EG605ME

Heat Transfer

Lab Manual

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May 1999

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Heat Transfer
EG605ME

Lab 1

Title: Heat Conduction

Objective

1) To investigate Fourier's Law of linear conduction
2) To investigate the temperature profile and heat transfer in radial direction of a cylinder
3) To investigate the effect of change in cross-sectional area on the temperature profile
4) To investigate conduction along a composite bar and evaluate the overall heat transfer coefficient
5) To investigate the effect of insulation upon conduction of heat between adjacent metals.

Introduction:

Conduction is a mode of heat transfer in which energy transfer takes place from high temperature region to low temperature region when a temperature gradient exists in a body. The basic law of conduction was established by Fourier. According to Fourier's law, heat flow by conduction in a certain direction is proportional to the area normal to that direction and to the temperature gradient in that direction.

$$Q = -kA\frac{dT}{dx}$$

Where Q = transferred heat

k = thermal conductivity

A = area

dT/dx = temperature gradient

The minus sign in the equation above shows that heat flows in the direction of decreasing temperature.

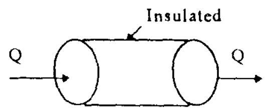
Thermal conductivity is the property of materials which shows heat conduction per unit length of material per degree of temperature difference.

Heat is conducted in solids in two ways: transport of energy by free electrons and lattice vibration. In good conductors, a large number of free electrons move about in the lattice structure of the material which transport heat from high temperature region to the low temperature region. The portion of energy transported by free electrons is larger than that by lattice vibration. An increase in temperature causes increase in both the lattice vibration and speed of free electrons, but increased vibration of lattice disturbs the movement of free electrons causing reduction in transport of energy by free electrons which means the overall conduction is reduced. In insulators and alloys, the transport of energy is mainly due to lattice vibration and an increase in temperature increases conduction.

Relevant theory and equations

Conduction of Heat Along a Simple Bar

Let us consider Fourier's law of conduction for the case of a simple bar with lateral surface insulated as shown in Fig.1-1.



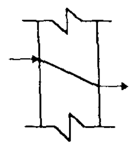


Fig.1-1 Fig.1-2

This is an approximation of one-dimensional conduction for a plane wall as shown in Fig.1-2. For steady state condition, it is assumed that the power generated by an electrical heater enters at one end and leaves from the other end uniformly. Then the thermal conductivity of the specimen can be determined as:

$$k(T) = \bar{k}(T) = \frac{Q}{A}\frac{\Delta x}{T} \qquad w/m.K \qquad (1)$$

Where, Q is heater power,

k(t) mean value of thermal conductivity between T1 and T2

T = mean value of T1 and T2

Conduction of Heat in radial direction

If the ends of the cylinder are insulated and its inner and outer surfaces are at uniform temperatures, then the heat flows in radial direction only.

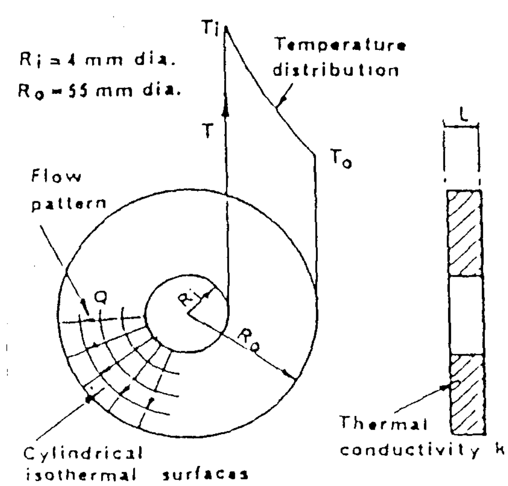


Figure 1-3

For this case, the heat transfer area is A = 2πrL. Then,

$$Q = -2\pi rLk\frac{dT}{dx}$$

Solving the above equation for T(r),

$$T(r) = Ti - (Ti - To)\frac{\ln\frac{r}{ri}}{\ln\frac{ro}{ri}} \quad \text{and,} \qquad (2)$$

$$Q = \frac{Ti - To}{\frac{1}{2\pi kL}\ln\frac{ro}{ri}}$$

Effect of Area Change in Heat Conduction

Let us consider step change in cross-sectional area as shown in Fig.1-4. According to Fourier's Law,

$$Q = -kA\frac{dT}{dx}$$

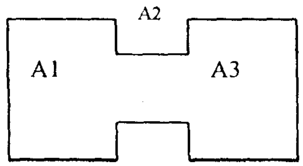


Figure 1-4

We know that heat flow rate for each section is the same. If conductivity is assumed constant, then,

$$A_1\left(\frac{dT}{dx}\right)_1 = A_2\left(\frac{dT}{dx}\right)_2 = A_3\left(\frac{dT}{dx}\right)_3 \qquad (3)$$

or, $\frac{A_1}{A_2} = \frac{(dT/dx)_2}{(dT/dx)_1}$

i.e. the temperature gradient is inversely proportional to the cross-sectional area.

Conduction Along Composite Bar

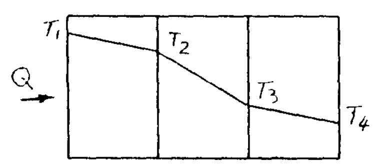
Let us consider heat conduction along a composite bar. For a composite bar,

$$\frac{Q}{A} = k_1\frac{T_1 - T_2}{x_1} = k_2\frac{T_2 - T_3}{x_2} = k_3\frac{T_3 - T_4}{x_3} \qquad (4)$$

or, $\frac{Q}{A} = (T_1 - T_4)U$ (5)

where, $\frac{1}{U} = \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3}$ (6)

Figure 1-5



Effect of Insulation on Heat Conduction

The study of effect of insulation on heat conduction between adjacent metals is very important. The analysis is done in the similar fashion as in case of composite bar.

