Investigations on Surfactant behavior and variable nozzle standoff distance on heat transfer rates of extruded hot metal surfaces in a sub boiling region.

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ABSTRACT

In method/ process industries, varied high heat removal techniques in various areas enforced in various applications for providing economical cooling, reliable operational conditions for the extended working life of the elements. Out of various cooling techniques, micro- channel cooling, jet impingement cooling, spray impingement cooling etc, spray impingement cooling has some added advantages of maintaining economies as it offers close control of flow rates (low fluid inventories), compact in size, light in weight with few moving elements and uniformity of high heat transfer rates. The properties of spray cooling take in to account: variable nozzle operative pressures, variation and surface improvement for achieving high cooling rates corresponding to the value of the mass fluxes. Further, optimization based on varied enhance surface with regard to nozzle diameter fluid properties is taken into account for experimental investigations which are mainly rely on thermal conductance of liquid, physical and chemical properties of liquid, heat transfer phenomenon in liquids, energy content in liquids and heat of vaporization and other important properties like superheat, surface wettability, surface morphology and size, thermal diffusivity and accustomed these parameters to optimize and also analyze these parameters on the basis of heat transfer coefficient (HTC) for impingement spray cooling.

Key words: Spray impingement cooling, Process optimization, Heat transfer, nozzle, surface morphology.

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 of absorption during liquid vapor phase transition. Because of the above mentioned merits of spray cooling, it becomes an obvious choice for use in different industrial cooling applications.

Heat transfer enhancement is one of 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 Nanofluids. 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 and the heat transfer aspects for the same have been discussed here.

Literature Review

W. Jia et al [1] performed an experiment for heat transfer analysis and modeling by considering the miner level of energy transformation within the different medium. He proposed a dynamic analysis of the liquid droplet which comes on the work piece surface during spray cooling. He used surfactant sodium do-decyl chloride with water solution to cool a 10mm diameter copper surface. He obtained a mathematical relation for droplet impingement energy mass balance between the hot surface and the droplet. His model was for nucleate boiling so film formation was not taking place. He observed by his experimental reading that using surfactant more heat flux is obtained.

G. Quinn et al. [2], investigated the effect of surfactant addition on boiling heat transfer in a liquid film flowing in a diverging open channel. He investigated that mixing a little amount of surfactant with the water one can get a increase in heat transfer rate. He used the boiling of water and surfactant mix solution in an open channel with inlet temperature ranges 40 C to 92 C. His experimental results shows that during boiling the surfactant solution creates a thick foam layer with high heat transfer rate and Nusselt numbers that are very weakly dependent on the inlet flow rate or the inlet Reynolds number.

Mostafa Jalal et al. [3], proposed a model for enhancement of heat transfer by using Al_2O_3 –water nano fluid. An array of jet were designed and predicted by using Taguchi method. At different Reynolds number (R=50,100,150,200), and nano fluid fraction (Ø=0, 1, 3,5%..) and jet to cross flow ratio (R=1,2.5,5,7.5).The result analysis showed that Nusselt number is optimized at maximum Reynolds number and nano particles volume fraction and minimum velocity ratio in range of designed factor.

Based on the result obtained by him heat transfer rate can be enhanced by utilizing nanofluids and can be designed and predicted with an acceptable error successfully. Optimum result and influencing factors can be designed by Taguchi method in this heat transfer enhancement model.

Pautsch et al (2004) [19] suggested that spray cooling has often been misrepresented by the term “spray evaporative cooling”. He points out that some spray cooling system designs realy very little on the evaporation of fluid to remove heat. Furthermore, he suggested that spray cooling designs with higher values of CHF have less evaporation than the designs with lower values of CHF. As a result, in order to show the difference between them, he proposed a new name if there is phase change, namely “spray cooling with phase change”.

Estes and Mudawar (1996) [20] A set of experiments were performed to understand the nucleate boiling and CHF for full cone sprays cooling system. They investigated the effect of spray nozzle, volume flux, sub cooling and the properties of the working fluid. They reported that the CHF increases with increasing flow rate and increasing sub cooling. They also investigated that the CHF is greater for smaller drops due to lower surface tension. For full cone sprays, Sauter mean diameter (d_{32}), the diameter of a drop, that has same volume per unit surface area of the entire spray, is dependent upon orifice diameter and Weber and Reynolds numbers based on the orifice flow conditions before the liquid breakup.

