ME341A-HEAT AND MASS TRANSFER

Experiment - 7

Critical Heat flux Apparatus (Boiling Heat Transfer)

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<u>Group – G1(a)</u>

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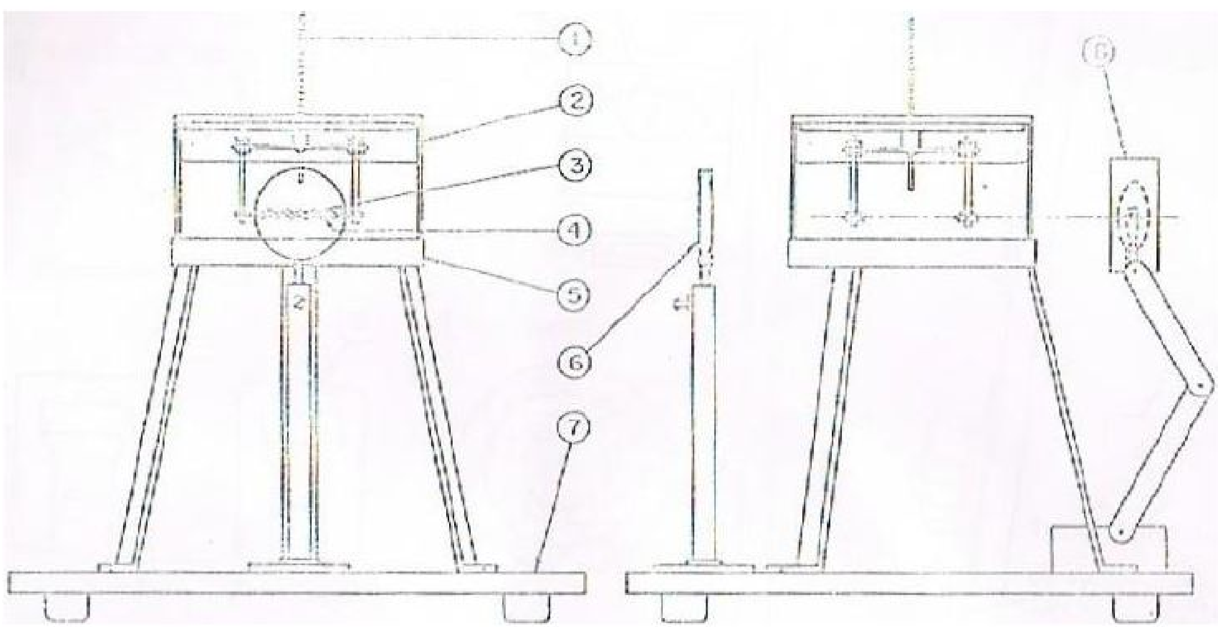
Objective

a) To calculate the critical heat flux at various bulk temperatures of water.
b) To compare the experimentally obtained critical heat flux at the saturation temperature with that obtained by Zuber's correlation.

Experiment

<u>Experiment set-up</u>: The apparatus consists of a cylindrical glass container housing the test heater and a heater coil for the initial heating of the water. This heater coil is directly connected to the mains (Heater R1) and the test heater (Nichrome wire) is connected also to mains via a dimmerstat. An ammeter is connected in series while a voltmeter across it to read the current and voltage, respectively. The glass container is kept on an iron stand which could be fixed on a platform. There is provision of illuminating the test heater wire with the help of a lamp projecting light from behind the container and the heater wire can be viewed through lens. The schematic arrangement of the apparatus is shown in Fig.



1. Thermometer 2. Glass p[illegible] heater 4. Tes[illegible] heater [illegible]
7 Board 8. Lamp

Specification

1. Glass Container Diameter - 200 mm Height - 100 mm (Approx)
2. Heater for initial Heating Nichrome Heater (R1) 1 Kw
3. Test Heater (R2) Nichrome wire size mm (phi) (to be calculated according to wire used say 36 SWG to 40 SWG)
4. Test heater length (R2) 100 mm

5. Dimmerstat for (3) --- Test heater
6. 6. Voltmeter for (3)
7. Ammeter for (3)
8. Thermometer (3)

Procedure

1. Take 3 to 4 litres of distilled water in the container
2. See that both the heaters are completely submerged
3. Connect the heater coil R1 (1 Kw Nichrome coil) and test heater wire across the studs and make the necessary electrical connections
4. Switch on the heater R1.
5. Keep it on till you get the required bulk temperature of water in the container say 50oC, 60oC, 70oC up to the saturation temperature.
6. Switch off the heater R1
7. Switch on the heater R2.
8. Very gradually increase the voltage across it by slowly changing the variac from one position to the other and stop a while at each position to observe the boiling phenomenon on wire.
9. Go on increasing the voltage till wire breaks and carefully note the voltage and current at this point. Repeat this experiment by altering the bulk temperature of water.

