and sub significant parameters further used to these parameters to optimize and the considered parameters on heat transfer coefficient (HTC) using impingement spray cooling.

Keywords: Experimental setup, Heat Target Assembly, Copper Plates, Thermocouples, Pressure of Nozzle.

I. INTRODUCTION

In the present industrial globalization, thermal control or heat removal process from the hot surface (where cooling is essential) is very important issue, because the quality and reliability of the parts and components is dependable on the operating temperature. Now days we are using other methods such as cooling fans, direct water flow over the surfaces in some processes in some industries which are not the effective techniques. Spray cooling processes are known to yield high heat transfer coefficients due to high heat rates associated with latent heat at absorption during liquid vapour phase transition of the spray cooling methods which are employed in current electronics cooling applications. Heat transfer enhancement is one the major parameters required to improve the performance of the thermal system in any industries such as Electronics, Aerospace, Automotive and steel manufacturing. Jet impingement cooling and spray impingement cooling are two of the most effective ways to improve the rate of heat transfer from the hot metal surface spray. Impingement cooling helps to achieve desired cooling rates from the surface by appropriate parametric control during the cooling process. Hence this process finds its use in many cooling application in particular to metal processing industry. In this technique the spray is done by a nozzle. Spray in general find wide use in applications including agriculture food processing, painting, combustion, fire suppression and metal quenching as well as high heat flux electronics. This method provides an excellent option for tackling with high heat transfers rate requirements but with the primary disadvantages of large, weight, cost and complexity. However, attainment of exceptionally high heat transfer rates has made the technique a still lucrative one compared to the other single phase or even two phase systems. This article is aimed to study the effect of different operating parameters on heat transfer characteristics during spray cooling & to see the relative dominance of one parameter over another. The experiments may be done by taking other medium of cooling expect water such as surfactant and Nano fluids. The surfactant is used in present experiments to see the effect on heat transfer characteristics. The different shapes of heated surface also effects the heat transfer rates, different from other previous studies the enhanced surfaces are used in present work.

II. EXPERIMENTAL SETUP

The major component of the experimental set up as shown in figure 2. In which these components are heater target assembly, accumulator, intensifier, calorimeter, water tank, and compressor. A reciprocating plunger pump supplied high pressure water from the nozzle to the target surface .This high pressure water is further accelerated by mixing it with compressed air .The mixture of air & water is targeted over the test surface supplied to the nozzle via accumulator. A water filter is employed on the pump suction to maintain a clean water supply to the nozzle. On the delivery side, a pressure relief valve, pressure gauge, a flow control valve, nozzle and a pneumatic pulsation damper are place in order.

To maintain the water supply to the nozzle. The pressure relief valve was adjusted to the required pressure. The water flow rate has been varied by the inlet pressure the top surface (i.e. heating surface) of the block was kept horizontal to ensure that water drives equally in all horizontal surface and the uniform film is formed on the surface.

In the experimental studies, to determine temperature variation along the upper part of the block, 4 (four) button type, calibrated J-type thermocouple are inserted in between the block and target surface. In the lower part of the block to accommodate 4(four) cartridge type heaters each of 1500W, 160mm long and 16mm in diameter. The heaters are connected in parallel and capable of supply heat upto 400 w to the top surface of the upper part of the block which is target.

The measure value of these temperature were utilize to estimate average surface heat flux and temperature of the target surface, the output of the thermocouple was fed to a 6 (six) channel temperature indicator of OMEGA make with an accuracy of ±0.1% of full scale.

Figure 1:- Experimental Setup

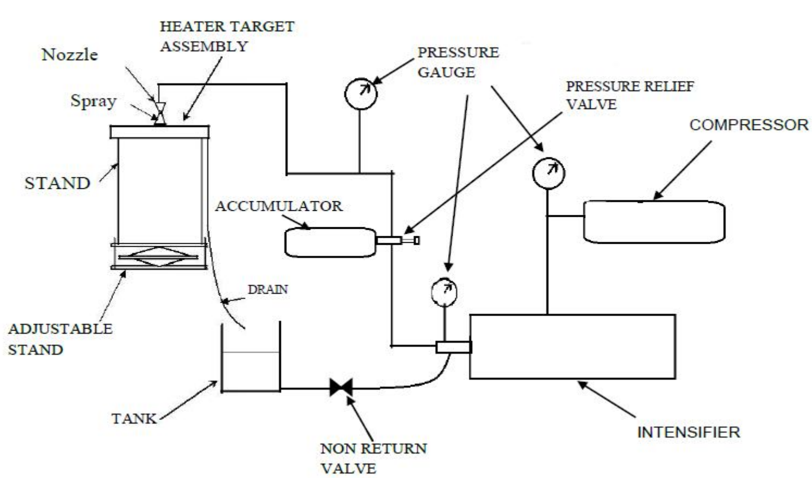


Figure 2:- Block Diagram of Experimental Setup

Water spray cooling system consist of following modules.