Chen et al. (2002) [21] discussed various effects of spray characteristics for non-critical heat flux in sub cooled water spray cooling with their experimental observations. They defined three independent spray parameters: such as, mean droplet velocity (V), mean spray droplet flux (N), and Sauter mean droplet diameter (d_{32}). The effect of these parameters on the CHF was determined, utilizing extensive experimental data. They suggested that CHF varies proportional to $V^{1/4}$ and $N^{1/6}$, and is relatively independent of d_{32}. The CHF and the heat transfer coefficient showed an increase when V increased. Increasing N also resulted in an increase in CHF and heat transfer coefficient when other parameters were kept in narrow ranges. According to their results, in order to increase the CHF for a given, a dilute spray with large droplet velocity is more effective than a dense spray with low velocities.

Toda (1972), [4] using water as a working fluid, found that the CHF increased approximately 50% as the mean droplet diameter increased from 88 to 120 microns. However, Pais et al. (1992) [11] and Estes and Mudawar (1996) [20] suggested that CHF could be increased by decreasing the droplet diameter. Sehmbey et al. (1995) [22] argued that the smaller droplets can produce the same values of CHF at smaller flow rates as larger droplets at larger flow rates. According to research by Bostanci (2010), [23] increasing flow rate beyond a certain level (the medium flow rate in their case) has a minimal effect on CHF.

Peterson (1970) [5], found that heat fluxes as high as 15 MW/m^2could be removed from a spray cooled surface. At surface temperature of 130°□C, heat fluxes in the order of 2.2 MW/m^2were removed by sprays used by Bonacina et al. (1979). Bonacina et al. (1975) [26], found that if the wall is fully wetted, the heat transfer rate is higher. According to Kim et al. (1997), larger film thickness produces lower heat transfer.

Yang et al. (1996) [6] observed that heat fluxes as high as 10 MW/m^2can be obtained in gas-assisted spray cooling with water in the presence of phase change from a low wall superheat. Using FC-72 as the working fluid, a 1 MW/m^2 heat flux was obtained by Estes and Mudawar (1996) [7].

Pautsch and Shedd (2006) [8] found that the most important and the least studied parameter of spray cooling is the thickness of the liquid film layer which exists on the heated surface. The values of the film thickness were 0 to 75 microns. They also explained that once the droplets hit the surface, they are swept off by the flow of subsequent droplets, the surface is continually wetted, and a thin liquid film forms. They explained different mechanisms of heat transfer in this film: conduction, convection, bubble nucleation, and gas bubbles entrained by impacting droplets. They concluded that each of these components contributes to the total heat removal process although their exact portion of contribution is unknown and almost all affect the film thickness.

EXPERIMENTAL SETUP

The major component of the experimental set up as shown in figure . 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 holes care provided in order 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 up to 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.

Water spray cooling system consists of following modules.

- Heater target assembly
    - The target copper surfaces
    - Cartridge heater
    - Calorimeter enclosure
    - Adjustable stand
    - Glass wool
- Spraying setup
    - Water tank
    - Pressure relief valve
    - Nozzle
    - Intensifier
    - Accumulator
- Temperature unit
    - Thermocouples (Button type)
    - Temperature indicators
- Pressure gauge
- Compressor
- Pressure reducing valve
- Power supply unit(220V &50Htz)
    - Voltage regulator
    - Voltmeter
    - Ammeter

Experimental Procedure

Initially the mixture of water and sodium lauryl sulphate was made by mixing 1 gram above mentioned surfactant with 1 liter of water. The flow of mixture was maintained through the pipe before the start of any experiment so that any foreign or impurities the material in the pipe may be removed. The same experiments were also repeated by using water in second phase. The cleaned surfaces were taken into the experiments. All readings were noted down carefully till steady state conditions were obtained. The reading were taken for the time period of 1-100 seconds at the interval of every ten seconds. The experiments were performed for different pressure as 2 bar, 4 bar and 6 bar. The distance of stand also varied as 5 cm, 6.5 cm, and 10 cm for each work piece. The initial surface temperature was taken 97°C. (Below saturation temperature of water)

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:-

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

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.