Laboratory Setup

Equipment:

The equipment used in the above experiments is the Armfield Thermal Conduction Apparatus (Fig.1-6) which consists of two electrically heated modules mounted on a bench support frame. One module contains multiple cylindrical metal bar arrangement for a variety of linear conduction experiments and the other module consists of a disk for radial profile studies. all test sections are equipped with an array of temperature sensors. Cooling water from laboratory tap is fed to one side of the test pieces in order to maintain a steady temperature gradient.
An electrical console provides electrical power for heaters in the specimen and digital readout of the temperature at selected points along the heat conduction path. The temperature probes have a resolution of 0.1 degree Celsius. The power control circuit provides a continuously variable electrical output of 0-80 watts with direct digital readout with a resolution of 0.1 watt.

Safety Considerations

1) Do not exceed 100°C on the linear conduction apparatus.
2) After finishing the experiment, the specimen removed from the linear conduction apparatus may be hot, be careful and handle with care.
3) A continuous flow of cooling water is necessary for the experiment, otherwise the apparatus may get damaged.

Laboratory Procedure:

Lab 1-1 Conduction of Heat Along a Simple Bar

1. The equipment should be setup as shown in figure 1-7. Ask for your instructor's help.
2. Apply conducting compound at the metal interface in order to reduce thermal contact resistance and install the specimen. When assembling the specimen between the heater and the cooler, take care to match the shallow shoulders in the nylon housing.
3. Ensure that the temperature measurement points are aligned along the longitudinal axis of the unit. Make sure that the temperature sensor wires are connected correctly.
4. Turn the heater power control knob fully counter-clockwise then turn ON the heater power. Make sure that the reading from the watt meter is zero.
5. Check the temperature readings from all the temperature probes. They should be equal to room temperature. If they are not contact your instructor.
6. Gradually increase the heater power by turning the knob clockwise. Set the heater power to 20W. Allow enough time to reach steady-state condition
7. Note the temperatures from all the probes by turning the selector switch.
8. .Repeat the processes 6 and 7 for 15W and 10W.
9. After completing the experiment, reduce the heating power to zero, turn OFF the heater power but let the cooling water run for some five more minutes to ensure that the specimen is cooled down.

Observation Sheet:

Specimen material: Brass
Thermal conductivity of the specimen from tables:
Diameter of specimen: 25mm
Length of specimen: 30mm
Distance between temperature probes: 10mm

Test Results:

Test No.	Wattmeter watts, Q	T1, °C	T2, °C	T3, °C	T4, °C	T5, °C	T6, °C	T7, °C	T8, °C	T9, °C
1	20									
2	15									
3	10									

Plot the temperature profile along the length of the core. Determine the thermal conductivity of the test specimen. Comment on the effect of increasing heater power on the thermal conductivity of the specimen. Compare the calculated thermal conductivity with the published data and comment on the difference if any. Apply proper conversion factor wherever necessary.

Lab 1-2 Conduction of Heat in Radial Direction

Connect the temperature probes to radial apparatus as shown in Fig.1-8 and follow the instructions below.

1. Apply conducting compound at the metal interface in order to reduce thermal contact resistance and install the specimen. When assembling the specimen between the heater and the cooler, take care to match the shallow shoulders in the nylon housing.
2. Ensure that the temperature measurement points are aligned along the longitudinal axis of the unit. Make sure that the temperature sensor wires are connected correctly.
3. Turn the heater power control knob fully counter-clockwise then turn ON the heater power. Make sure that the reading from the watt meter is zero.
4. Check the temperature readings from all the temperature probes. They should be equal to room temperature. If they are not contact your instructor.
5. Gradually increase the heater power by turning the knob clockwise. Set the heater power to 20W. Allow enough time to reach steady-state condition
6. Note the temperatures from all the probes by turning the selector switch.
7. .Repeat the processes 6 and 7 for 15W and 10W.
8. After completing the experiment, reduce the heating power to zero, turn OFF the heater power but let the cooling water run for some five more minutes to ensure that the specimen is cooled down.

Observation Sheet

Specimen material: Brass
Thermal conductivity of the specimen from tables:
Outer diameter of specimen: 110mm
Inner diameter of specimen: 8mm
Length of specimen: 3mm
Distance between temperature probes: 10mm

Test Results:

Test No	Wattmeter watts Q	T_1, °C	T2, °C	T3, °C	T7, °C	T8, °C	T9, °C
1	20						
2	15						
3	10						

Plot the temperature profile along the radius of the specimen and determine the temperature at the outer radius from the plot. Use these data to determine the radial heat conduction from equation (2) and compare with the measured heat input. Comment on the difference if any. Apply proper conversion factor if necessary. Comment on the difference between temperature distribution in the simple bar and the disk.

Lab 1-3 Effect of Area Change in Heat Conduction

Change the test specimen of linear conduction apparatus by a of smaller diameter (13mm diameter). Ask your instructor for set up and follow the instructions below.

1 The equipment should be setup as shown in figure 1-7. Ask for your instructor's help.
2. Apply conducting compound at the metal interface in order to reduce thermal contact resistance and install the specimen. When assembling the specimen between the heater and the cooler, take care to match the shallow shoulders in the nylon housing.
3. Ensure that the temperature measurement points are aligned along the longitudinal axis of the unit. Make sure that the temperature sensor wires are connected correctly.
4. Turn the heater power control knob fully counter-clockwise then turn ON the heater power. Make sure that the reading from the watt meter is zero.
5. Check the temperature readings from all the temperature probes. They should be equal to room temperature. If they are not contact your instructor.
6. Gradually increase the heater power by turning the knob clockwise. Set the heater power to 20W. Allow enough time to reach steady-state condition
7. Note the temperatures from all the probes by turning the selector switch.
8. .Repeat the processes 6 and 7 for 15W and 10W.
9. After completing the experiment, reduce the heating power to zero, turn OFF the heater power but let the cooling water run for some five more minutes to ensure that the specimen is cooled down.