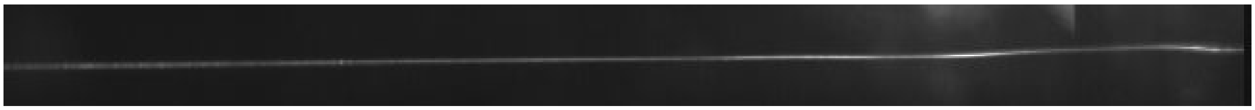
Precautions

1. Keep the variac at zero voltage position before starting the experiments.
2. Take sufficient amount of distilled water in the container so that both the heaters are completely immersed
3. Connect the test heater wire across the studs tightly
4. Do not touch the water or terminal points after putting the switch in the on – position
5. Very gently operate the variac in steps and allow sufficient time in between
6. After the attainment of critical heat flux condition decrease slowly the voltage and bring it to zero.

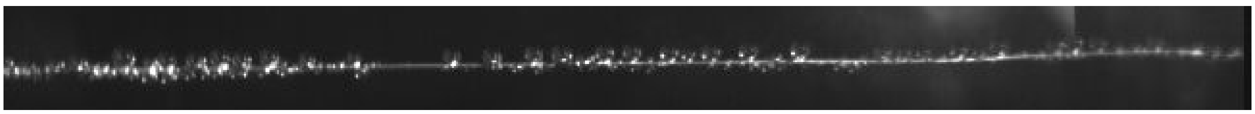
Observations

1. Diameter of test heater wire, d = 0.2 mm
2. Length of the test heater, L = 10 cm
3. Surface area, $A = \pi dL = 0.0000628\ m^2$

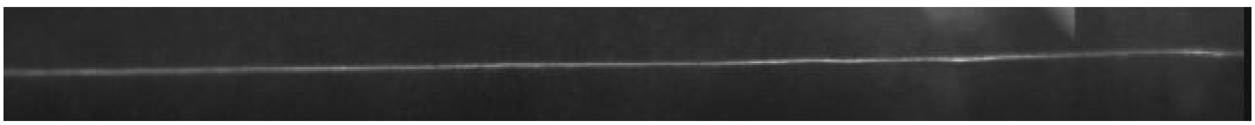
Bulk temp. Of wagter (deg. C)	Ammeter reading (A)	Voltmeter reading (V)
25	11.8	35
50	11.7	32
100 (Saturation temp.)	4.9	18



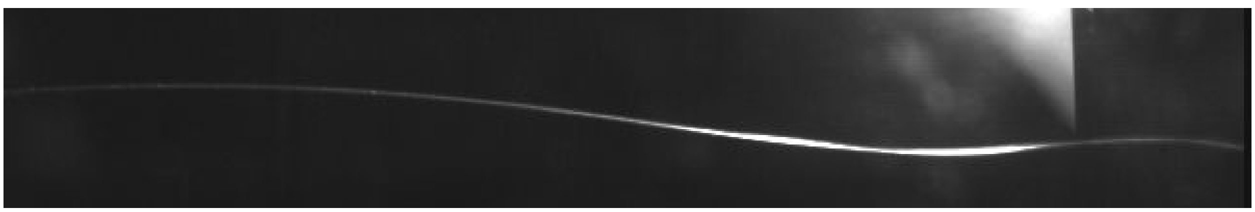
Initial



Nucleate boiling starts



Complete film



Wire breaks

Results and Calculations

The critical heat flux at various bulk temperatures of water can be calculated by the following procedure.

Heat Input = V.I Watts.

Critical q = 0.86 x V.I kCal/hr

(q/A) Critical = $\frac{0.86 \text{ x V.I}}{A}$ Kcal/hr-m^2

Peak heat flux in saturated pool boiling =

Zuber has the following equation for calculating the peak heat flux in saturated pool boiling

$$\frac{q}{A} = \frac{\pi}{24} \cdot \lambda . \rho_v \left[\frac{\sigma . g . (\rho_L - \rho_v)}{{\rho_v}^2}\right]^{\frac{1}{4}} \left[\frac{\rho_L + \rho_v}{\rho_L}\right]^{\frac{1}{2}}$$

Where, λ, ρ_l and ρ_v are evaluated at the liquid saturation temperature.

It can be observed that the critical heat flux value goes on decreasing as the bulk temperature approaches the saturation temperature as expected.
The experimental value of critical heat flux at the saturation temperature is comparable to that obtained by Zuber's correlation.