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

RESULT AND DISCUSSION:

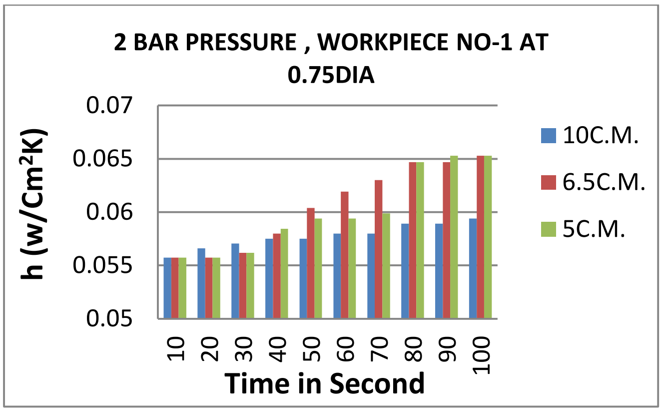
1.1THE EFFECT OF WATER AS MEDIUM TAKING DISTANCE BETWEEN HEATED SURFACE AND NOZZLE AS PARAMETER:
1.1.1 FOR TRINGULAR ENHANCED SURFACE

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

i) Forced convection
ii) Film evaporation

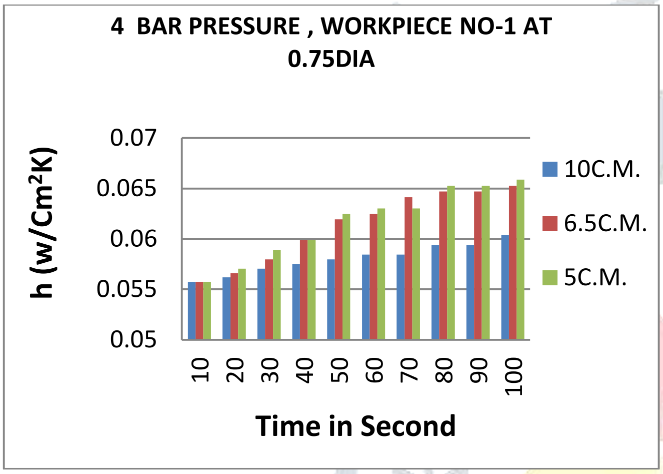
It was found that the increase in the operating pressure results in the increment of mass flux and droplet velocity. As water pressure increases, the high heat transfer rates are achieved, however the heat transfer also depends on the velocity of drop but it is difficult to mention that which one is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

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 1 Variation of h, For 2 Bar, Triangular enhanced surface for water for 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.

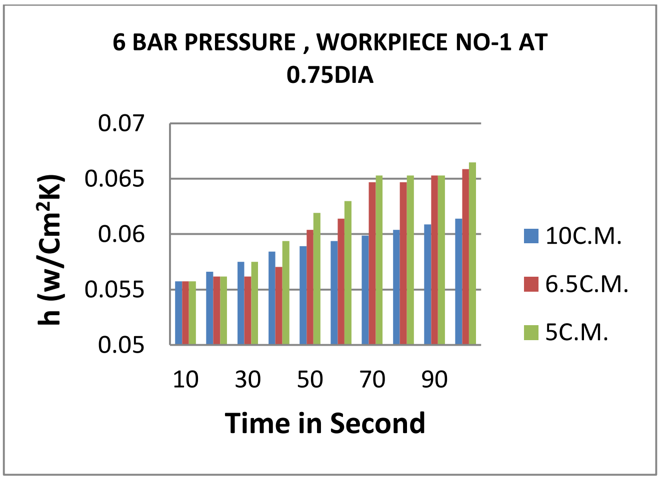


Graph No 2: Variation of h, For 4 Bar, Triangular enhanced surface for water for different standoff distance.

The result for 10cm distance was still less because the significant impact of droplets on heated surface was not found. In this effect, the pressure was taken constant and the distance between nozzle was varied.

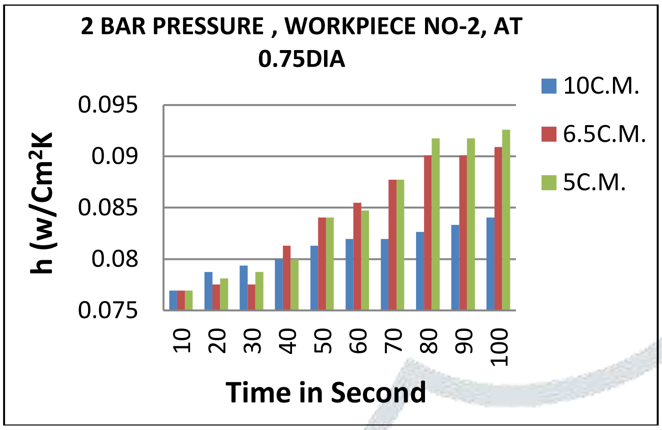
1.1.2 Rectangular Enhanced Surface

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 3: Variation of h, For 6 Bar, Triangular enhanced surface for water for different standoff distance.

