HEAT TRANSFER IMPROVEMENT IN POOL BOILING BY MEASUREMENT OF CONTACT ANGLE OF DROP ON HORIZONTAL SURFACE

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Abstract: The heat transfer can be enhanced by dissolving small amount of surfactant in pure water. It changes the condition of behaviour of the boiling phenomenon. The initial motto behind this experiment is to find out the effects of optimum concentration of surfactant on the heat transfer rate of pure water without any abnormalities. In this experiment Sodium Laureth Sulphate (SLS) used as additives in pure water. The boiling behaviour (bubble nucleation, growth and departure) was recorded by video camera. The boiling curves q Vs. (Tw-Tsat) for different concentrations of additives in pure water was obtained. From experiment, the heat transfer coefficient for pure water with and without surfactants were calculated and compared.

The results of this experiment showed that the addition of additives (SLS) in pure water can improve the heat transfer in boiling. Also the behaviour of bubble and the mechanism of heat transfer for the additive solution are quite different those from of pure water. To study the effect of wettability on a surface, it is essential to measure the contact angle. Wettability will be increases if the contact angle becomes lower and result in enhancement of heat transfer. Also if the wettability is less the contact angle will be greater than 90^0 and it reduces heat transfer. The heat transfer coefficient is improved with the surface which had a water contact angle close to either 0^0 to 90^0. Hence it promotes the heat transfer.

***Index Terms* - Contact angle, Surfactant, Boiling and Heat Transfer.**

I. INTRODUCTION

Boiling heat transfer is defined as a mode of heat transfer, which occurs with a change in phase from liquid to vapour. There are two basic types of boiling:
1. Pool boiling: which is a technique where heated surface is submerged below a free surface of liquid.
2. Flow boiling: which is another technique where the liquid flows on a heated surface.
These two techniques of boiling are important in power industries and process industries like cold storage, milk storage, ice factories, etc. In this experiment the pool boiling technique was used. The pool boiling techniques are using in various industries like, thermal, refrigeration, processing, etc. The interest on enhancement of heat transfer is closely related with energy prices. Due to increase in its demand as well as crisis, there is now an incentive to save energy, and enhanced heat transfer can be exploited to do so. Due to the energy crisis problem, there is opportunity to reduce the energy required for phase change process during the pool boiling. By increasing heat transfer rate the boiling curve must shift to left in such way that the required energy for phase change process is less. [3]

Generally, it is believed that small amount of surfactant can increase the boiling heat transfer. From literature survey it was found that, the enhancement dependent on additives concentration. The Sodium Laureth Sulphate (SLS) is used as surfactant in pure water at various concentrations to increase heat transfer. Small amount of surfactant in water reduces the surface tension considerably also its level of reduction depends mainly on the amount and type of surfactant presented in the solution. The generation of nucleate sites, bubble formation and dynamics influence the boiling heat transfer. The contact angle of water drop on surface is having more importance in heat transfer. According to different researchers contact angle is less then wettability on surface is good, that means more heat transfer. This can be achievable by adding different surfactants in pure water.[1]

I.I Wetting Phenomenon

i) Wetting of a surface with liquids is an important parameter in the engineering process such as heat transfer from condenser, evaporator and heat exchanger. Wetting is significant term on the tubes where a higher wetted area leads to an increase of the interfacial area and enhances heat and mass transfer rates.

ii) The heat and mass transfer depends on the wettability of the surface. So the proposed work is to investigate to study the effect of pool boiling and wettability on heat transfer.

iii) An ability of liquid wetting on a solid surface is known as wettability. The surface forces such as adhesive and cohesive controls the wettability on the surface. Adhesive forces between solid and liquid cause a liquid drop to spread over the surface. The cohesive forces within the liquid have a tendency to avoid contact of drop with the surface. Wetting is the ability of a liquid to have a proper contact with a solid surface, resulting from intermolecular interactions when the two are brought together. The degree of wetting i.e. wettability is determined by a force balance between the forces of adhesive and cohesive of drop on the surface. To study wetting phenomenon is a relatively fascinating field of surface science since it deals with the three phases of materials like gas, liquid and solid. A sessile drop on a solid surface is typical phenomena to explain the wettability is shown in fig 1.