Observation Sheet

Specimen material: Brass
Thermal conductivity of the specimen from tables:
Diameter of specimen: 13mm
Length of specimen:30mm (temperature sensors not fitted)
Distance between temperature probes: 10mm

Test Results:

Test No	Wattmeter watts Q	T_1, °C	T2, °C	T3, °C	T7, °C	T8, °C	T9, °C
1	20						
2	15						
3	10						

Plot the temperature profile in the heater and cooler and extrapolate to the interface in order to determine the temperature gradient across the reduced area of specimen. Using this graph, determine the ratio of temperature gradient in heater/cooler to gradient within the reduced area. Comment on the result and on any differences between measured and calculated results.

Lab 1-4 Conduction Along Composite Bar

Change the test specimen of linear conduction apparatus by a specimen made of a different material (steel in this case). Ask your instructor for set up and follow the Instructions below.

1. The equipment should be setup as shown in figure 1-7. Ask for instructor's help.
2. Apply conducting compound at the metal interface in order to reduce thermal contact resistance and install the specimen. When assembling the specimen between the heater and the cooler, take care to match the shallow shoulders in the nylon housing.
3. Ensure that the temperature measurement points are aligned along the longitudinal axis of the unit. Make sure that the temperature sensor wires are connected correctly.
4. Turn the heater power control knob fully counter-clockwise then turn ON the heater power. Make sure that the reading from the watt meter is zero.
5. Check the temperature readings from all the temperature probes. They should be equal to room temperature. If they are not contact your instructor.
6. Gradually increase the heater power by turning the knob clockwise. Set the heater power to 20W. Allow enough time to reach steady-state condition
7. Note the temperatures from all the probes by turning the selector switch.
8. .Repeat the processes 6 and 7 for 15W and 10W.
9. After completing the experiment, reduce the heating power to zero, turn OFF the heater power but let the cooling water run for some five more minutes to ensure that the specimen is cooled down.

Observation sheet

Specimen material: Steel
Thermal conductivity of the specimen from tables:
Diameter of specimen: 25mm
Length of specimen:30mm (temperature sensors not fitted)
Distance between temperature probes: 10mm

Test Results:

Test No	Wattmeter watts Q	T_1, °C	T2, °C	T3, °C	T7, °C	T8, °C	T9, °C
1	20						
2	15						
3	10						

Plot the temperature profile in the heater and cooler and extrapolate the curve to determine the respective outer surface temperature and interface temperature. Use these temperatures to determine the overall heat transfer coefficient using equation (5). Compare this value with the value obtained using equation (6). Use published data to determine thermal conductivity of heater and cooler material. Thermal conductivity of specimen can be determined using the temperature gradient within the specimen and equation (1). What is the practical significance of overall heat transfer coefficient ? What was the effect of varying input power on overall heat transfer coefficient ?

Lab 1-5 Effect of Heat Insulation on Heat Conduction

Remove the test specimen from the linear conduction apparatus and put insulation specimen (paper or cork) between the heater and the cooler. Do not smear conducting compound on the interfaces.Then, follow the instructions below.

1. The equipment should be setup as shown in figure 1-7. Ask for your instructor's help.
2. Apply conducting compound at the metal interface in order to reduce thermal contact resistance and install the specimen. When assembling the specimen between the heater and the cooler, take care to match the shallow shoulders in the nylon housing.
3. Ensure that the temperature measurement points are aligned along the longitudinal axis of the unit. Make sure that the temperature sensor wires are connected correctly.
4. Turn the heater power control knob fully counter-clockwise then turn ON the heater power. Make sure that the reading from the watt meter is zero.
5. Check the temperature readings from all the temperature probes. They should be equal to room temperature. If they are not contact your instructor.
6. Gradually increase the heater power by turning the knob clockwise. Set the heater power to 20W. Allow enough time to reach steady-state condition
7. Note the temperatures from all the probes by turning the selector switch.
8. .Repeat the processes 6 and 7 for 15W and 10W.
9. After completing the experiment, reduce the heating power to zero, turn OFF the heater power but let the cooling water run for some five more minutes to ensure that the specimen is cooled down.

Note:

Using micrometer measure the thickness of the paper disc or cork disc before clamping it between heater and cooler. Do not smear conducting compound between mating faces of heater/cooler and insulation. set the heater power to 15 watts and allow time to reach steady-state conditions. In the mean time, make sure that the temperature of heater does not exceed 100 degrees Celsius. Then follow instructions 5,7, and 9 from above.

Observation Sheet

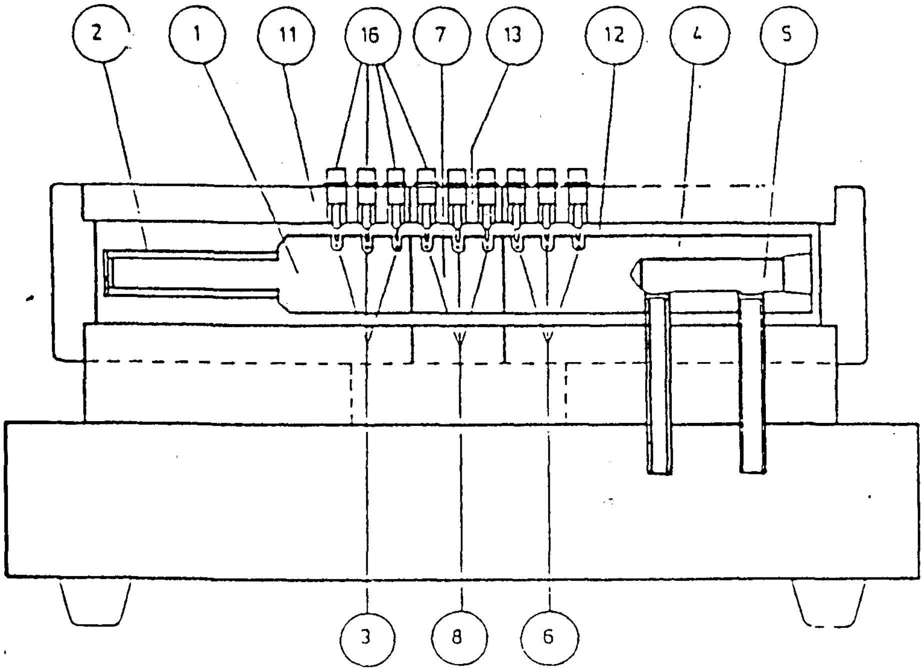
Specimen material: Paper or Cork
Thermal conductivity of the specimen from tables:
Diameter of specimen: 25mm
Length of specimen:
Distance between temperature probes: 10mm

Test Results:

Wattmeter watts Q	T_1, °C	T_2, °C	T_3, °C	T_7, °C	T_8, °C	T_9, °C
15						

Plot the temperature profile in heater and cooler and extrapolate it to interfaces in order to determine the temperature gradient across the insulating disc. Determine thermal conductivity, compare with the published data and comment on the difference.

