HEAR TRANSFER LABORATORY
DEPARTMENT OF MECHANICAL ENGINEERING

Expt.No.7: CRITICAL HEAT FLUX APPARATUS (BOILING HEAT TRANSFER)

OBJECTIVES:

(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

INTRODUCTION:

When heat is added to a liquid from a submerged solid surface which is at a temperature higher than the saturation temperature of the liquid, it is usual for a part of the liquid to change phase. This change of phase is called boiling. Boiling is of various types, the type depending upon the temperature difference between the surface and the liquid. The different types are indicated in Fig. 1, in which a typical experimental boiling curve obtained in a saturated pool of liquid is drawn.

This heat flux supplied to the surface is plotted against (T_w - T_s), the difference between the temperature of the surface and the saturation temperature of the liquid. It is seen that the boiling curve can be divided into three regions:

1. Natural Convection Region
2. Nucleate Boiling Region
3. Film Boiling Region

The region of natural convection occurs at low temperature differences (of the order of 10^o C or less). Heat transfer from the heated surface to the liquid in its vicinity causes the liquid to be superheated. This superheated liquid rises to the free liquid surface by natural convection, where vapour is produced by evaporation. As the temperature difference (T_w - T_s) is increased, nucleate boiling starts. In this region, it is observed that bubbles start to form at certain locations on the heated surface. Region II consists of two parts. In the first part, II-a, the bubbles formed are very few in number. They condense in the liquid and do not reach the free surface.

In the second part, II-b, the rate of bubble formation as well as the number of locations where they are formed, increases. Some of the bubbles now rise all the way to the free surface.

With the increasing temperature difference, a stage is finally reached when the rate of formation of bubbles is so high, that they start to coalesce and blanket the surface with a vapour film. This is the beginning of region III viz. film boiling. In the first part of this region III-a, the vapour film is unstable, so that film boiling may be occurring on a portion of the heated surface area, while nucleate boiling may be occurring on the remaining area. In the second part, III-b, a stable film covers the entire surface. The temperature difference in this region is of the order of 1000^oC and consequently radiative heat transfer across the vapour film is also significant. It will be observed from Fig. 1, that the heat flux does not increase in a regular manner with the temperature difference. In region, I, the heat flux is proportional to $(T_w - T_s)^n$ where n is slightly greater than unity (about 1.3). When the transition from natural convection to nucleate boiling occurs the heat flux starts to increase more rapidly with temperature difference, the value of n increasing to about 3.At the end of region II, the boiling curve reaches a peak (Point A). Beyond this, in region III-a, inspite of increasing temperature difference, the heat flux decreases because the thermal resistance to the heat flow increases with the formation of a vapour film. The heat flux passed through a minimum (Point B) at the end of region III-a. It starts to increase again with (T_w - T_s) only when stable film boiling begins and radiation becomes increasingly important.

It is of interest to note how the temperature of the heating surface changes as the heat flux is steadily increased from zero. Up to the point A, natural convection boiling and then nucleate boiling occur and the temperature of the heating surface is obtained by reading off the value (T_w - T_s) from the boiling curve and adding t o it the value T_s. If the heat flux is increased even a little beyond the value at A, the temperature of the surface will shoot up to the value corresponding to the point C. It is apparent from Fig. 1, that the surface temperature corresponding to point C is high. For most surfaces, it is high enough to cause the material to melt. Thus in most practical situations, it is undesirable to exceed the value of heat flux corresponding to point A. This value is therefore of considerable engineering significance and is called the critical or peak heat flux. The pool boiling curve as described above is known as Nukiyama Pool Boiling Curve. The discussion so far has been concerned with various types of boiling which occur in saturated pool boiling. If the liquid is below the saturation temperature we say that sub-cooled pool boiling is taking place. Also in many practical situations, e.g. steam generators, one is interested in boiling the liquid flowing through tubes. This is called forced convection boiling and may also be saturated or sub-cooled or nucleate or film type.

Thus in order to completely specify boiling occurring in any process, one must state (i) whether it is forced convection boiling or pool boiling, (ii) whether the liquid is saturated or sub-cooled, and (iii) whether it is in the natural convection, nucleate or film boiling region.

APPARATUS:

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. 2.

SPECIFICATIONS:

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. Voltmeter for (3)
7. Ammeter for (3)
8. Thermometer (3)

EXPERIMENTS:

This experimental set up is designed to study the pool boiling phenomenon up to critical heat flux point. The pool boiling over heater wire can be visualised in the different regions up to critical heat flux point at which the wire melts. The heat from the wire is slowly increased by gradually increasing applied voltage across the test wire and the change over from natural convection to nucleate boiling can be seen.

