Aim:

studies on heat transfer by Natural Convection

Objectives:

(i) Study of convection heat transfer in natural convection.
(ii) To find out the heat transfer co efficient of vertical cylinder in natural convection.

Theory:

Convection is defined as process of heat transfer by combined action of heat conduction and mixing motion. Convection heat transfer is further classified as natural convection and forced convection. If the mixing motion takes place due to density difference caused by temperature gradient, then the process of heat transfer by natural or free convection. If the mixing motion is induced by some external means such as a pump or blower, then the process is known as heat transfer by forced convection.

Natural convection is the phenomenon is due to the temperature difference between the surface and the fluid and is not created by any external agency. The setup is designed and fabricated to study the natural convection phenomenon from a vertical cylinder in terms of average heat transfer coefficient.

The heat transfer co-efficient is given by

$$h = \frac{Q_a}{A(T_s - T_a)} \quad (1)$$

where Q = heat transfer/input power
T_s = steady state temp.
T_a = ambient Temp.

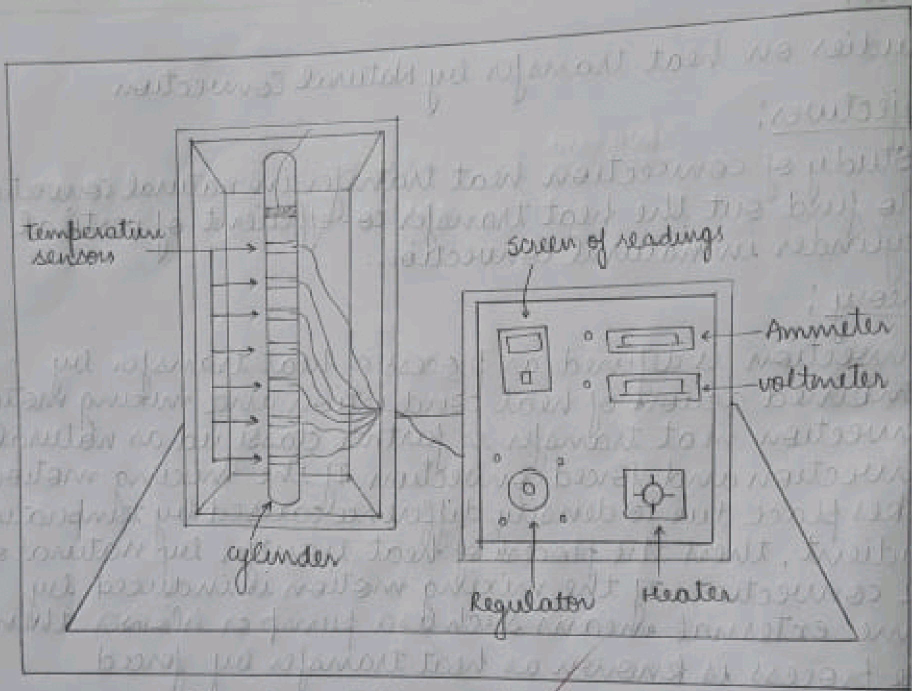

Fig: Natural Convection Apparatus

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Experimental Details;

The apparatus consists of a brass tube fitted in a rectangular duct in a vertical fashion. The duct is open at the top and bottom and forms an enclosure and serves the purpose of undisturbed surrounding. One side of it is made up of glass/acrylic for visulization. A heating element is kept in the vertical tube, which heats the tube surface. The heat is lost from the tube to the surrounding air by natural convection. Digital temperature indicator measures the temperature at the different points with the help of seven temperature sensors. The heat input to the heater is measured by digital temperature and digital voltmeter and can be varied by a dimmerstat.

Experimental Procedure;

Starting Procedure:

(i) Clean the apparatus and make it free from dust first.
(ii) Ensure that all ON/OFF switches given on the panel are at OFF position.
(iii) Ensure that variac knob is at ZERO position, given on the panel.
(iv) Switch on the panel with the help of Mains ON/OFF switch given on the panel.
(v) Fix the power input to the heater with the help of Variac, Voltmeter and Ammeter provided.
(vi) After 30 minutes record the temperature of test section at various points in each 5 minutes interval.
(vii) If temperature readings are same for three times, assume that steady state is achieved.