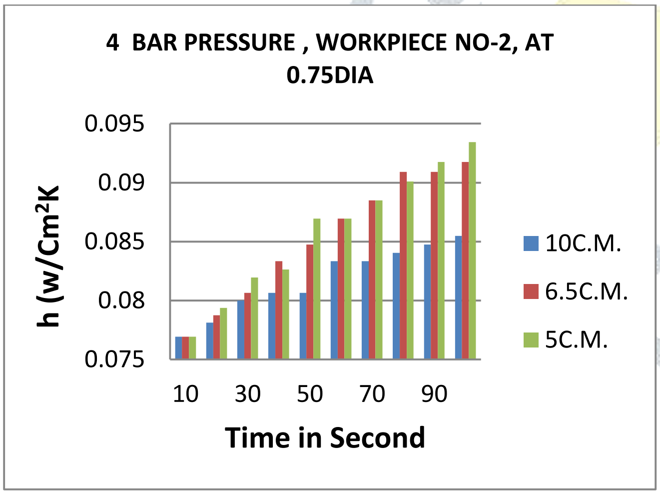
Graph no.5, includes three curves corresponding to the stand of distances 10 cm,6.5cm and 5 cm,It is found that the variation in heat transfer with respect to time reaches at highest value for lowest stand of distance. The curve corresponding to 6.5 cm is comparable with the curve of 5 cm at very few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



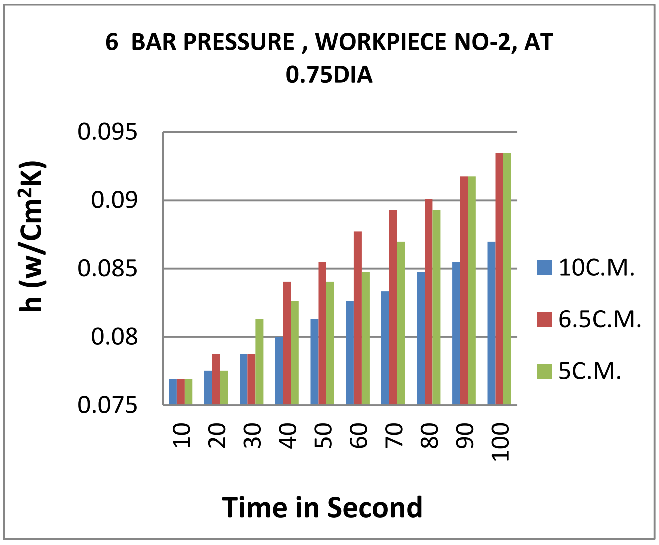
Graph No 4: Variation of h, For 2 Bar, Rectangular enhanced surface for water for different standoff distance.

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.

The result for 6.5 cm and 5 cm followed same path because the distance was very less between them while for 10 cm height, the results were minimum.



Graph No .5: Variation of h, For 4 Bar, Rectangular enhanced surface for water for different standoff distance



Graph No .6: Variation of h, For 6 Bar, Rectangular enhanced surface for water for different standoff distance.

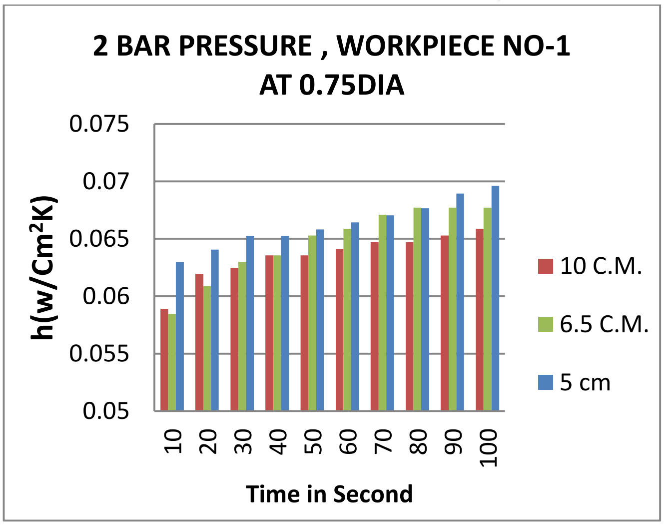
For 6 bar as well as highest mass flux the maximum heat transfer which indicates that mass flux is a key issue to increase the heat transfer but the effect of the distance also followed same pattern.