Fig-1: Wettability [ref. 10]

II. Experimental Set up

The said experimental work was useful to study the phenomenon of the pool boiling as well as to measure contact angle of liquid drop formed on nichrome wire which was in horizontal position. The experimental set up was constructed as shown below in fig 2.

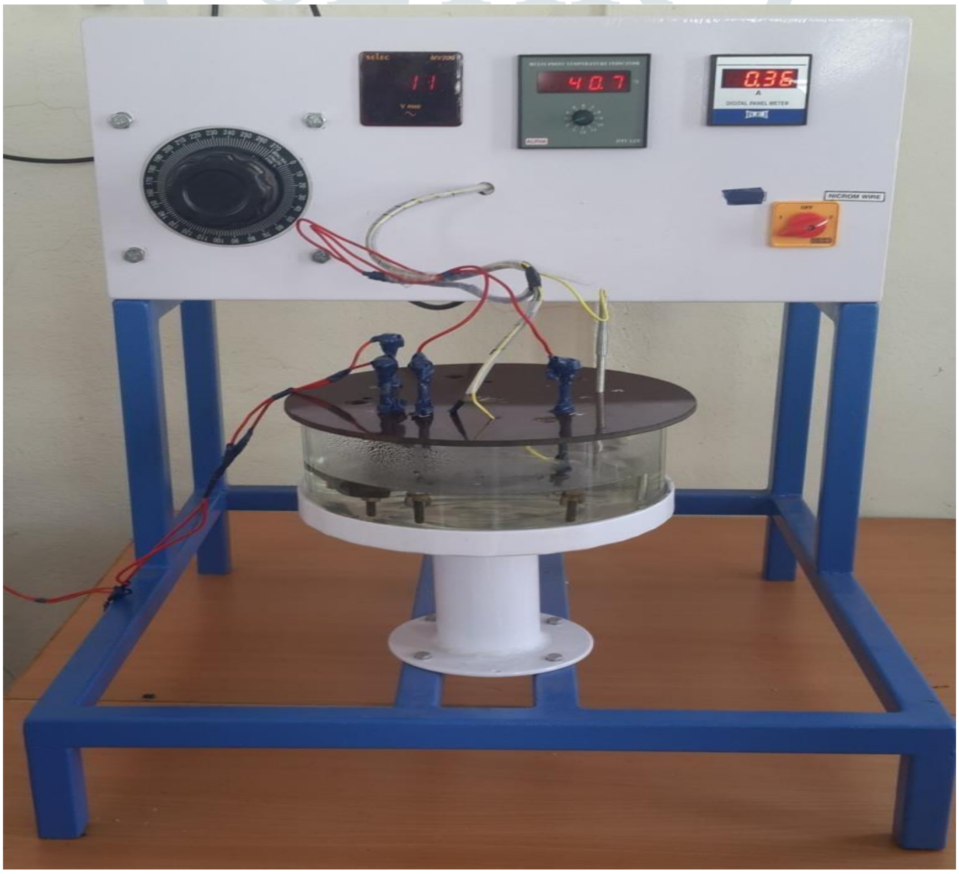


Fig -2: Experimental Set up

The set up consists of a cylindrical glass container, the test heater with nichrome wire at base and the heating coil for the initial heating of the water. The heater coil is directly connected to the mains (Auxiliary Heater) and the test heater (Nichrome wire) is connected also to mains via a dimmer stat. An ammeter (range 0-10 A) is connected in series while for measurement of current and the voltmeter across it to read the voltage. Voltage selector switch was used to select the voltage range 0-20 V. These control units were placed inside the control panel.

