ME-341A – HEAT AND MASS TRANSFER

Department of Mechanical Engineering, IIT Kanpur

<u>EXPERIMENT 7</u>

CRITICAL HEAT FLUX APPARATUS
(BOILING HEAT TRANSFER)

GROUP MEMBERS [Group No. G1(B)]

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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.

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.
10. Repeat this experiment by altering the bulk temperature of water.

Observation

Specification:-

1. Diameter of test heater wire, d = 0.2 mm
2. Length of the test heater, L = 10 cm
3. Surface Area A = (pi)(d)(L) = 0.00006284 m2

S. No.	**Bulk temp. Of water** (deg. C)	**Ammeter reading** (A)	**Voltmeter reading** (V)
1.	25	12.3	33
2.	50	10.5	30
3.	100 (Saturation T)	5.5	16

Results

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 = A 0.86*VI Kcal/hr-m2

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

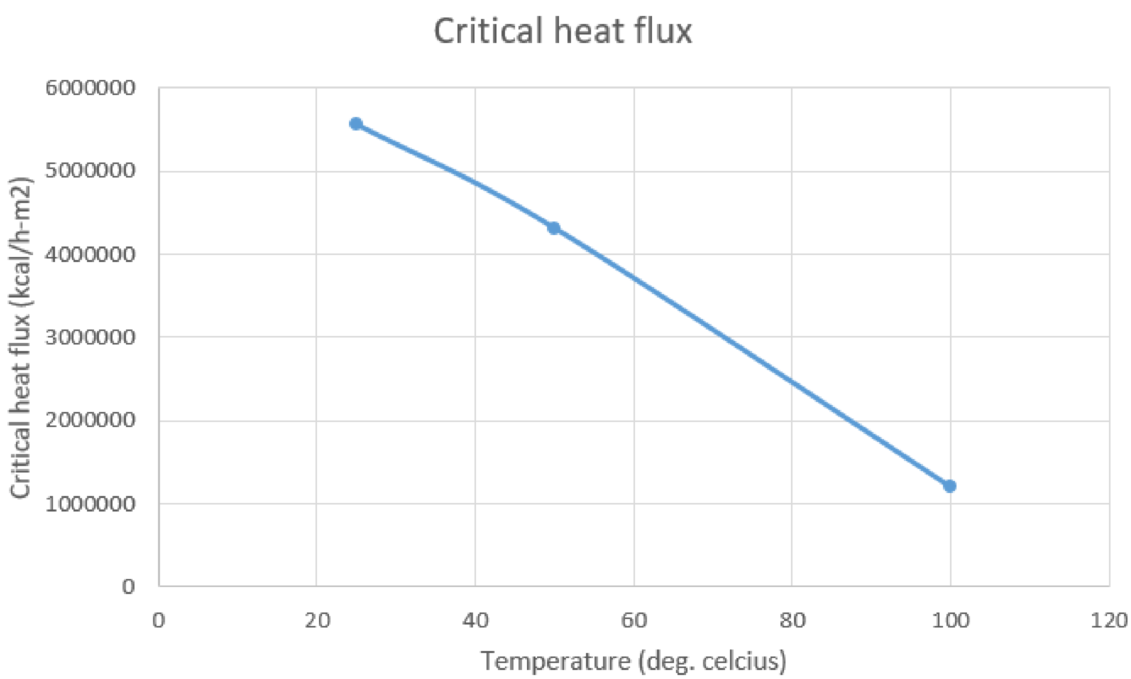
$$\frac{q}{A} = \frac{\pi}{24} \cdot \lambda \cdot \rho_v \left[\frac{\sigma \cdot g \cdot (\rho_L - \rho_v)}{\rho_v^{\ 2}}\right]^{\frac{1}{4}} \left[\frac{\rho_L + \rho_v}{\rho_L}\right]^{\frac{1}{2}}$$

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.

Critical Value of heat flux at different bulk temperature

Bulk temperature	**Critical heat flux** (kcal/hr-m2)	**Zuber Value** (kcal/hr-m2)
25	5554964.99	954503.65
50	4310948.44	954503.65
100	1204328.453	954503.65



Discussion

Heat transfer from the heated surface to the liquid in its vicinity causes the liquid to be superheated. As the temperature of wire increases first nucleation starts and then a film of superheated vapor form around. The Thermal conductivity of superheated film is very small which does not allow the heat generated in the wire to transmit. Which leads to overheating of wire and eventually the wire melts down.