Sample Calculation:

* Sample calculation :-

(A) Dia. of test heater wire, $d = 0.2\,mm$

length of test heater wire, $L = 10\,cm$

surface area, $A = \pi d L$

$= 0.00006283\ m^2$

Heat input $= VI = 35 \times 11.8$

$= 413\ W$

Critical, $q = 0.86 \times VI = 355.18$ kcal

Critical heat flux $= q/A = \dfrac{355.18}{0.00006283} = 5652.86$ kcal/hr-m²

(B) Comparision with zuber's correlation's calculation -

$$\frac{q}{A} = \frac{\pi}{24} \cdot \lambda \cdot \rho_v \left[\frac{\sigma g(\rho_L - \rho_v)}{\rho_v^2}\right]^{1/4} \left[\frac{(\rho_L + \rho_v)}{\rho_L}\right]^{1/2}$$

where, $\lambda = 2251 \times 10^3\ J/kg$; $\rho_v = 0.0231\ kg/m^3$

$\sigma = 0.0584\ N/m$; $\rho_L = 9970.13\ kg/m^3$

$g = 10\ m/s^2$ at $T_{sat} = 25^\circ C$

On putting above value, we get $\dfrac{q}{A} = 3072.20$ kcal/hr

$(q/A)_{zuber}$ is comparable to value of q/A from part (A).

Bulk Temperature	Critical heat flux experimental (Kcal/hr-m^2)	Critical heat flux by Zuber's correlation (Kcal/hr-m^2)
25	5652.86	3072.20
50	5124.50	4181.90
100 (Saturation temp.)	1207.20	1116.78

Error:

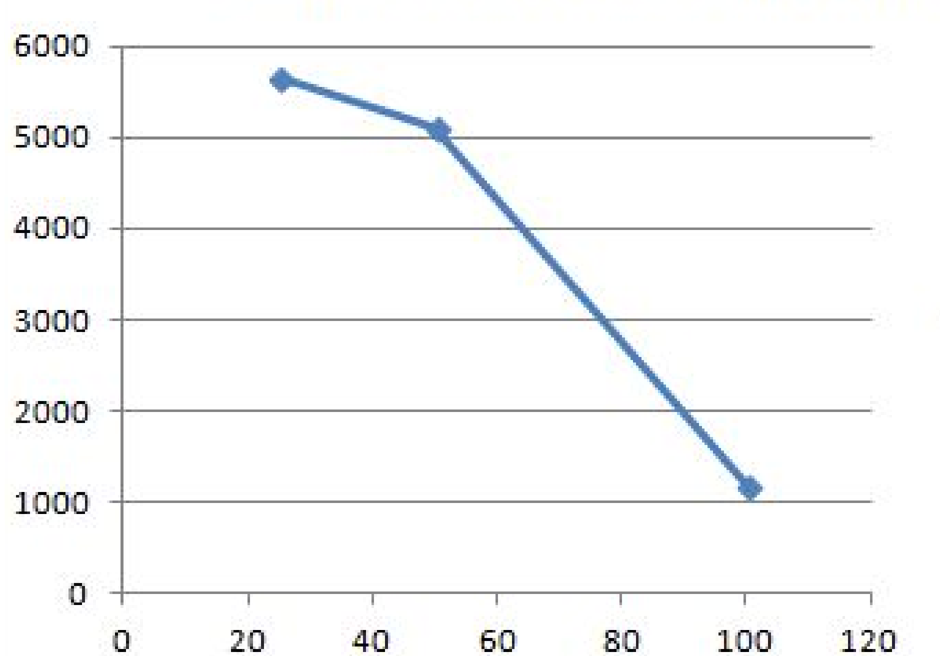
ε = [(Critical heat flux experimental - Critical heat flux by Zuber's correlation)/Critical heat flux by Zuber's correlation] x 100

= (1207.20 - 1116.78)/1116.78 x 100

= 8.09%

Graph:

Critical heat flux Vs Temp



Uncertainty Analysis:

* Uncertainity Analysis :-

$$(q/A)_{critical} = \frac{0.86 \times V.I.}{A} \quad \text{Kcal/hr-m}^2$$

$$V = (35 \pm 1)\,V$$

$$I = (11.8 \pm 0.1)\,A$$

$$A = 0.00006283\ m^2 \text{ (given)}$$

$$U = \left[\left(\frac{\partial (q/A)_{critical}}{\partial V} \cdot U_V\right)^2 + \left(\frac{\partial (q/A)_{critical}}{\partial I}\, U_I\right)^2\right]^{1/2}$$