What is the effect of insulation on conduction of heat between the heater and cooler ? How does a insulator inhibit conduction ? Suggest practical uses for insulating materials.



LINEAR MODULE

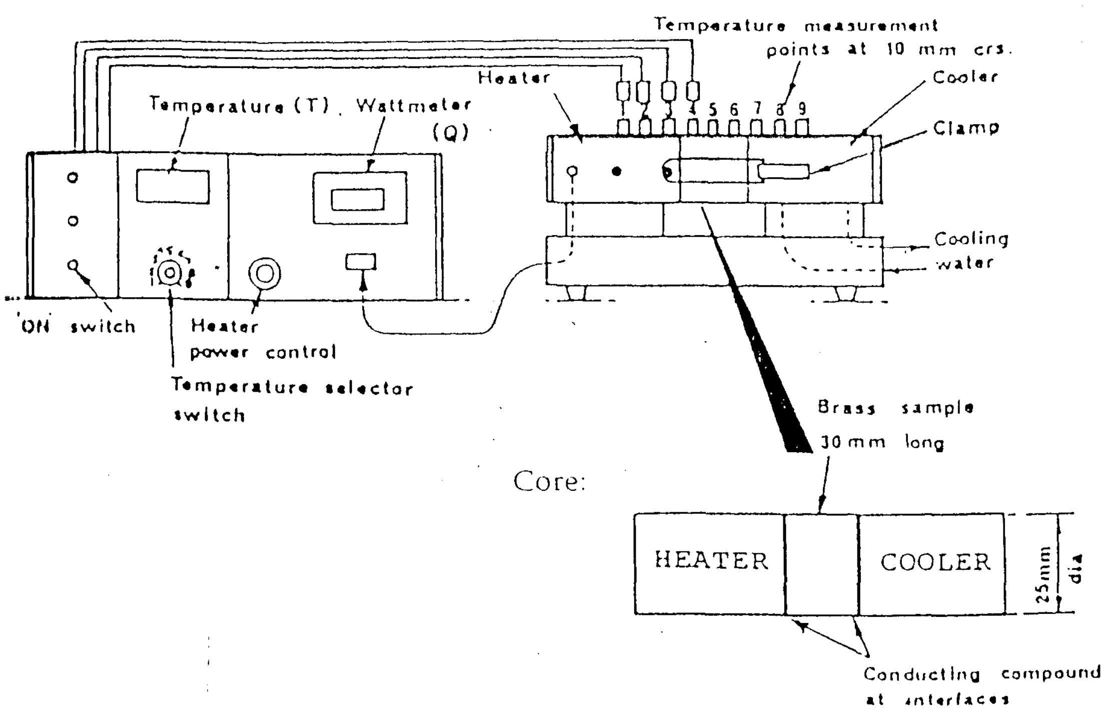
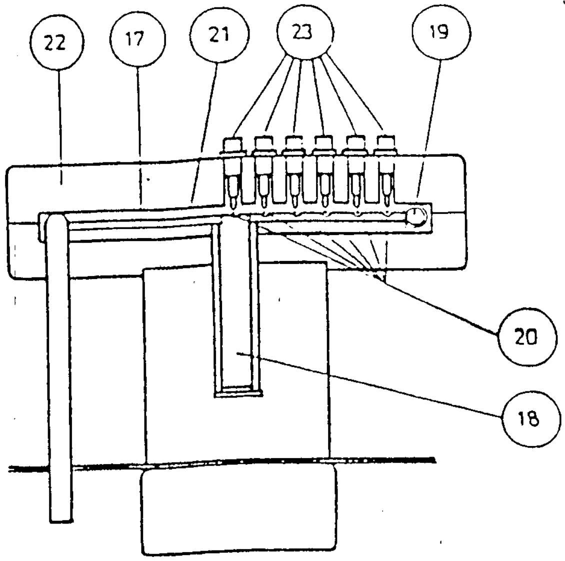