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Expt.-5: Heat transfer in Natural Convection —

Time (min)	Volts (V)	I (A)	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
0	70	0.38	49.1	57.0	52.3	53.8	53.1	50.0	48.3	32.9
5	70	0.38	51.5	53.5	54.7	56.2	55.5	52.2	50.3	33.2
15	70	0.38	54.0	56.0	57.5	59.0	58.3	55.2	53.5	33.4
25	70	0.38	55.9	57.9	59.3	60.7	60.0	56.8	55.2	33.9
35	70	0.38	56.6	58.8	60.2	61.7	61.1	57.9	56.1	33.7
35	60	0.33	57.1	59.0	60.4	61.9	61.3	58.1	56.4	33.9
45	60	0.33	56.6	58.5	59.4	60.7	60.2	57.6	56.1	33.8

(viii) Record the final temperatures.

Closing Procedure;

(i) when experiment is over, switch off heater first.

(ii) Adjust Variac at zero.

(iii) switch off the panel with the help of Mains On/off switch given on the panel.

(iv) switch off power supply to panel.

Observations and Calculations;

Time (min.)	Volts (V)	I (A)	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
0	70	0.38	49.1	51.0	52.3	53.8	53.1	50.0	48.3	32.9
5	70	0.38	51.5	53.0	54.7	56.2	55.5	52.2	50.3	33.2
15	70	0.38	54.0	56.0	57.5	59.0	58.3	55.2	53.5	33.4
25	70	0.38	55.9	57.9	59.3	60.7	60.0	56.8	55.2	33.9
35	70	0.38	56.6	58.8	60.2	61.7	61.1	57.9	56.1	33.7
35	60	0.33	57.1	59.0	60.4	61.9	61.3	58.1	56.4	33.9
45	60	0.33	56.6	58.5	59.4	60.7	60.2	57.6	56.1	33.8

Steady state

{T_i in (°c)}

V = Voltage reading (volts)

T_1 to T_7 = surface temp. of test section (°c)

T_a = T_8 = Temperature of air (°c)

L = length of cylinder (m)

A = Heat transfer area (m^2)

d = Diameter of cylinder (m)

T_s = Average surface temp. (°c)

I = Ampere reading (amp)

h = Heat transfer coefficient (W/m^2°c)

Q = Amount of heat transfer. (W)

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Calculations:

DATA → $L = 0.5\,m$, $d = 0.038\,m$

$A = \pi d L = 0.059\,m^2$

⇨ for $V = 70$ volts and $I = 0.38A$ —

$$T_s = T_{avg.} = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7}{7}$$

$$= \frac{56.6 + 58.8 + 60.2 + 61.7 + 61.1 + 57.9 + 56.1}{7} = 58.91°C$$

$T_a = T_8 = 33.7°C$

for temporary state, $Q = V \times I = 70 \times 0.38 = 26.6$ J/sec

using eqⁿ-①,

$$h = \frac{Q}{A(T_s - T_a)} = \frac{26.6}{0.059(58.91 - 33.7)} = 17.88\ W/m^2 °C$$

⇨ for $V = 60$ volts and $I = 0.33A$ —

$$T_s = T_{avg.} = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7}{7} = \frac{56.6 + 58.5 + 59.4 + 60.7 + 60.2 + 57.6 + 56.1}{7}$$

$= 58.44°C$

using eqⁿ-①,

$$h = \frac{Q}{A(T_s - T_a)} = \frac{60 \times 0.33}{0.059(58.44 - 33.8)} = 13.62\ W/m^2 °C$$

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Discussion:

The observed temperature data portrays at the system's movement towards the steady state. In depth analysis of temperature profiles across different points of the cylinder facilitates the determination of heat transfer coefficient. The coefficient stands as a pivotal factor in gauging the efficiency of heat transfer in natural convec-tion. Trends in data portrays a consistent reduction in temperature gradients as the system reaches near steady state, indicating decrease in heat transfer rate due to the equilibrium stablished.

