EXPERIMRNT 13: TO STUDY THE UNSTEADY STATE HEAT TRANSFER BY THE LUMPED CAPACITANCE

INTRODUCTION

In many situations where steady state is not prevalent, analysis becomes much more difficult. It is in these situations where unsteady heat flow causes temperature and other variables to change with time. However, in some unsteady situations, for which a certain criterion is met, the use of the lumped capacitance theory greatly simplifies the analysis.

The criterion is based on the assumption that temperature gradients within a solid are negligible compared to the temperature gradients between the solid and fluid.

THEORY

To understand the lumped heat capacitance theory, we consider a hot metal block that is submerged in water. The basic concept of this theory is that the temperature within the solid block is assumed to be spatially uniform at any instant throughout the unsteady heating process. This implies that the temperature gradient within the solid is negligible compared to the gradient across the solid-fluid interface.

Heat transfer process that is dependent on time is termed as transient heat transfer or unsteady state heat transfer. Such processes are analyzed by solving the general heat conduction equation using some simplified assumption like considering only one directional heat transfer.

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

Assuming a system with negligible internal resistance i.e. a system that has infinite thermal conductivity (Ideal case). This assumption is justified when external thermal resistance between the surface of the system and surrounding medium is very large as compared to the internal thermal resistance e.g. consider a metallic surface at temperature T, (at t=0) being suddenly placed in a bath of water where temperature is maintained at T_∞ (t >0), then the energy balance for the metallic body over a small time interval, dt , is :

$$\rho V C_p\, dT/dt = -h A (T - T_\infty) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Eq – 1 can be written as :

$$\frac{dT}{T - T_\infty} = -\frac{h A}{\rho C_p V} dt \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Integration yields:

$$\ln\left(\frac{T - T_8}{T_i - T_8}\right) = -\frac{hA}{\rho C_p V} t \quad \textbf{-------------- (3)}$$

From Eqn. 3 we have

$$\ln \frac{T - T_\infty}{T_i - T_\infty} = -\frac{h A}{\rho C_p V} t$$

$$\frac{T - T_\infty}{T_i - T_\infty} = e^{-(h A / \rho Cp V) t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Thermal capacitance of the system is given by :

$$C_t = C_p \rho V$$

Thermal resistance is given by:

$$R_t = 1/h A$$

Defining the following dimensionless numbers as:

Biot Number, Bi = $\frac{h (V / A)}{k}$ (for a cylinder)

Fourier Number, Fo = $\frac{\alpha t}{(V / A)^2}$. (For a cylinder)

In terms of these two dimensional groups,

Eqn – 4 can be written as :

$$\frac{T - T_\infty}{T_i - T_\infty} = e^{-Bi\,Fo} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

When (Bi < 0.1, the body has a negligible internal thermal resistance)

DESCRIPTION

The apparatus consists of a small test cylinder rod made of Copper/S.S./Aluminum. The cylinder is heated by a constant temperature water bath, till steady state is reached. During heating, temperature of the cylinder is function of time and hence, heating of cylinder is under unsteady state heat transfer.

The temperature of cylinder is measured with the help of temperature sensor inserted in the center. The hot water bath is provided with a heater.

SPECIFICATION

Water Bath	:	**Material: Stainless Steel**
		Capacity: 1 Ltr (approx.)
Heater	:	**Nichrome Wire Heater 500W.**

Test Piece	**:**	**Material: copper (50 mm dia,40 mm l)**
Temp. Sensor	**:**	**k type**
Control Panel	**:**	**Digital Temp. Indicator (0-200 ºC)**
		ON/OFF Switch, Mains Indicator etc.

EXPERIMENTAL PROCEDURE

1. Fill the water bath with oil up to the desired level.
2. Place sample into bath and start heater by adjusting voltage and ampere with help of dimmer .
3. Hold the sample in bath up to 80 c temperature.
4. Now quickly transfer sample to cool water tank.
5. Start collecting the data temp vs time between 1 min to 2 min.
6. Repeat the above steps for another water temperature. And for different material smaple.

OBSERVATIONS & CALCULATIONS

Record the physical dimensions of the test piece (copper/s.s./aluminium)

Ro = Radius of the cylinder 50 mm

L = Length of the cylinder 40 mm

For copper:

ρ = 8940 kg/m3

Cp = 376.812 J/kgº K

k = 400 W/mº K

OBSERVATION TABLE

1. FOR __________ ROD

T_∞ = _____________ Ti = _____________

Sr. No.	Time (t) sec	Temp. (T) º C	$\frac{T - T_\infty}{T_i - T_\infty}$

T_∞ = Bath Temperature

T = Test Piece Temperature at any time, t

T_i = Initial temperature of the test piece

$$\alpha = \frac{k}{\rho\, C_p}$$

t = Time in sec.

Based on the physical dimensions of the test piece, calculate the following:

Volume of the test piece (V) = $\pi R_o^2 L$ (FOR CYLINDER)

Area of the test piece (A) = $2 \pi R_o L$ (FOR CYLINDER)

Plot $\dfrac{T - T_\infty}{T_i - T_\infty}$ Vs. time (t) on a semi-log graph paper

Draw the best straight line through the experimental points. Please include the data only up to the time when steady state just starts.

Measure the slope from the graph :

$$\text{Slope} = \frac{-hA}{\rho\, C_p\, V}$$

$$h = -\frac{\rho C_p V}{A} * \text{Slope}$$

Calculate Biot Number,

$$Bi = \frac{h R_o}{2 k}$$

If Bi < 0.1, the body has negligible internal thermal resistance. If it is not, then use Heisler chart to estimate thermal resistance.

2. FOR ___________ ROD

T_∞ = _____________ Ti = _____________

Sr. No.	**Time (t) sec**	**Temp. (T) °C**	$\frac{T - T_\infty}{T_i - T_\infty}$

T_∞ = Bath Temperature

T = Test Piece Temperature at any time, t

Ti = Initial temperature of the test piece

$\alpha = \frac{k}{\rho C_p}$

t = Time in sec.

Volume of the test piece (V) = $\pi R_o^2 L$

Area of the test piece (A) = $2 \pi R_o L$

Plot $\frac{T - T_\infty}{T_i - T_\infty}$ Vs. time (t) on a semi-log graph paper

Draw the best straight line through the experimental points. Please include the data only up to the time when steady state just starts.

Measure the slope from the graph :

Slope = $\frac{-hA}{\rho C_p V}$

$$h = -\frac{\rho C_p V}{A} * \text{Slope}$$

Calculate Biot Number,

$$Bi = \frac{h R_o}{2k}$$

If Bi < 0.1, the body has negligible internal thermal resistance. If it is not, then use Heisler chart to estimate thermal resistance.

Conclusion

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Marks Obtained **Sign of Faculty**