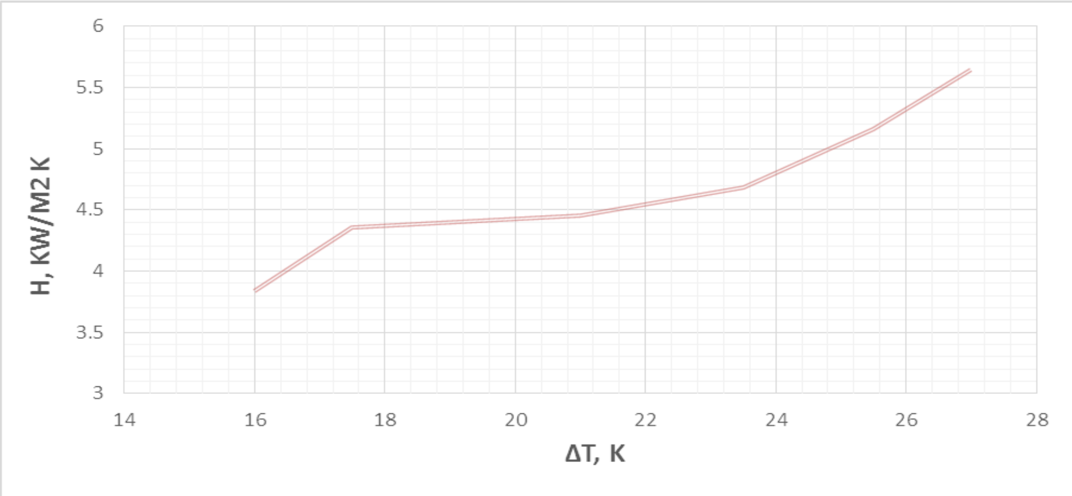
S-S sensor was present in control panel to measure the temperature of bulk water i.e. saturation temperature of water. The temperature of nichrome wire heater was measured by using a Cr-Al k-type thermocouple on a digital temperature indicator having least count 0.1^0 C.

To study the kinetics of vapour bubble in a pool boiling for that experiment was conducted. In which, first start the main heater to heat the water initially up to 40^0 C to 50^0 C. After that switch off the power of main heater and start the auxiliary i.e. nichrome wire heater. Increase and adjust the voltage for a range between 2 V to 10 V. Noted the current required to the heat the nichrome wire. Same procedure was repeated for addition of surfactants in pure water at different concentration. The current and voltage data was used to calculate the required power. Also calculated heat flux, and heat transfer coefficient. A camera was fixed on a stand near to apparatus. The boiling phenomenon could be recorded by using camera (Canon EOS 6D). It could help to saw the bubble nucleation, growth and its departure from the nichrome wire. The Adobe Photo Shop software was used for measurement of contact angle. Electronic balance was used for the measurement of the mass of SLS powder had least count of 1mg.