Conclusion:

This experiment focusses on natural heat transfer and aimed to determine the heat transfer coefficient. The steps includes setting up the experiment, stab-ilizing the system, recording temperature data, analyzing steady state, ~~calcu~~ calculated heat transfer coefficients. The findings revealed insights into a convection equilibrium, with changing temp-erature gradient to near constant indicating steady state. The accuracy enhances on extended time intervals. Overall, this experiment depends on heat transfer convection & finding coefficient.

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CRITICAL COMMENTS :—

Precautions -

(i) Never run the apparatus if power supply is less than 180V and above than 230 volts.

(ii) Never switch ON mains power supply before ensuring that all ON/OFF switched off.

(iii) operate selector switch off temperature indicator gently.

(iv) Always keep the apparatus free from dust.

(v) Prevent heat loss to the surrounding by proper insulation.

Improvements —

To enhance the experiment, a potential way could be manifesting through an experimental extended duration, passing 30 minutes, thereby ensuring an exhaustive determination of steady state. The utilization of systems capable of real-time temperature monitoring could elevate the accuracy of findings.

Industrial use -

The insights from this experiment find an application with industries reliant on heat transfer process. The findings can revolutionize cooling and heating applications enhancing operational efficiency and cost effectiveness.

DATE 21/8/23 | Experiment - 6 : Determination of Critical Heat flux | SHEET NO 35

Aim:
Determination of Critical Heat flux

Objectives:
(i) To calculate the critical heat flux of water at various temperatures of water.
(ii) To study the boiling phenomenon upto critical heat flux.

Introduction:
The determination of the critical heat flux is a crucial phenomenon in the study of heat transfer involving boiling liquids. Boiling is a complex process. The critical Heat flux represents the upper limit of heat flux that a heated surface can endure before transitioning to film boiling, which leads to a significant reduction in heat transfer efficiency and on result in formation of vapour barrier that impedes further heat transfer. In this experiment our focus is to investigate and determine the critical heat flux of water at various conditions. To achieve this goal we employ a setup with heater coil to raise the bulk temperature of coil and subsequently a test heater is used with the nichrome wire to study the process.

Theory:
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. This phase change is called Boiling. The region of natural convection occurs at low temperature differences. As the temperature difference is increased nucleate boiling starts. In this region, it is

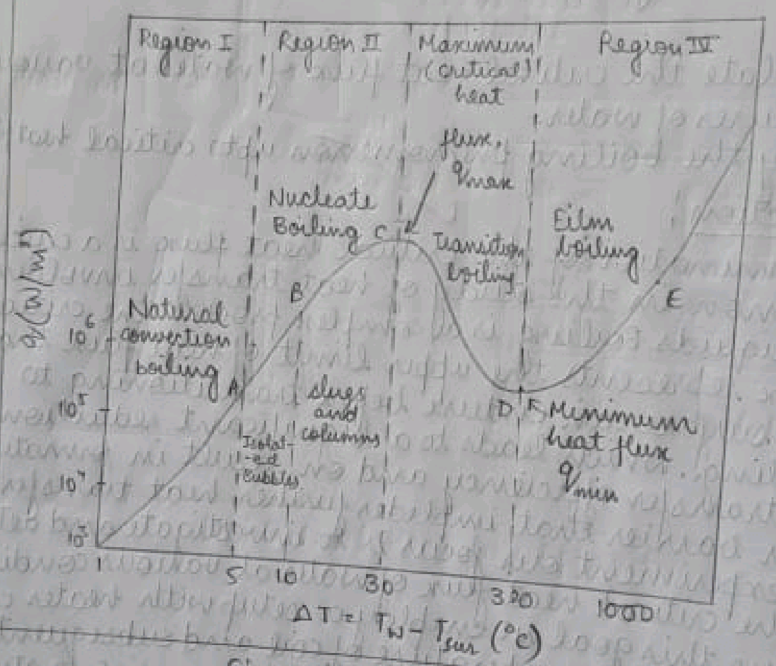

Fig: Boiling curve

observed that bubbles start to form at certain locations on heated surface. with increasing temperature difference, a stage is finally reached when the rate of formation of bubbles is so high, they start to coalese and blanket the surface with film. this is film beginning of the region, film boiling.