For 6 bar distance, the results for 5 cm distance and 6.5 cm distance were same. So it may be said that at high heat flux and rectangular enhanced surface, for minimum difference of the height may be obtained same.

At 10 cm distance, the results were less compared to other heights which were taken because at higher stand of distance the effect of evaporation occurs. Sprayed water do not be able to obtain proper impact of droplets on heated surface.
On the basis of previously mentioned graph it is clear that stand of distance is dominating factor over pressure since variation of pressure can not compensate the effect of stand of distance however pressure causes an increment in heat transfer rate as denoted by the rise in gradients of the curve in each graph.

1.2. THE EFFECT OF WATER AND SAFACTANT AS MEDIUM TAKING DISTANCE BETWEEN HEATED SURFACE AND NOZZLE AS PARAMETER:

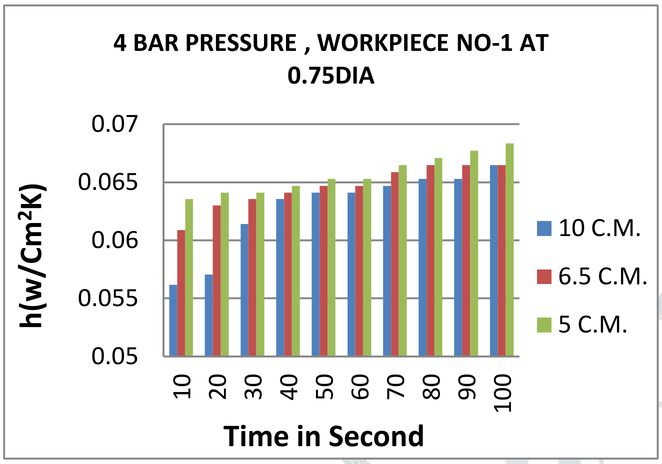
1.2.1FOR TRINGULAR ENHANCED SURFACE:
At 2 bar pressure, the graph indicates that the value of the heat transfer and heat transfer coefficient varies according to the height of the distance for 5 cm height the result were obtained maximum while for 10 cm distance the result obtained were minimum.



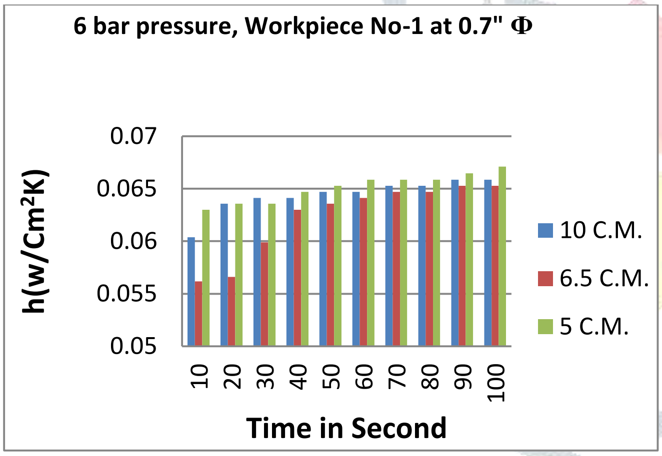
Graph No 7:- Variation of h, For 2 Bar, Triangular enhanced surface for surfactant for different standoff distance.

At 4 bar pressure, it is observed that due to the increment in the mass flux the values for 6.5 cm and 10 cm. For 5 cm height still the results were maximum.

At 6 bar, For the 5 cm distance the heat transfer rate and the heat transfer coefficient obtained was maximum. The difference which was observed between the previous graphs was that the result for 10 cm height were better than the 6.5 cm height.



Graph No 8:- Variation of h, For 4 Bar, Triangular enhanced surface for surfactant for different standoff distance.

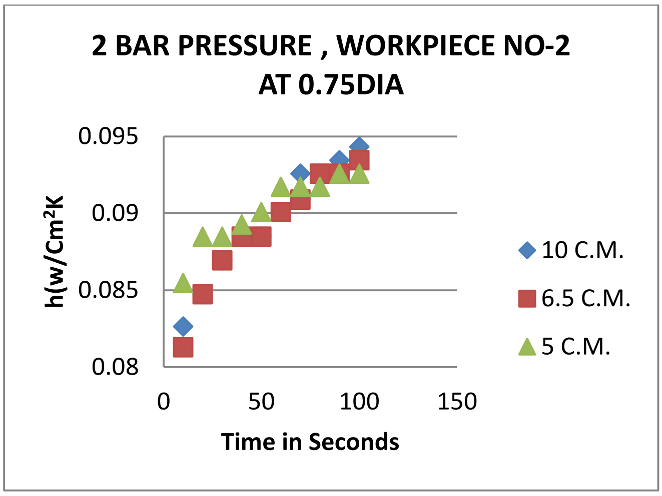


Graph No 9:- Variation of h, For 6 Bar, Triangular enhanced surface for surfactant for different standoff distance.