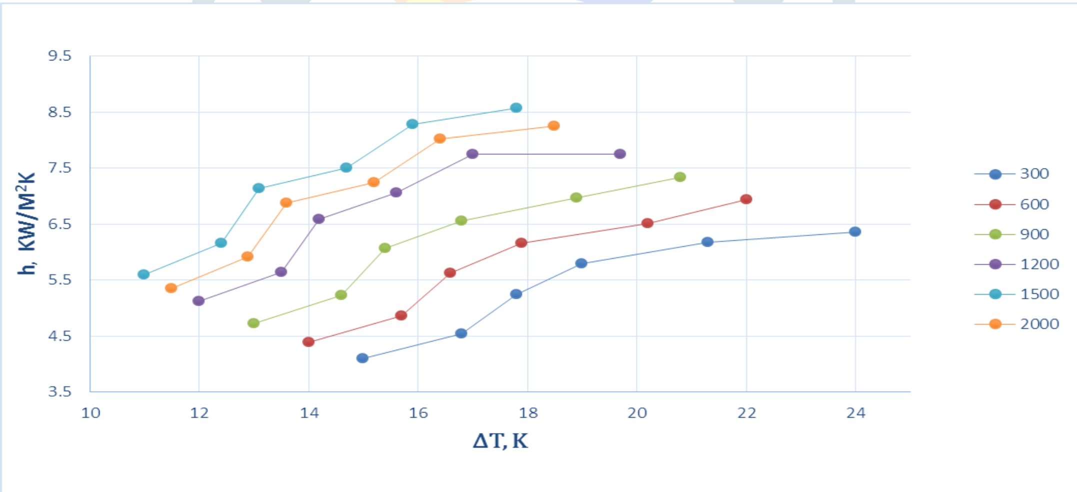
III. RESULTS AND DISCUSSION

The extensive experimentation of pool boiling was carried for pure water with and without surfactant for varying concentrations of SLS and heat flux. From the obtained experimental data, results were plotted in terms of boiling curve as a heat transfer coefficient vs. heater excess temperature. Also the some images of contact angles of bubbles are measured with different concentrations of SLS in pure water.

The graph is plotted in between excess temp. ΔT against heat transfer coefficient h for pure water as well as for SLS in water at different concentrations. Also concentration verses contact angle graph was plotted. The contact angle was measurement by plotting the tangent to the drop in Adobe Photoshop software. Then after according to trigonometric relation calculated the angle.



Graph-1: Excess temp. ΔT Vs Heat transfer coefficient H for pure water



Graph-2: Excess temp. ΔT Vs Heat transfer coefficient H for addition of SLS in water from 300 PPM to 2000 PPM