Fig 1-7



RADIAL MODULE

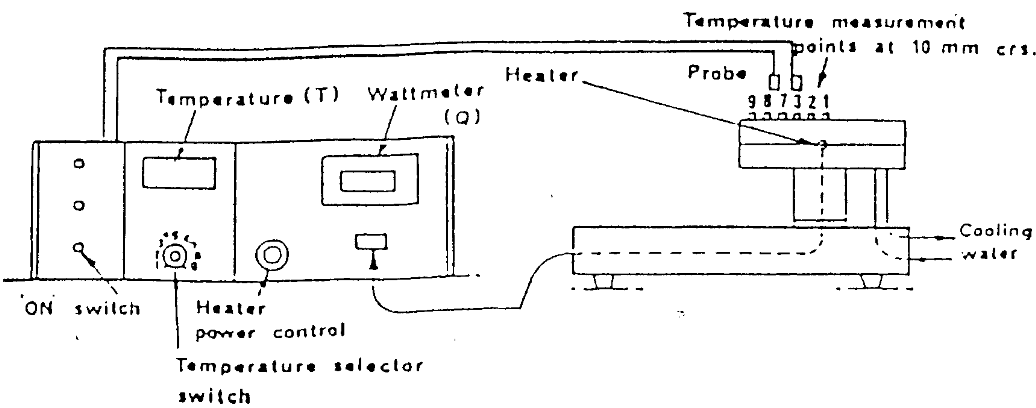
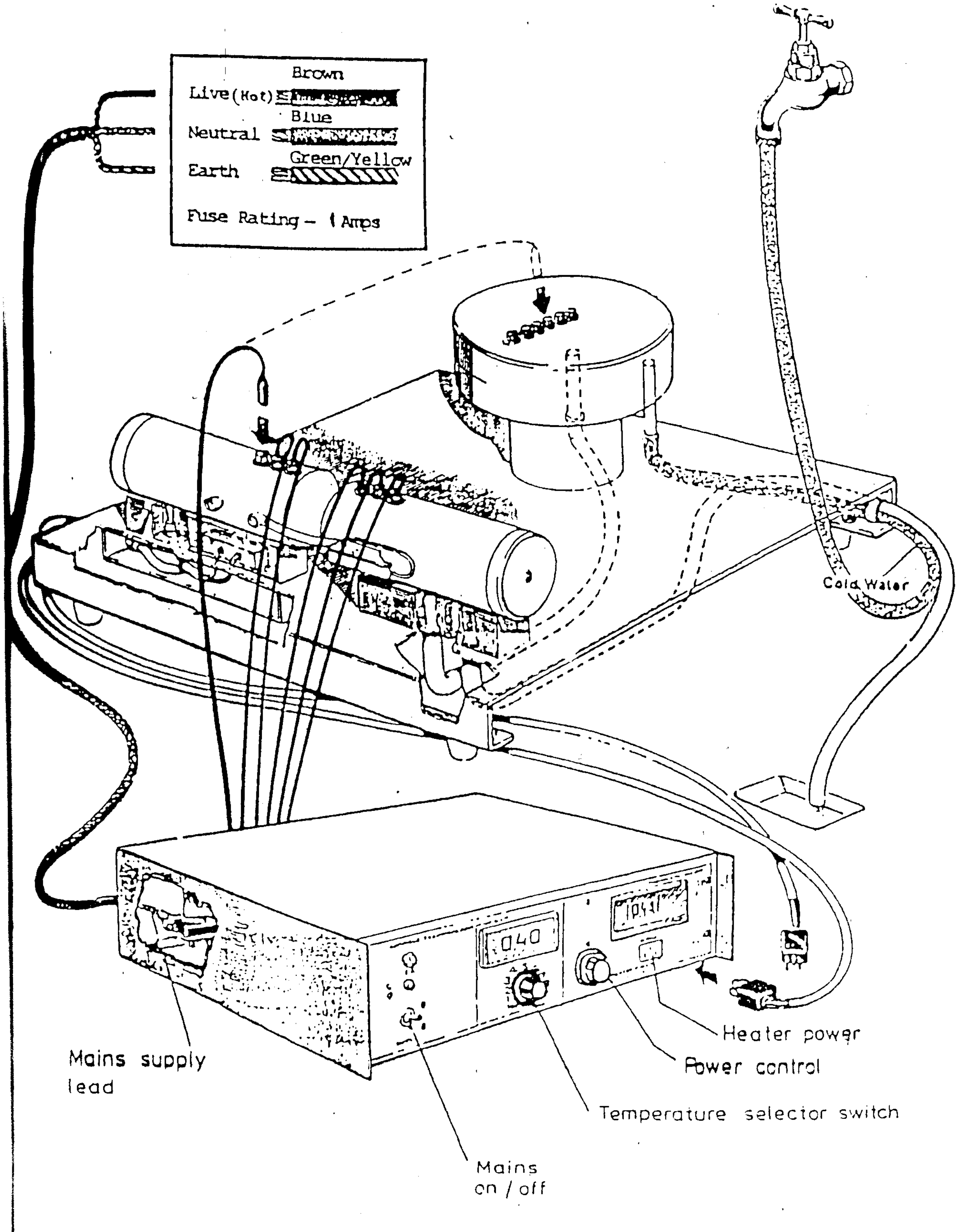


Fig 1-8



Heat Conduction Apparatus Interconnection

EG 605 ME
Heat Transfer

ab 2

Heat Convection

jectives:

- To learn the effect of surface temperature on heat transfer in free convection from vertical plate
- To demonstrate the effect of extended surfaces in heat transfer
- To investigate the temperature distribution along the extended surface.

troduction

Convection is a mode of heat transfer in which energy exchange occurs between a surface and adjacent fluid when the temperatures of the surface and the fluid are different. If the fluid motion is artificially induced, the heat transfer is called forced convection and if it is induced because of buoyancy effects caused by temperature difference in the fluid, the heat transfer is called free-convection. In the process of convection, the motion of fluid influences the temperature field and determination of temperature distribution and of heat transfer becomes complicated. To simplify heat transfer calculations in such situations, Newton's law of cooling is used:

$$q = h\,(T_w - T_f)$$

Where T_w and T_f are surface and fluid temperatures
h is heat transfer coefficient and
q is heat flux.

Depending on whether the heat transfer is free or forced convection, the calculation of heat transfer coefficient depends on dimension less parameters such as Reynolds' Number, Nusselt Number, Prandtl Number, Grashof Number, etc.. For free convection, h is a function of Grashof and Prandtl numbers and for forced convection, h is a function of Reynolds' and Prandtl numbers. These parameters are listed below.

$$\mathrm{Re} = \frac{U\infty L}{\nu} = \frac{\rho U\infty L^2 U\infty}{\mu (U\infty / L) L} = \frac{\text{inertial force}}{\text{viscous force}}$$

Cha. L = 0.1 m

$$\mathrm{Pr} = \frac{c_p \mu}{k} = \frac{\mu / \rho}{k / \rho c_p} = \frac{\nu}{\alpha} = \frac{\text{molecular diffusivity of momentum}}{\text{molecular diffusivity of heat}}$$

$$Nu = \frac{hL}{k} = \frac{h\Delta T}{k\Delta T / L} = \frac{\text{heat transfer by convection}}{\text{conduction across fluid layer of thickness L}}$$

$$Gr = \frac{g\beta L^3 (T_w - T_\infty)}{\nu^2} = \frac{\text{buoyancy force}}{\text{viscous force}}$$