1) Heater target assembly
   a) The target copper srfaces
   b) Cartridge heater
   c) Calorimeter enclosure
   d) Adjustable stand
   e) Glass wool
2) Spraying setup
   a) Water tank
   b) Pressure relief valve
   c) Nozzle
   d) Intensifier
   e) Accumulator
3) Temperature unit
   a) Thermocouples (Button type)
   b) Temperature indicators
4) Pressure gauge
5) Compressor
6) Pressure reducing valve
7) Power supply unit(220V &50Htz)
   a) Voltage regulator
   b) Voltmeter
   c) Ammeter

A. *Heater-Target Assembly*

1) Heater assembly serve the purpose of simulated hot surface with provision of heating and controlling the heat input to the impingement surface. The heating assembly consists of calorimeter and the provision to give measured amount of heat to the calorimeter along with provision for measuring the temperature. Figure shows the schematic of the calorimeter and also direct photograph of the calorimeter. The detailed description of different components involved in the heater assembly is given as under.

Figure 3:- Heater target assembly

B. Temperature Unit (Thermocouples)

To determine the temperature along the of the copper block, four calibrated J-type (Button type) thermocouples are inserted in 8 mm diameter holes at the position of 10 mm,30mm , 30 mm and 10 mm from the top surface of upper copper block. The measured values of these temperature were utilized to estimate the surface temperature of the target and average heat flux. A thermocouple consists of two dissimilar conductors in contact, which produces a voltage when heated .The size of the voltage is dependent on the difference of temperature of the junction to other parts of the circuit. The temperature range of J type thermocouple is vary from -40 to 750^{O} C .It consists two wires Iron and Constant. It has sensitivity of 55.

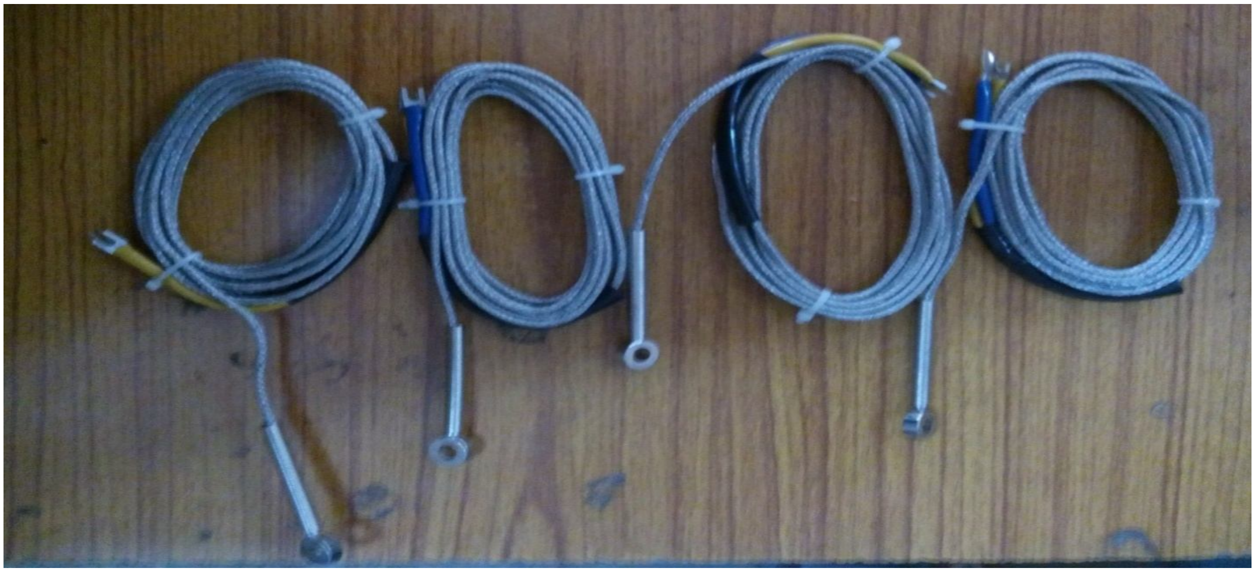


Figure 4:- J-type (Button type) thermocouples

III. DATA ANALYSIS

The main variable observed in the research was the temperature of the heated surface. The calculation for surface temperature and heat flux were done by using temperature readings assuming one dimensional heat transfer and the use of Fourier's law also taken place:

$$q' = k\frac{\Delta T}{\Delta x}$$

The thermal conductivity of heat plate is denoted by k, ΔT is the temperature difference between thermocouple levels and the distance between the thermocouple is mentioned by Δx.

$T_{surface}$ is obtained by:

$$T_{surface} = TC_{avg} - \frac{q' x}{k}$$

TC_{avg} is the average of thermocouple reading. X is the known distance. The average heat transfer coefficient is calculated by

$$h = \frac{q'}{(T_{surface} - T_{water})}$$

After calculating the value of h (heat transfer coefficient HTC), So Nusselt number is calculated using the following relation:-

$$Nu = \frac{hL}{k_f}$$

Where L is the length of heated target surface and k is thermal conductivity of water at bulb fluid temperatureT_{mf}

$$T_{mf} = \frac{T_s + T_f}{2}$$

Now Re (Reynolds number) is calculated as with m* mass flux of water spray and μ is the coefficient of viscosity of water at the mean fluid temperature.

$$Re = \frac{m * D}{\mu}$$

IV. RESULT AND ANALYSIS

A. Effect Of Wateras Medium Taking Operating Pressure Of Nozzle As Vaiable Parameter

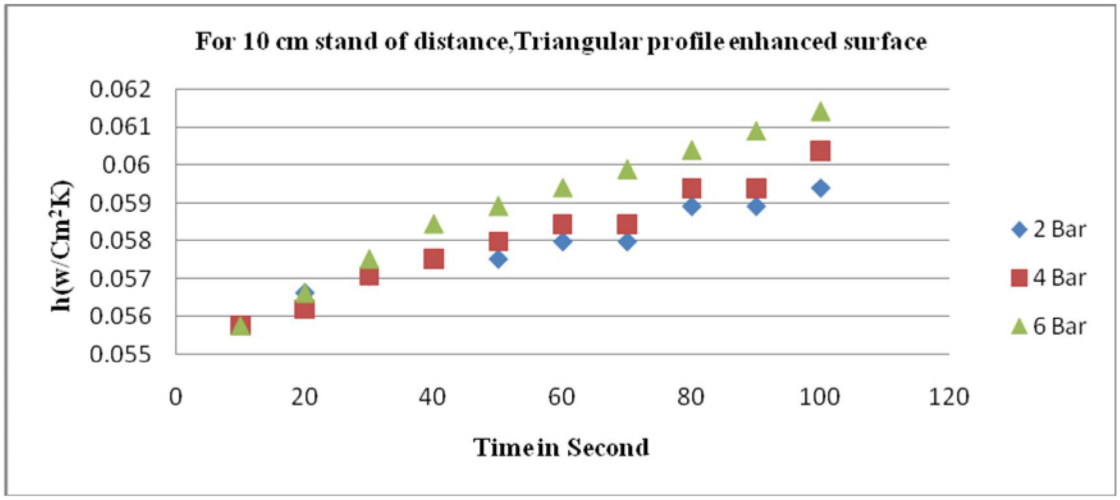
1) For Triangular Enhanced Profile Surface

The mechanism of heat transfer in the regime of non-boiling depends upon two important factors:

a) Forced convection

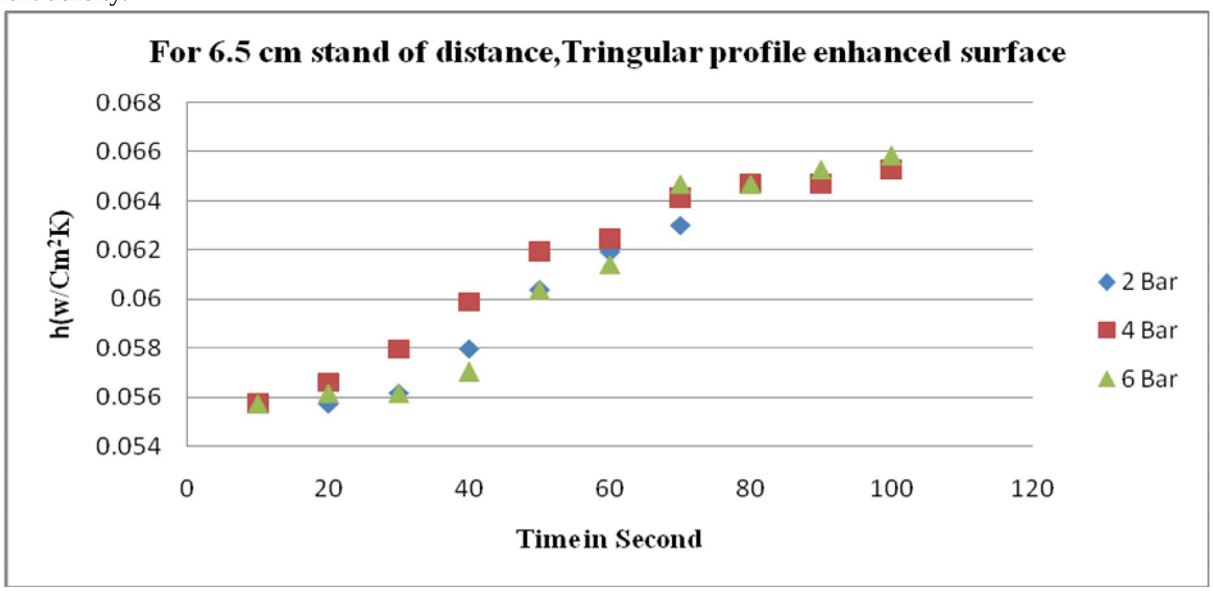
b) Film evaporation

It was found that the increase in the operating pressure results in the increment of mass flux and droplet velocity. As water pressure increases, the high heat transfer rates are achieved ,however the heat transfer also depends on the velocity of drop but it is difficult to mention that which one is the dominating factor to increase the heat transfer coefficient.



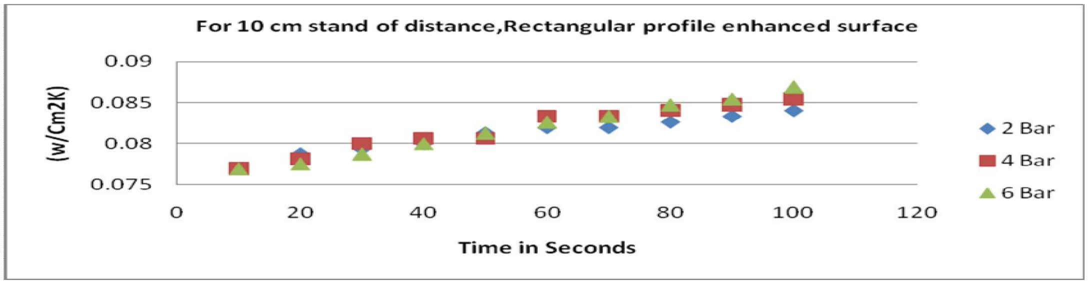
Graph No 4.1:-Variation of h,For 10 cm distance, Triangular enhanced surface for water for different operating pressure

As per the object, the impact of pressure was studied over heat transfer coefficient, the distance of nozzle were kept 10 c.m. to study the effect of pressure. It can easily be seen from the graph that the pressure is very important factor for heat transfer coefficient. As pressure increased the heat transfer coefficient was found in the increasing order simultaneously. At 6 bar, the maximum heat transfer coefficient were obtained because of the high mass flux which has direct impact on heat transfer coefficient. The graph no. 4.2 also indicates that for the high amount of heat transfer the pressure should be at maximum to certain extent because of better impingement density.