Critical heat flux is expected to decrease with increase in bulk temperature of water which is justifies by the experiment.

Value of critical heat flux is (1.558 ± 0.095)*10 6 Kcal/hr-m2 . Error is around 64% which is quite large.

Appendix

Sample calculations

SAMPLE CALCULATION

q = Heat input = VI

(Taking 3rd case when Bulk temp of water is 100°C (Saturation T))

$VI = (5.5) \times (16)$

$= 88\ W$

$= 75.68\ Kcal/hr$

$$\boxed{\frac{q}{A} = \frac{75.68}{6.284 \times 10^{-5}} \Rightarrow 1.204 \times 10^{6}\ \frac{kcal}{hr\,m^2}}$$

Area $\Rightarrow A = \pi d L = \pi (0.2 \times 10^{-3})(0.1) \Rightarrow 6.284 \times 10^{-5}\ m^2$

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

Here λ, ρ_L, ρ_v are evaluated at liq satn temperature

So, $\lambda = 2257 \times 10^3\ J/kg$ $\quad \rho_v = 0.6\ kg/m^3$

$\sigma = 0.0589\ N/m$ $\quad g = 9.8\ m/s^2$

$\rho_L = 957.9\ kg/m^3$

Using above, we get

$$\boxed{\frac{q}{A} \Rightarrow 954503.65\ Kcal/hr\text{-}m^2}$$

Uncertainty and Error Analysis

$$\boxed{\text{UNCERTAINTY ANALYSIS}}$$

$$\left(\frac{q}{A}\right)_{critical} = 0.86\,\frac{VI}{A}\ \text{Kcal/hr-m}^2 \qquad V(@\,T_{sat} = 100^\circ C) = 16\ V$$

$$U_V = 1\ V$$

$$I\,(@\,T_{sat}) = \cancel{6.7}\ 5.5\ A\ ; \quad U_I = 0.1\ A \qquad \text{So, } V = (16 \pm 1)\ V$$

$$\therefore\ I = (\cancel{6.7}\ 5.5 \pm 0.1)\ A$$

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

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

$$\text{Area } (A) = 6.284 \times 10^{-5}\ m^2 = \text{constant}$$

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

$$\Rightarrow \frac{0.86}{6.284} \times 10^5 \left[(0.1 \times 16)^2 + (1 \times \cancel{6.7}\ 5.5)^2\right]^{1/2}$$

$$\Rightarrow 0.784 \times 10^5\ \text{Kcal/hr-m}^2$$

$$\&\ \left(\frac{q}{A}\right)_{crit} = \frac{0.86 \times VI}{A} \Rightarrow \frac{0.86 \times 16 \times 5.5}{6.284 \times 10^{-5}} \Rightarrow 1.204 \times 10^6\ \text{Kcal/hr-m}^2$$

So, therefore

$$(q/A)_{crit} = (1.204 \pm 0.0784) \times 10^6\ \text{Kcal/hr-m}^2$$

$\boxed{\text{ERROR ANALYSIS}}$

Critical heat flux at saturation temperature (exp) $\Rightarrow 1.204 \times 10^6 \frac{Kcal}{hr-m^2}$

Value obtained using

"Zuber Correlation" $\Rightarrow$ 954503.65 Kcal/hr-m^2

$$\text{Error} = \frac{|(\text{Exp. value}) - (\text{Theor. value})|}{(\text{Theoretical value})} \times 100$$

$$\Rightarrow \frac{954503.65 - 1204328.45}{\cancel{1204328.4}\ 954503.65} \times 100$$

$\boxed{\text{Error} \Rightarrow 26.17\%}$

Reasons for the Error

1. Human Error – The Voltage must be increased slowly and gradually. If it is not done in that way then it will lead to melting will occur at higher voltage than expected as it take time for wire to heat up, which explain the error.
2. Machine error – The sensitivity of voltmeter is 1 V which very poor and hence the result obtained is not very precise.

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.

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 manual, Prof. Panigrahi, IITK.