The average Nusselt number for free convection from a vertical plate at uniform surface temperature can be correlated by the relation:

$$Nu = c\,(Gr_L Pr)^n \qquad (1)$$

Where,

$\beta = (\rho_\infty/\rho - 1)/(T_\infty - T)$

ρ_∞ = bulk fluid density

ρ = fluid density at temperature T

$c = 0.59,\ n = 1/4$ if $10^4 < Gr_L Pr < 10^9$
$c = 0.1,\ n = 1/3$ if $10^9 < Gr_L Pr < 10^{13}$

Heat transfer from an object can be increased by increasing the contact area between the fluid and the object. In order to make the overall size compact, fins or pins are added to the object to increase surface area. These features are called extended surfaces. The analytical calculation of heat transfer from extended surfaces is too involving unless the required parameters are known. Therefore, in this experiment, only the experimental and results will be compared.

Laboratory Setup

Equipment

The equipment used in the above experiments is the Armfield Free and Forced convection Heat Transfer apparatus which is shown in Fig 2-1. The apparatus consists of a vertical rectangular duct supported by a bench mounted stand. A flat plate, pinned and finned exchanger may be installed in the duct and secured by a quick release catch on each side. For forced convection purposes, and upward flow of air may be generated in the duct with a variable speed fan mounted on the top. A thermistor probe is used to measure in-going and out-going air temperature as well as surface temperature of exchanger pins and fins. These temperatures are determined by inserting the probe through access holes in the duct wall. Air velocity is measured with a portable anemometer mounted on the duct. An electric console is used for supplying power to heaters which incorporates variable transformer. The power supplied to exchanger as well as temperature are digitally indicated. The temperature readout has a resolution of 0.1 degree Celsius. A variable DC supply is provided for the fan. Power is supplied to the equipment by the lead connected to the rear of the console.

Safety Consideration:

1) Do not exceed the given power level
2) The specimen may be hot after removing from the equipment. Handle with care.

Laboratory Procedure

Lab 2-1 Effect of Surface Temperature on Heat transfer in free convection from vertical plate

1. The equipment should be set up as shown in figure 2-2. Ask for your instructors' help.
2. Place the flat plate exchanger into the duct
3. Turn the heater power control knob fully counter-clockwise then turn ON the heater power
4. Record the ambient air temperature
5. Set the heater power to 75 watts. Allow the temperature to rise to about 80 °C, then adjust the heater power to 20 watts and wait until the steady reading is obtained.
6. Record the hot plate temperature
7. Repeat process 5 and 6 for 30 watts power level.

Observation Sheet

Ambient air temperature t_A =

Input Power , W	Heater temp. t_H °C	$t_H - t_A$ °C
20		
30		

Comment on the difference in ($t_H - t_A$) at different power levels. At which power level is the heat transfer high ? What makes you think so ? Confirm your conclusion using eq. 1.

I-2 Effect of Extended Surfaces on Heat Transfer

- Replace the flat plate exchanger in the duct by finned exchanger (fig 2-2)
- Place the finned exchanger into the duct
- urn the heater power control knob fully counter-clockwise then turn ON the heater ower
- cord the ambient air temperature
- the heater power to 75 watts. Allow the temperature to rise to about 80 °C, then just the heater power to 20 watts and wait until the steady reading is obtained.
- cord the hot plate temperature
- the fan speed control to give 1 m/s using thermal anemometer
- cord hot-surface temperature
- peat the above process for 1.5 m/s and 2 m/s air velocities
- place finned exchanger by pinned exchanger and repeat the above process again.

vation Sheet

t air temperature =
ower = 20 W

ocity m/s	Heater temp. tH, °C	tH - tA, °C

e graph of (tH-tA) vs. air velocity. What conclusions can you make regarding of air velocity ? Which of the two (finned and pinned) surfaces has a better mance ? Why ?

laminar flow $Re < 10^5$

$$Nu = 0.664 \, Re^{1/2} \cdot Pr^{1/3}$$

Lab 2-3 Investigation of Temperature distribution along the extended surfaces

1) Measure from the back plate, the distances of 3 access holes on the pinned exchanger
2) Place pinned exchanger in the duct (fig 2-2)
3) Set the heater power to 60 watts and allow time to achieve steady state
4) Note ambient air temperature
5) Note base plate temperature
6) Insert the thermometer probe into the duct through the hole nearest the heated plate ensuring that the tip of probe is in contact with the pin. A small amount of conduction compound can be applied on the tip
7) Note this temperature t1. Record the pin temperatures t2 and t3 using the remaining two holes. Repeat this procedure at 1 m/s and 2 m/s air velocities.

Observation Sheet

Ambient air temperature =
Power input =
Distance of the nearest hole =
Distance of the middle hole =
Distance of the farthest hole =

Air Velocity m/s	t1 , °C	t2, °C	t3, °C
0			
1			
2			

Plot graphs of surface temperature against distance from back plate for the two heat exchangers at various air velocities. Comment on the graphs. What can you say about the effectiveness of the exchangers ? Which is the better extended surface based on the temperature distribution ?