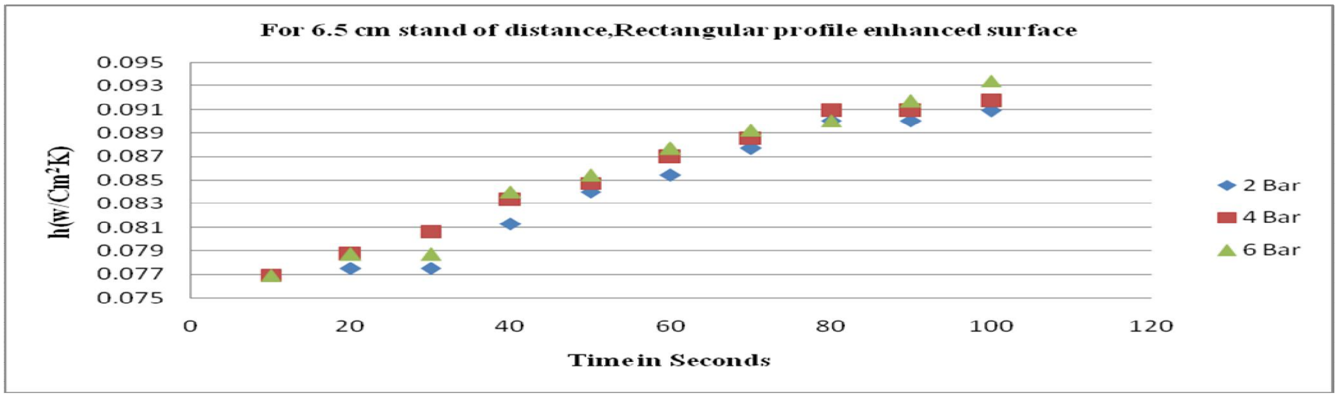
Graph No 4.2:-Variation of h,For 6.5 cm distance, Triangular enhanced surface for water
For different operating pressure

2) *For Rectangular Enhanced Surface:* The study was also done for rectangular enhanced surfaces. It was found that the effect of pressure remained same for this type of surface.



Graph No 4.3:-Variation of h,For 10 cm distance, Rectangular enhanced surface for water for different operating pressure

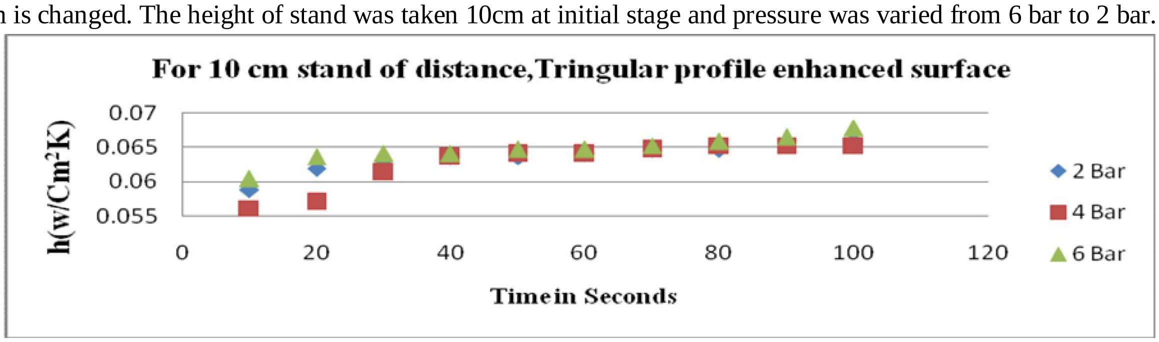
The value of heat flux followed the same pattern according to the pressure. The amount of heat transfer increased because of this surface enhancement. The density of droplet impingement increased so that the corresponding results were found in increasing order. The height was also varied to 6.5 c.m. to see the effect of pressure but the result were obtained in same manner, hence it can be said that the nozzle pressure is the very important factor to achieve a good heat transfer coefficient .



Graph No 4.4:-Variation of h,For 6.5 cm distance, Rectangular enhanced surface for water for different operating pressure

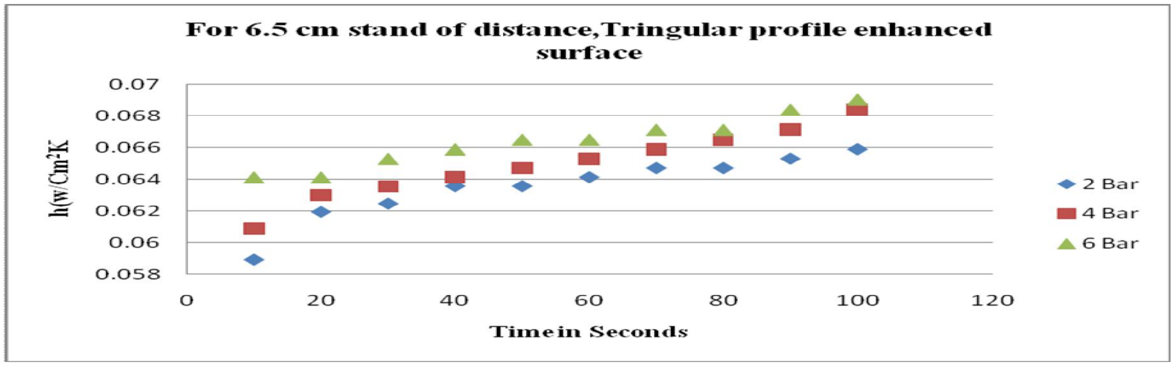
B. *The Effect Of Water And Surfactant As Medium Taking Operating Pressure Of Nozzle Asvariable Parameter*