It will be observed from fig 3 heat flux does not increase in regular manner with the temperature difference. In region 1, heat flux is directly proportional to $(T_w - T_s)^n$. When transition from natural convection to nucleate boiling occurs. the heat flux starts to increase more rapidly with temperature difference ($n > 3$). At end of region 2, the boiling point reaches peak. Beyond this, in region III, in spite of increasing temperature difference, the heat flux decreases because the thermal resistance to heat flow increases with the formation of vapor film. If the heat flux is increased a little beyond the value of A, the temperature of the surface shoots.

Experiment details;

this experiment is set up to study the boiling pheno-menon up to critical flux point. The heater wire is visualised in the different regions at which wire melts. The heat flux from the wire is slowly increased by gradually increasing the applied voltage across the test wire and the change from natural convection to nucleate boiling can be seen (fig. 1).

Apparatus;

(i) cylindrical glass container housing the test coil and

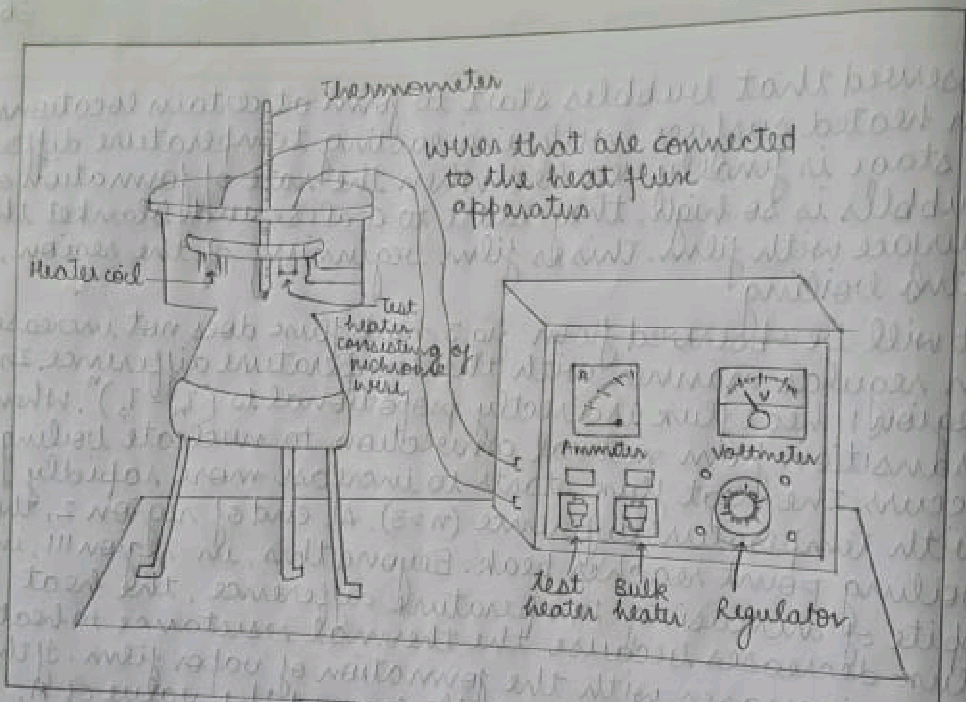

Fig: Critical Heat flux Apparatus

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heating coil for bulk heating.

(ii) Heater coil is directly proportional to mains (heater R_1) & test heater (Nichrome wire) connected is connected in series

(iii) Voltmeter to read the current and voltage.

(iv) wooden platform.

Specifications;

(i) Glass container - diameter 200 mm

(ii) Height = 100 mm

(iii) Nichrome heater (R_1) = 1 KW

(iv) Test heater (R_2)

(v) Nichrome wire size = 28 mm

(vi) Length of test heater = 100 mm

(vii) Dimmerstat for (3) = 10 Amp, 260V

(viii) Voltmeter for (3) = 0-50 volts

(ix) Ammeter (3) = 0 to 10 Amps.

(x) Thermometer = 0 to 100°C

Procedure;

(i) Take 3 to 4 litres of distilled water in the container.

(ii) See both the heaters are completely submerged.

(iii) connect the heater coil (R_1) (1KW nichrome coil) & test heater wire across & make necessary electrical connection.

(iv) switch on the heater R_1.

(v) Keep it on till you get required bulk temperature of water up to saturation temperature.