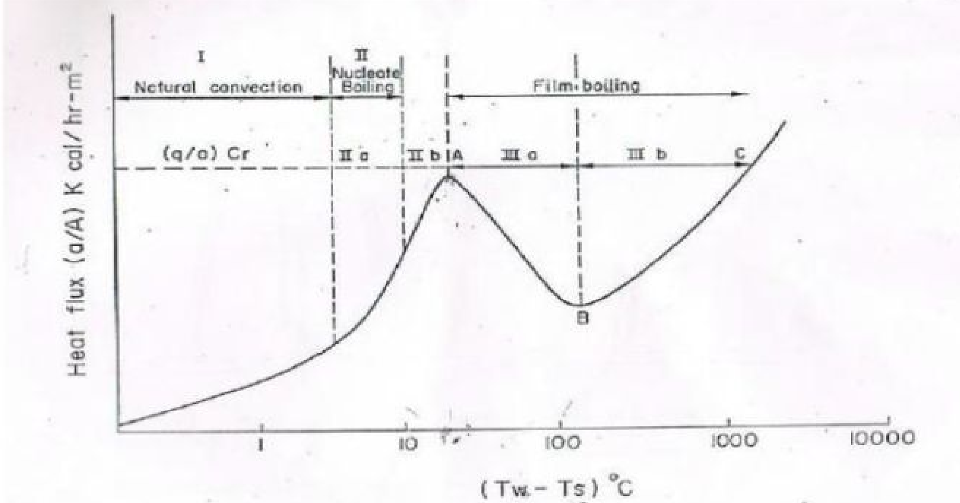
$$= \left[\left(\frac{0.86\,V I}{A}\, U_V\right)^2 + \left(\frac{0.86\,V}{A}\, U_I\right)^2\right]^{1/2}$$

$$= \frac{0.86}{A}\left[(I U_V)^2 + (V U_I)^2\right]^{1/2}$$

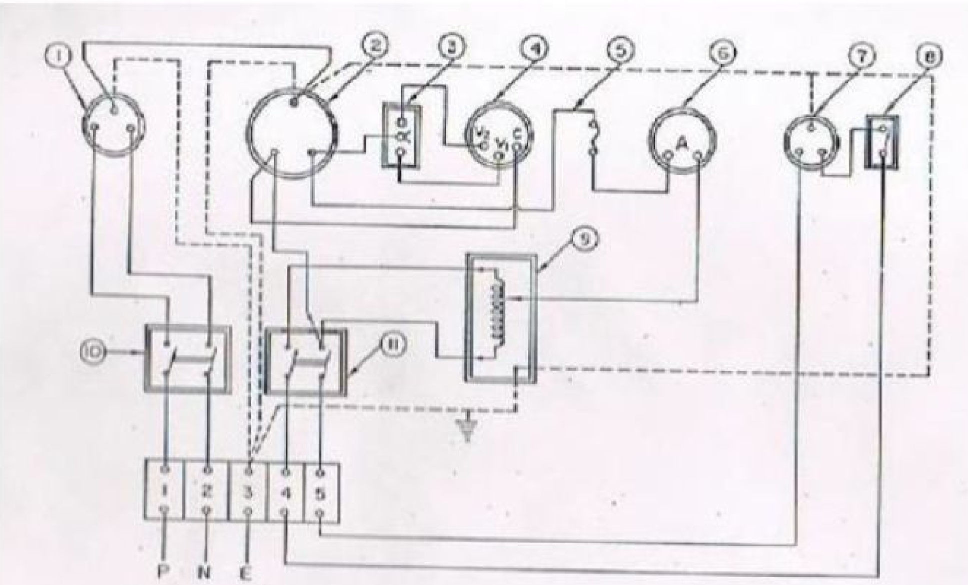
$$= \frac{0.86}{0.0006283}\left[(0.1 \times 35)^2 + (1 \times 11.8)^2\right]^{1/2}$$

$$\Rightarrow U = 168.47 \text{ KCal/hr-m}^2$$

Expected curves:



Typical pool boiling curve



1 Socket 5 A (Bulk heater) 2 Socket 15 A (Test heater) 3 Voltmeter selector switch
4 Voltmeter 5 Fuse 6 Ammeter 7 Socket 5A for lamp 8 Switch for 7
9 Dimmer stat 10 D.P. Switch 15 A 11 D.P. Switch 30 A

Circuit diagram for critical heat flux apparatus control panel

References:

1. A text book on Heat Transfer by Dr. S. P. Sukhatme. (First Edition)

2. N. Zuber, On the stability of Boiling Heat Transfer, Trans. ASME, Vol. 80 pp. 771 (1958).
3. Heat and Mass Transfer by Yunus A Cengel and Afsin J Ghajar
4. ME 341 Lab report template, IIT Kanpur fall spring 2018.