The formation of bubbles and their growth in size and number can be visualised, followed by the vigorous bubble formation and their immediate carrying over to surface and ending thus in the breaking of the wire indicating the occurrence of critical heat flux point. This is repeated for various temperatures of the water in the container upto the saturation temperature.

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 50^oC, 60^oC, 70^oC 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.

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: (FOR FINDING CRITICAL HEAT FLUX VALUES)

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

Bulk Temperature of water degree C	Ammeter Reading I Amp.	Voltmeter Reading V volts
40		
50		
60		
70		
80		
90		
95		
Saturation Temperature		

NOTE:

The Ammeter and the Voltmeter readings are to be noted down when the wire melts.

RESULTS: (EXPERIMENT BASED)

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

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

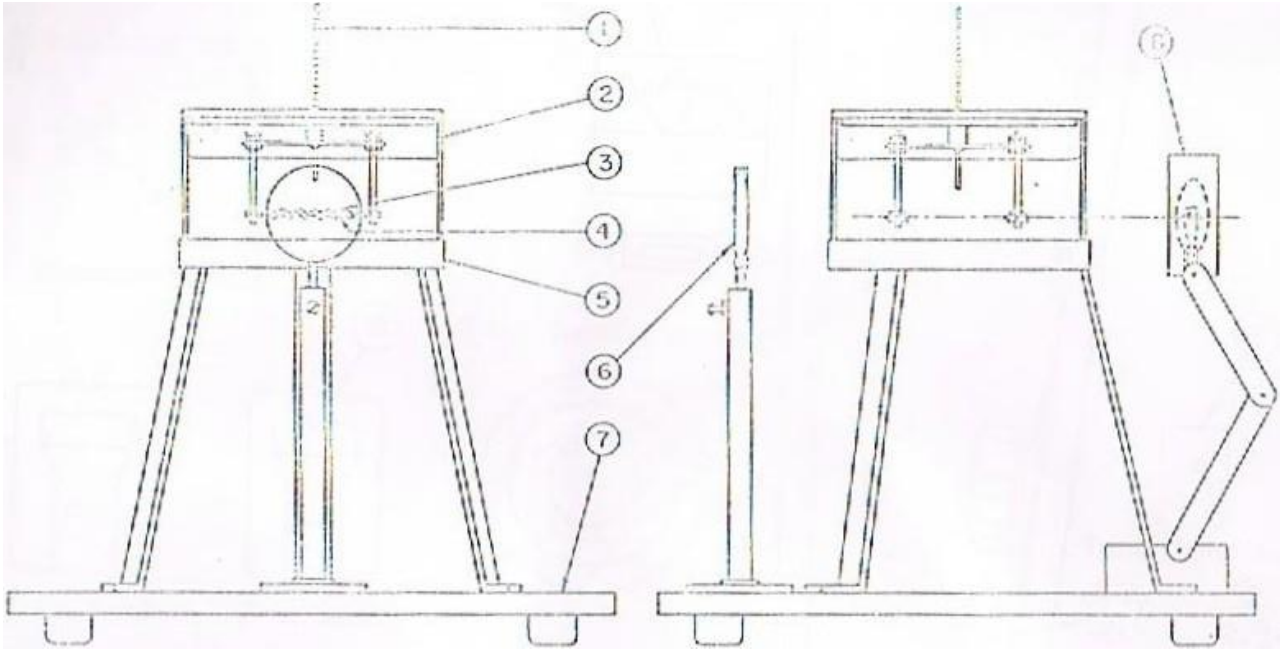
where, λ , ρ_L and ρ_v are evaluated at the liquid saturation temperature. [Refer, ref (1) page 238]

It can be observed that the critical heat flux value goes on decreasing as the bulk temperature approaches the saturation temperature as expected (Fig. 3).

The experimental value of critical heat flux at the saturation temperature is comparable to that obtained by Zuber's correlation.