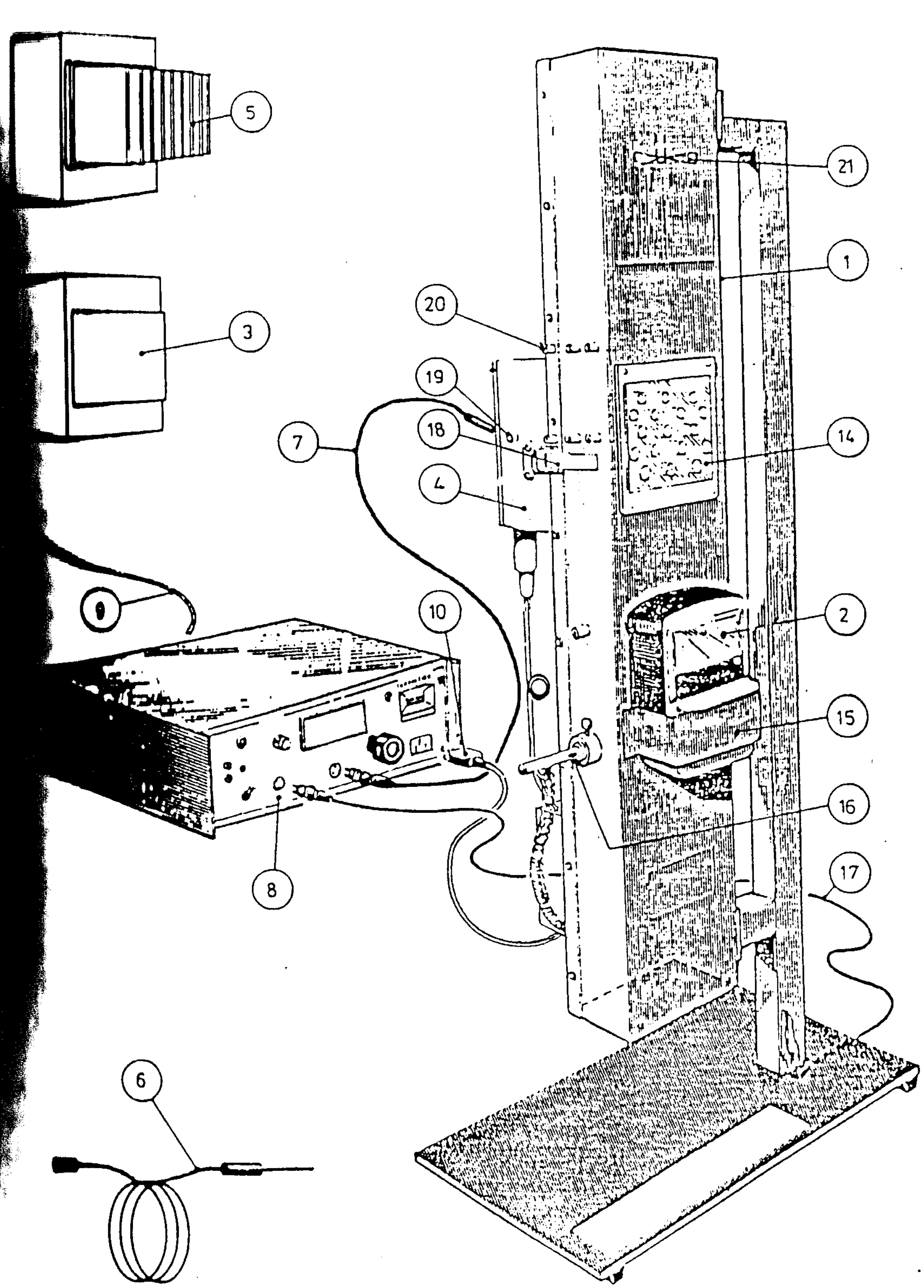


FIG 2.1 CONVECTION HEAT TRANSFER APPARATUS

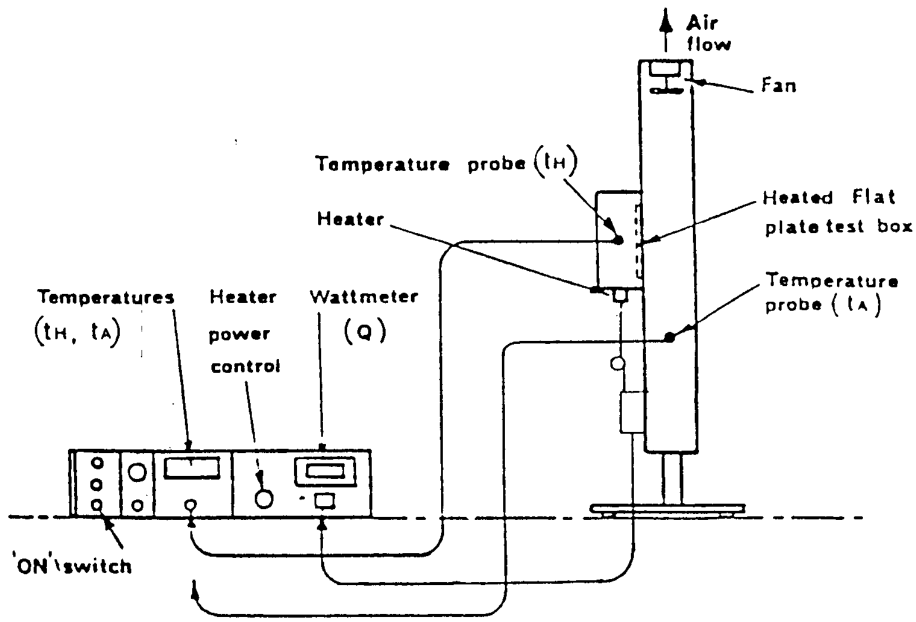

Air
flow
Fan
Temperature probe (t_H)
Heater
Heated Flat
plate test box
Temperature
probe (t_A)
Temperatures
(t_H, t_A)
Heater
power
control
Wattmeter
(Q)
'ON' switch

Fig. 2.2

Lab 3

Title: Heat Radiation

Objective

1) To investigate Stefan-Boltzmann relationship
2) To determine the emissivity of different surfaces
3) To demonstrate the effect of view factor on radiation heat transfer.

Introduction:

Thermal radiation is a mode of heat transfer which differs significantly from conduction and convection in that it does not require any medium for energy transfer. The energy is transferred from one surface to another surface by means of electromagnetic waves.

Stefan-Boltzmann law states that the intensity of radiation varies as the fourth power of the source temperature.