1) *For Tringular Enhanced Surface:* The experiment was repeated for surfactant to see the effect of pressure when cooling medium is changed. The height of stand was taken 10cm at initial stage and pressure was varied from 6 bar to 2 bar.



Graph No 4.5:-Variation of h,For 10 cm distance, Triangular enhanced surface for surfactantfor different operating pressure

At 10cm height, it was found that at high pressure the maximum mass flow rate was achieved which is suitable for high heat transfer rates. The resultant value of heat transfer coefficient was maximum at 6 bar.
It was seen that with the increase in the mass flux of water the heat transfer as well as heat transfer coefficient is continuously increasing. The high liquid velocity over the surface is achieved because of high fluid flow. To increase mass flux, the nozzle pressure needs to be higher.
At 6.5cm distance, the trends were as earlier because the effect of pressure were found similar as shown graph no 4.5

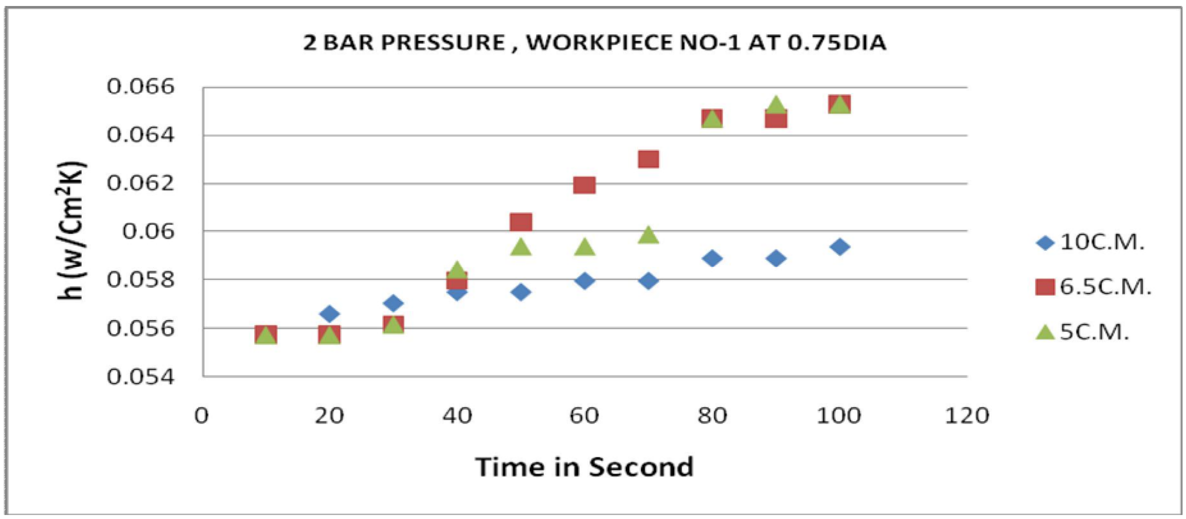


Graph No 4.6:- Variation of h,For 6.5 cm distance, Triangular enhanced surface for surfactantfor different operating pressure