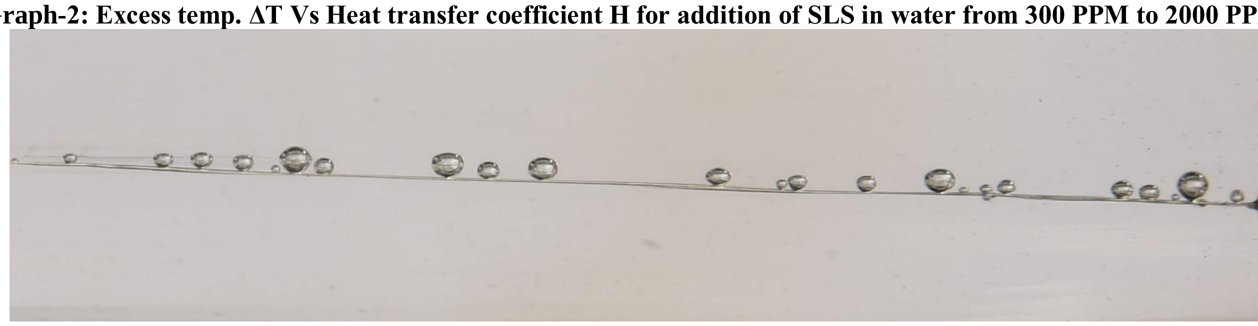


Fig- 3: Bubble Behaviour of pure water for heat flux = 61.53 kw/m^2

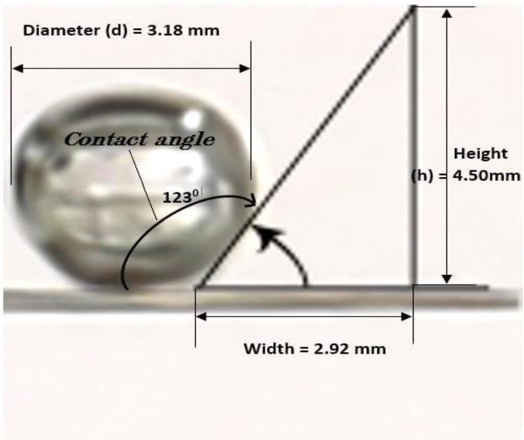


Fig- 4: Measured angle for pure water

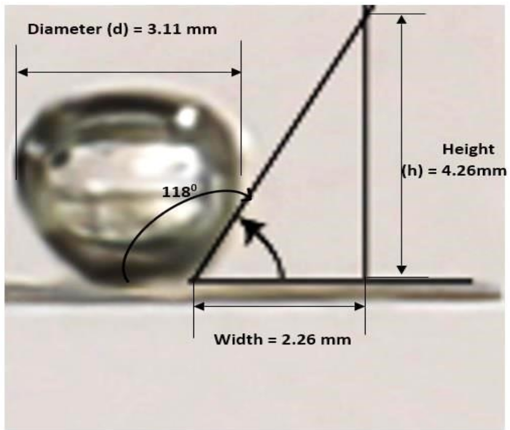


Fig- 5: Measured angle for pure water with SLS at 300 PPM

By using high mega pixel camera it was easy to take photo graph of bubble formation on nichrome wire as shown in fig 3. With the help of this figure, a single drop had taken for measurement of contact angle. It was found that the measured contact angle for SLS was less than compared to pure water. The sample calculation was done in which contact angle, heat transfer coefficient, surface tension, etc were calculated.

3.1 Sample Calculations

1) Contact angle = (θ) = $\{180 - (\tan^{-1}\frac{4.50}{2.92})\} = 123^0$ ....for pure water
2) Surface area of nichrome wire (πDL) = $\pi\,(0.3\text{x}10^{-3})$ x 0.1 = 9.4247 10-5 m^2
3) Power (P) = Volt x Current = 10 x 0.58 = 5.8 Watt
4) Excess Temperature (ΔT)

   ΔT = Nichrom wire Temp. – Water Temp.

   $\Delta T = T_N - T_W$

   = 68-52

   = 16 ^{0}C
5) Heat flux (q)

   $q = \frac{\Delta T}{A \text{ x } 1000}$

   $= \frac{10 \text{ x } 0.58}{(9.4247 \text{ x } 10^{-5}) \text{ x } 1000}$

   = 61.53 kw/m^2
6) Heat transfer coefficient (h)

   $h = \frac{q}{\Delta T}$

   $= \frac{61.53}{16}$

   = 3.84 kw/m^2 k
7) Surface tension (σ):-

   According to Nukiyamas equation for surface tension is,

   $\sigma_{water} = 235.8 \text{ x } [1 - \frac{T_{sat}}{T_c}]^{1.756} \text{ x } [1\text{-}0.625\,(1\text{-}\frac{T_{sat}}{T_c})]$

   $= 235.8 \text{ x } [1 - \frac{100}{374}]^{1.756} \text{x } [1\text{-}0.625\,(1\text{-}\frac{100}{374})]$

   = 74.0202 mN/m

   = 0.074 N/m

Table-1: Results of SLS for different parameters

Sr. No.	Concentration C (PPM)	Contact Angle (θ^0)	Surface Tension σ (N/M)	Heat Transfer Coeff. h (%)
1	300	119	0.065	4.15
2	600	111	0.043	11.47
3	900	104	0.036	20
4	1200	98	0.030	29.59
5	1500	94	0.028	41.29
6	2000	98	0.028	35.78

The table 1 shows the different parameters. As concentration of SLS increases in pure water the surface tension decreases which results in decrease in contact angle up to 1500 PPM and after that it was constant. The heat transfer coefficient also increases as concentration increases.

IV CONCLUSIONS

1) The formations of bubbles in water with surfactant solutions were much smaller than the pure water and it covered the surface area of nichrome wire faster.
2) The measured contact angle with surfactants had less contact angle compared with pure water. Hence the drop was spread which increases the wettability towards surface.
3) Heat transfer was enhanced due to increase in wettability.
4) As heat flux increases, the heat transfer coefficient also increases and surface tension and contact angle decreases for SLS up to 1500 PPM, after that it is increases.

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