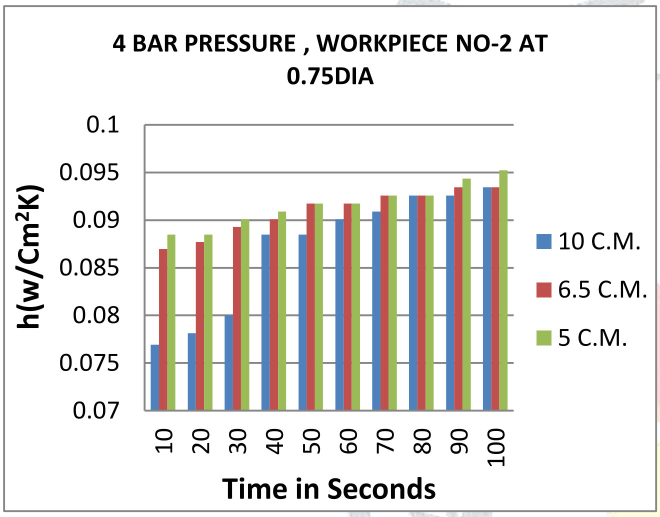
1.2.2 For Rectangular Enhanced Profile Surface

The maximum rate of the heat transfer and resultant heat transfer coefficient was observed during this experiment. It was found that at 5 cm height for water using rectangular enhanced surface was proved best option among all. Graph followed that as height increased the value of the heat transfer decreases.

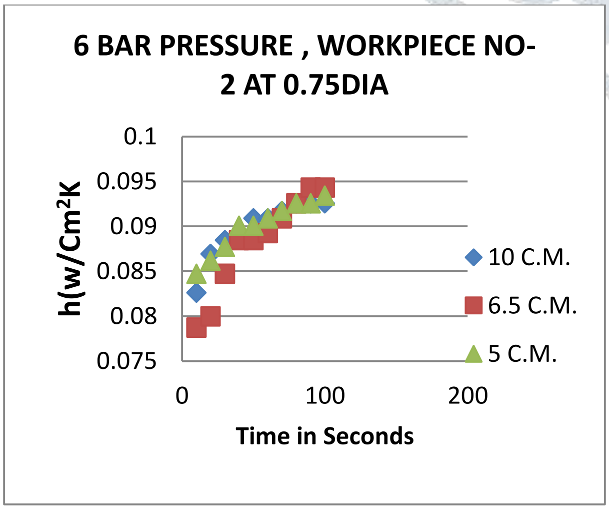
At 6 bar, the heat transfer rate and heat transfer coefficient were found maximum at the height of 6.5 cm. The result for 5 cm distance was found slightly less compared to 6.5 cm of distance



Graph No 10:- Variation of h, For 2 Bar, Rectangular enhanced surface for surfactant for different standoff distance.



Graph No 11:- Variation of h, For 4 Bar, Rectangular enhanced surface for surfactant for different standoff distance.



Graph No 12: Variation of h, For 6 Bar, Rectangular enhanced surface for surfactant for different standoff distance.

So, it may be said that the distance between the nozzle and the heated surface is inversely proportional to the heat transfer coefficient.

It can also be said that the surfactant is better cooling medium compare to water which is used in this experiment. The triangle enhanced surface is found to be less appropriate compare to rectangular enhanced surface because of less area of contact. The height of stand of distance is also the effective factor. The distance of nozzle played an important role in heat transfer.

The Effect of Adding Surfactant to Water

As through the literature review it was found that the addition of surfactant to water increases the heat transfer rates. The surfactant increases the nucleation of bubbles and the formation of spray. The surface tension is also may be reduced by adding surfactant to water. It upgrades the foaming which plays efficient role in increasing heat transfer rates. It is also observed that the cooling time is decreased by adding surfactant.

The experiments which were performed using surfactant gave satisfactory results which may be seen in form of heat transfer coefficients, temperature drop and heat transfer rate.

CONCLUSIONS

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:

1. 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.
2. 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.
3. 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.
4. 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.
5. 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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