C. The Effect Of Water As Medium Taking Distance Between Heated Surface And Nozzle As Parameter

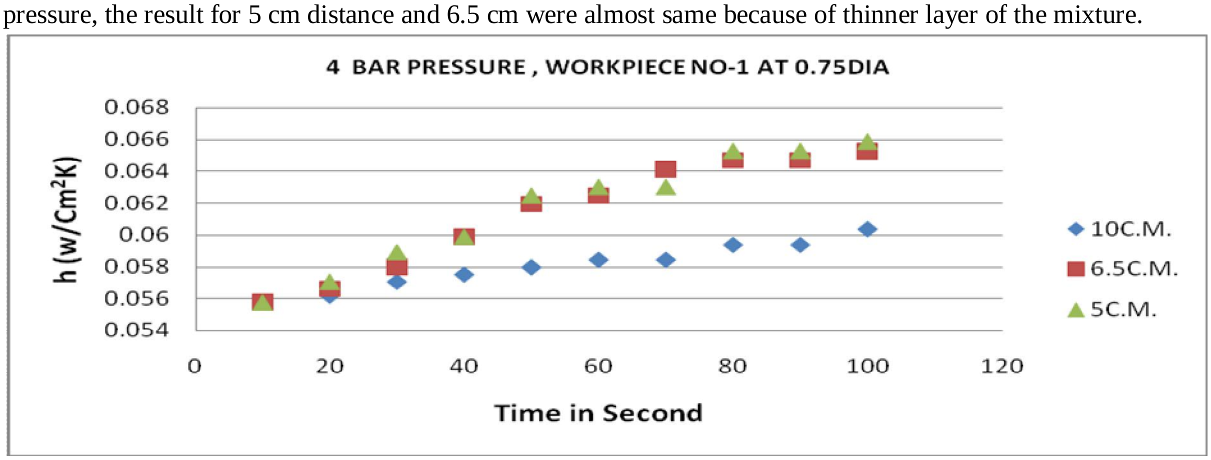
1) *For Tringular Enhanced Surface:* For Triangular enhanced surface , It was seen that because of the rectangular enhanced surface the heat transfer rate and the heat transfer coefficient were higher compared to the triangular enhanced surface.

For 2 bar pressure, the effect of the distance was not as earlier. Even then, it can be observed that the input of the velocity and layer formation remained same. Soothe value of h was found maximum for 5 cm distance.



Graph No 4.7:- Variation of h,For 2 Bar, Triangular enhanced surface for waterfor different standoff distance

For 4 bar pressure, the result for 5 cm distance and 6.5 cm were almost same because of thinner layer of the mixture.



Graph No 4.8:- Variation of h,For 4 Bar, Triangular enhanced surface for waterfor different standoff distance

The result for 10cm distance was still less because the significant impact of droplets on heated surface was not found.

2) *For Ractangular Enhanced Surface:* At 2 bar pressure, the graph indicates that the maximum value of heat transfer and heat transfer coefficient was achieved at 5cm of distance of nozzle. The reason is that the impact of the velocity was maximum at lowest distance .

Graph no.4.9 includes three curves corresponding to the stand of distances 10 cm,6.5cm and 5 cm,It is found that the variation in heat transfer with respect to time reaches at highest value for lowest stand of distance. The curve corresponding to 6.5 cm is comparable with the curve of 5 cm at very few points. The curve corresponding to 10 cm attains lowest values showing the effect of stand of distance on heat transfer rate.

Graph No 4.9:- Variation of h,For 2 Bar, Rectangular enhanced surface for waterfor different standoff distance

This graph indicates for 4 bar pressure, the value of mass flux increased so that the increment in the result of the heat transfer and heat transfer coefficient also increased

Graph No 4.10:- Variation of h,For 4 Bar, Rectangular enhanced surface for waterfor different standoff distance

V. CONCLUSION

The aim of present study is to investigate the heat transfer characteristics of the mixture of surfactant(Sodium Lauryl sulphate) with water and water separately.The temperature of heated was taken below saturation temperature at initial stage.

Effect of operating parameters such as nozzle pressure, distance of stand, enhanced surfaces on heat transfer has been studied.

Following conclusions are made during the experiment; these were various effects on cooling of copper enhanced surfaces by changing the different operating parameters of spray cooling are described below:

A. The operating pressure of nozzle is an very important factor to attain required amount of heat transfer which is essential to achieve high heat transfer coefficient.

B. The distance between nozzle and heated surface play an very important role to achieve good results. Increment in distance of height caused the low heat transfer rate. The rate of heat transfer depends on the distance between nozzle and heated surface.

C. To get high heat transfer as well heat transfer coefficient the mass flux should be increased. It helps to get high liquid velocity over the surface which results the thinner thermal boundary layer as droplet impact also increases.

D. The heat transfer rate on triangular enhanced surface is found less compare to rectangular enhanced surface because the area of contact was less so that the layer formation could not happen.

E. The study of surfactant is another key factor. The appropriate amount of mixture should be prepared to obtain proper heat transfer rates

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