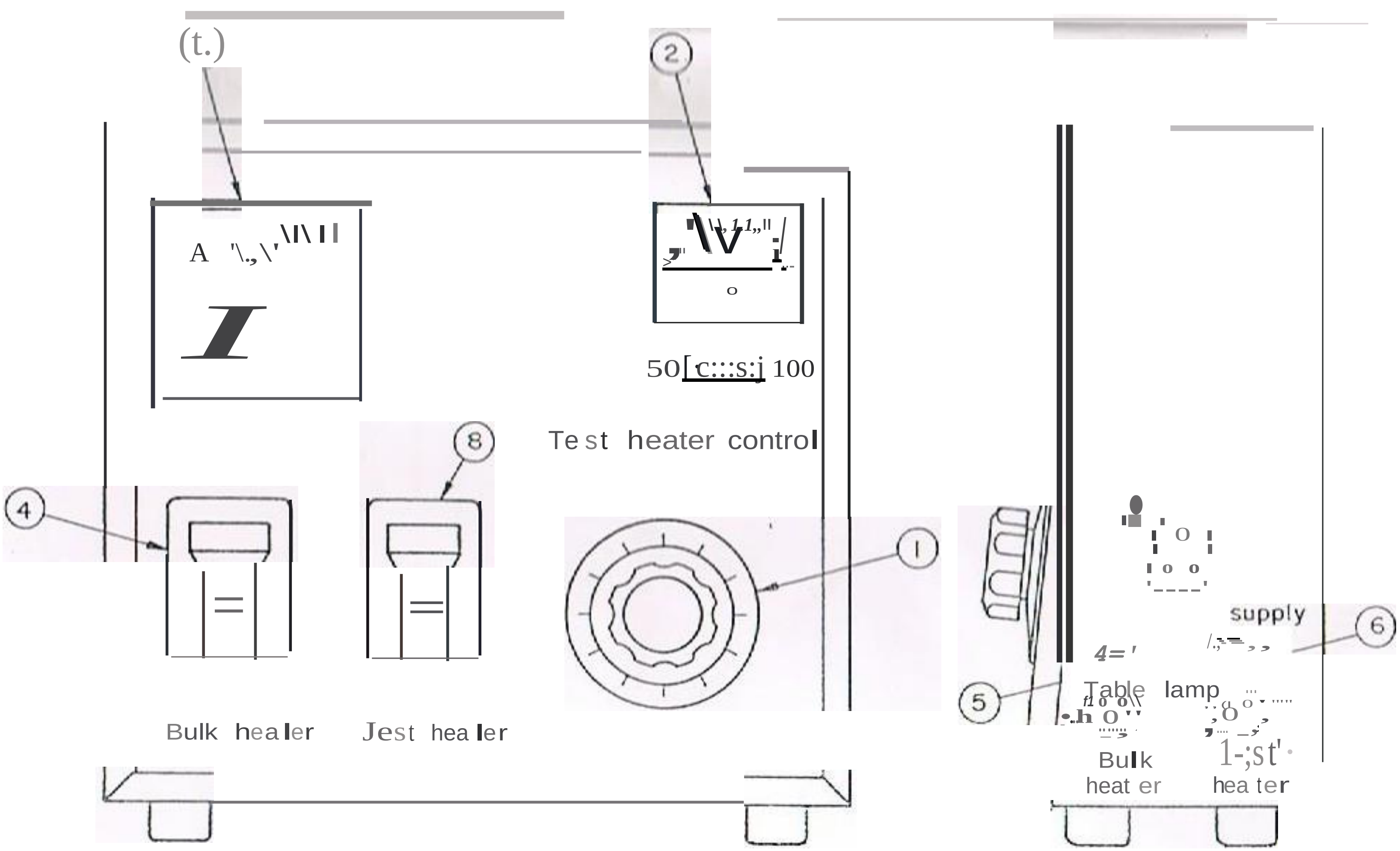
REFERENCES:

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).



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

[illegible] c diagram [illegible] us.



1- Dimmer stat 2 · Voltmeter 3. Ammeter 4. D.P. Switch (Bulk heater) 5. Power socket 5 amp. 6. Power socket 15 amp 7. Main socket 5 amp 8. D.P. Switch (Test heater)