(vi) switch off the heater R_1.

(vii) Switch on test heater R_2.

(viii) Very gradually increase the voltage across it by slowly changing the variac from the position to other & stop a while at each position to observe boiling phenomenon

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Expt-6: Critical Heat Flux

36 gauge wire - 0.0076 inch dia

100mm - length

πDL - heat dissipation area

S.No.	Volts (V)	I (A)	Bulk Temp. (°C) at breaking point
1.	80	8	58
2.	66	7	67
3.	66	6.8	72

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1. $Q = \frac{I \times V}{A} = \frac{80 \times 8}{6.063 \times 10^{-5}} = 105.56 \times 10^{5}\ J/m^2$

2. $Q = \frac{66 \times 7}{6063 \times 10^{-5}} = 76.19 \times 10^{5}\ J/m^2$

3. $Q = \frac{66 \times 6.8}{6.063 \times 10^{-5}} = 74.02 \times 10^{5}\ J/m^2$

on wire.

(ix) Go on increasing voltage till wire breaks & note voltage & current readings

(x) Repeat this experiment by altering bulk temperature of heater.

Observations;

(i) Diameter of test heater wire, $d = 6mm$

(ii) Length of test heater, $L = 100mm$

(iii) Surface Area, $A = dl = 6.063 \times 10^{-5} m^2$

S.No.	Voltmeter reading V (volts)	Ammeter reading (Amp.)	Bulk Temp. of water at breaking point (°c)
1.	80	8	58
2.	66	7	67
3.	66	6.8	72

Calculations and Results;

1. Heat input $= V \times I$ Watts
$= 80 \times 8 = 640W$

Critical $= 0.86 \times V \times I$ Kcal/hr
$= 0.86 \times 80 \times 8 = 550.4$ Kcal/hr

Critical flux $= 0.86 \times V \times \frac{I}{A}$ Kcal/m²

$$= \frac{0.86 \times 80 \times 8}{6.063 \times 10^{5}} = 9.078 \times 10^{6} \text{ Kcal/m}^2$$

2. critical flux $= \frac{0.86 \times 66 \times 7}{6.063 \times 10^{-5}} = 6.553 \times 10^{6}$ Kcal/m²

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3. Critical flux $= \frac{0.86 \times 66 \times 6.8}{6.063 \times 10^{-5}} = 63.66 \times 10^{5}$ Kcal/m^2

Discussion;

The experiment successfully demonstrated the transition between different boiling regimes upto and the occurence of critical heat flux. The boiling curve's behavior was consistent with theoretical expectations. Power decreases for the test heater as the bulb temperature increases. However, variations in the values might be attributed to the factors like heater wire quality, water purity, and observational limitations.

Conclusion;

In this experiment, the boiling phenomenon was studied using a setup that allowed observation of different boiling regions upto the critical heat flux point. The boiling curve illustrated three distinct regions; natural convection, nucleate boiling, and film boiling. The critical heat flux was determined by noting the voltage and current when the test heater wire melted. The critical heat flux values were calculated using appropriate equations. It was observed that the critical heat flux decreased as the bulk temperature reached saturation.

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CRITICAL COMMENTS :—

Potential errors —

(i) Temperature measurement inaccuracy in the sensors or reading devices ~~to~~ lead to inaccuracy.

(ii) Wire properties such as thickness, length might have introduced variability.

(iii) Transient effects in rapid changes in temperature might have influenced wire's behavior and boiling process.

(iv) Influenced by changes in water conductivity, as the bulk temperature increases.

(v) changes in the bubble formation, growth and detachment can impact the heat transfer process.

Importance of Heat flux in Industry —

(i) optimising reactions that involves heat transfer.

(ii) Effective dissipation of heat from electronic components.

(iii) Ensuring safe heat transfer for nuclear reactor.

Improving the experiment —

(i) controlled condition such as uniform heating by automatic stirrer.

(ii) conducting multiple trails and averaging results to reduce random errors.

New methods for Heat flux calculation —

(i) Thermal imaging — using infrared cameras to visualise and analyse temperature distributions on heated surface.

(ii) High Speed Cameras — recording high speed videos of ~~cameras by~~ boiling phenomenon to analyze bubble dynamics & heat flux.