Critical heat flux apparatus

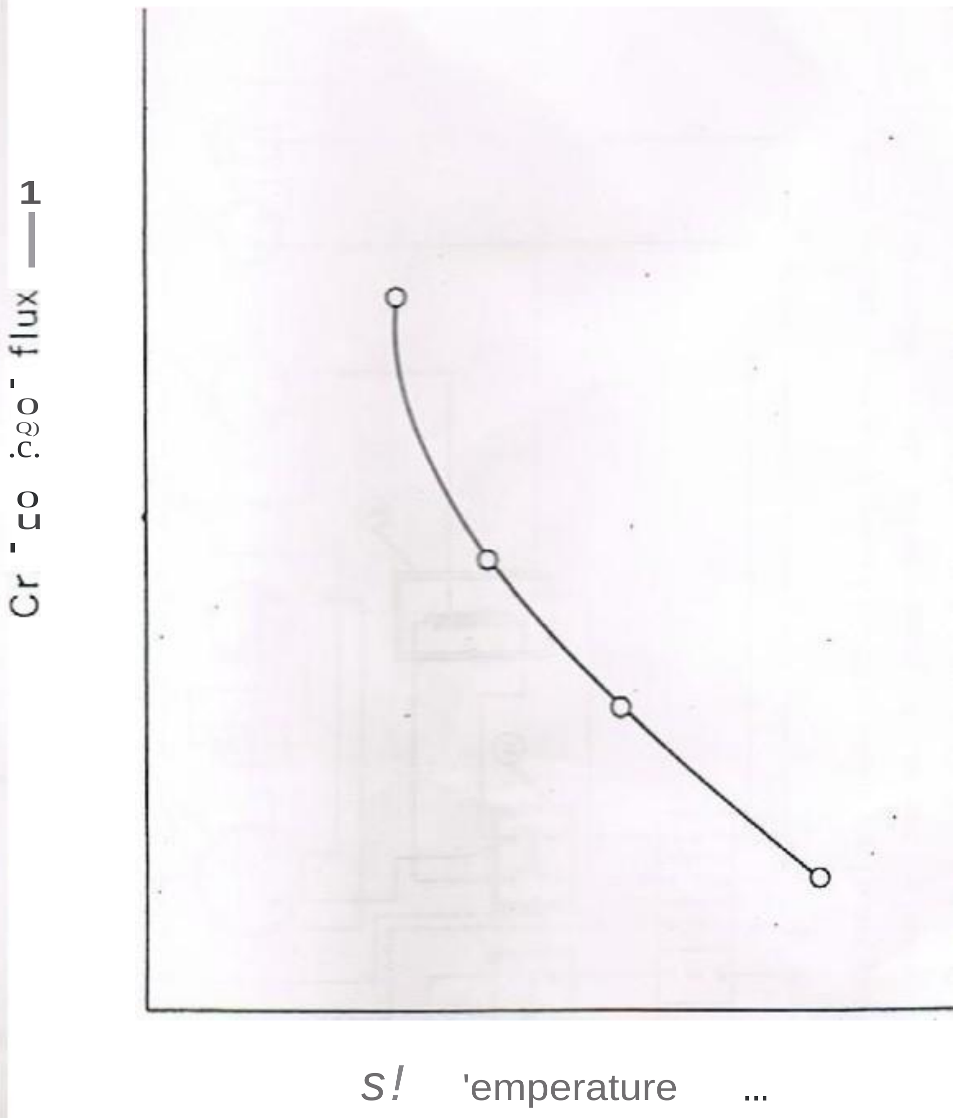
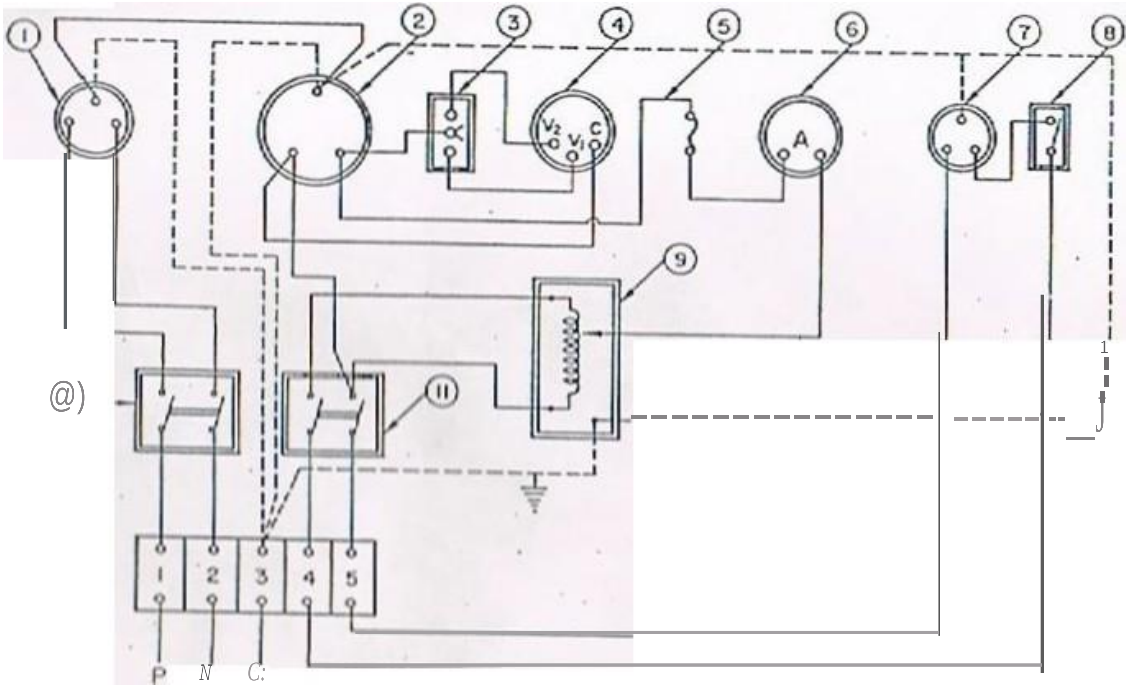
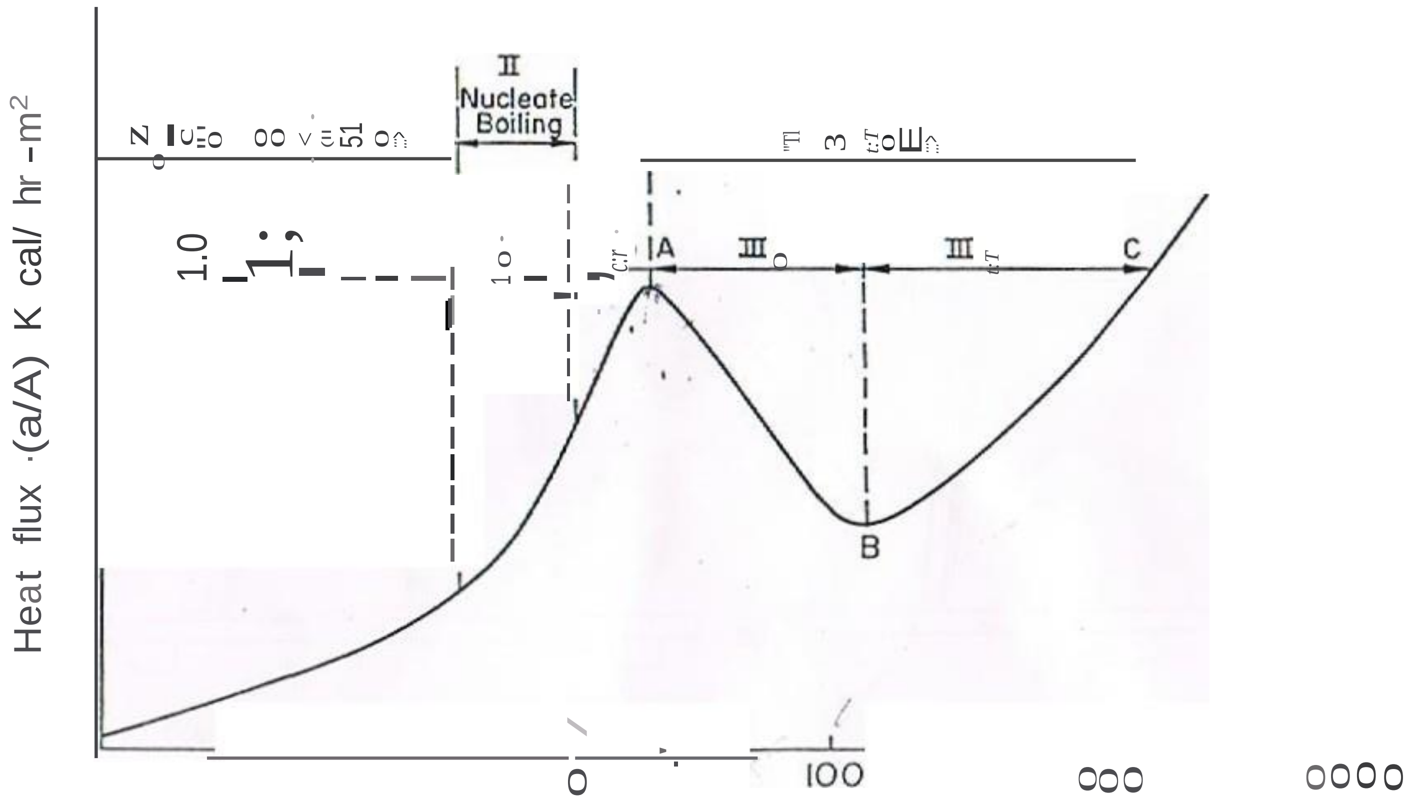


Fig. 3



1 Socket 5A (Bulk heater) 2. Socket 15A (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 15A 11 D.P. Switch 30A

Circuit diagram for critical heat flux apparatus control panel



[illegible] ng curve