$E_b \propto T^4$

or, $E_b = \sigma T^4$

If two surfaces are participating in radiation,

$E_b = \sigma(T_1^4 - T_2^4)$

Where E_b = energy emitted by a black body surface, W/m^2
T_1 and T_2 = absolute temperatures of the surfaces, K
σ = Stefan-Boltzmann constant, 5.67×10^{-8} W/m^{2}K^4

A black body is the one which absorbs all the radiation incident upon it and is also a perfect emitter, where as other bodies can not absorb all the incident radiation or emit perfectly. There exists a fixed ratio of energy emitted by a black body and other bodies at any source temperature. If we know black body temperature and sorrounding temperature, we can calculate the energy emitted by a black body. The energy absorbed by the other body can be measured with the help of instruments. The ratio of these two values of energy must be same at any source temperature. If so, the Stefan-Boltzmann law is satisfied.

Emissivity of a material affects radiation heat transfer. Since emissivity function is always less than unity for materials other than black body, the heat emission is always less than from black body for such materials. Similarly, view factor also affects radiative heat

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Heat Transfer

Lab 3

Title: Heat Radiation

Objective

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2) To determine the emissivity of different surfaces
3) To demonstrate the effect of view factor on radiation heat transfer.

Introduction:

Thermal radiation is a mode of heat transfer which differs significantly from conduction and convection in that it does not require any medium for energy transfer. The energy is transferred from one surface to another surface by means of electromagnetic waves.

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$E_b \propto T^4$

or, $E_b = \sigma T^4$

If two surfaces are participating in radiation,

$E_b = \sigma (T_1^4 - T_2^4)$

Where E_b = energy emitted by a black body surface, W/m^2
T_1 and T_2 = absolute temperatures of the surfaces, K
σ = Stefan-Boltzmann constant, 5.67×10^{-8} W/m^2K^4

A black body is the one which absorbs all the radiation incident upon it and is also a perfect emitter, where as other bodies can not absorb all the incident radiation or emit perfectly. There exists a fixed ratio of energy emitted by a black body and other bodies at any source temperature. If we know black body temperature and sorrounding temperature, we can calculate the energy emitted by a black body. The energy absorbed by the other body can be measured with the help of instruments. The ratio of these two values of energy must be same at any source temperature. If so, the Stefan-Boltzmann law is satisfied.

Emissivity of a material affects radiation heat transfer. Since emissivity function is always less than unity for materials other than black body, the heat emission is always less than from black body for such materials. Similarly, view factor also affects radiative heat

त्रिभुवन विश्वविद्यालय
इन्जिनीयरिङ अध्ययन संस्थान
डीनको कार्यालय

पुल्चोक, ललितपुर
फोन ५-५२१५३१
पो. बक्स नं. १९१५
फ्याक्स : ९७७-१-५५२५८३०

पत्र संख्याः डी.का.यो.फा.नं.( )च.नं.।६ ।०६८/०६९ **मिति** :२०६८।८।२६

डा. राजेन्द्र श्रेष्ठज्यू
उप-प्राध्यापक
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विषय : Ph.D Reseearch Co-Supervisor नियुक्ति गरिएको बारे ।

महोदय,

त्रि.वि., इ.अ.सं. पुल्चोक क्याम्पस अन्तर्गत मेकानिकल इञ्जिनियरिङ्ग विभागमा संचालन भै रहेको Ph.D. (विद्यावारिधि) कार्यक्रममा भर्ना भई अध्ययनरत विद्यार्थी रामप्रसाद धितालको पिएच.डी. अध्ययन तथा अनुसन्धान कार्यका लागि तपाईलाई सोध उप-निर्देशकमा नियुक्ति गरिएको छ। पिएच.डी. निर्देशिकाको संलग्न TOR अनुसार उल्लेखित विद्यार्थीहरुको अध्ययन अनुसन्धान कार्यको अनुगमन, मूल्यांकन तथा सुपरिवेक्षण कार्य गर्नु हुन अनुरोध गर्दछु ।

(रामचन्द्र सापकोटा)
सदस्य-सचिव
इ.अ.सं., अनुसन्धान समिति

बोधार्थः

१. श्री पुल्चोक क्याम्पस, इ.अ.सं., पुल्चोक । *(नियमानुसारको पारिश्रमिकको व्यवस्था गर्नु हुन ।)*
२. श्री DRC, मेकानिकल इ. विभाग, पुल्चोक क्याम्पस, इ.अ.सं., पुल्चोक ।
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Planning/Letter/Research

transfer. View factor also has a maximum value of unity. The larger this factor the larger is the radiation heat transfer between two bodies.

Laboratory Procedure:

Lab 3-1 Investigation of Stephan-Boltzman Relationship

1) The equipment should be set up as shown in fig 3-1. Your instructors will help to setup the equipment.
2) Turn the heater power control knob fully counter clockwise and then turn ON the heater
3) Place the radio meter at a distance of 110 mm from the heat source
4) Place the black plate at a distance of 50 mm from the heat source
5) Do not open the radiometer cover until the black plate temperature stabilizes
6) Record the temperature reading and radiometer reading at ambient condition
7) Increase the temperature through selected increments and record both ambient temperature and radiometer reading

Observation Sheet

T = (t + 273) K

σ = 5.67 x 10^{-8} W/m^2K^4

Source temp, T_s, K	Ambient temp, T_A, K	Radiometer reading,(R) W/m^2	$E_b = \sigma(T_s^4 - T_A^4)$ W/m^2	$\beta = E_b/R$

Have -

Compare calculated values of β and comment on it. Are they equal ? Should they be equal? Are they comparable if not equal ? What could be the reason if not equal ?

Lab 3-2 Determining Emissivity of Different Surfaces

- Replace the black plate by the polished plate in the carrier
- Vary the power through selected increments and record metal plate temperature and radiometer reading
- Repeat the procedure for silver anodized plate and black plate

Observation Sheet

For each plate

Ambient temperature TA =

Value β from lab 3-1 =

Source temp, K	Ambient temp, T_A, K	Radiometer reading, W/m^2	$E_b = \beta R/\beta$	$\varepsilon = \dfrac{E_b}{\sigma(T_s^4 - T_A^4)}$

Assume ε =1 for black plate.

Comment on the values of ε for anodized plate and polished plate.

Lab 3-3 Investigation of Effect of View Factor on Radiation Heat Transfer

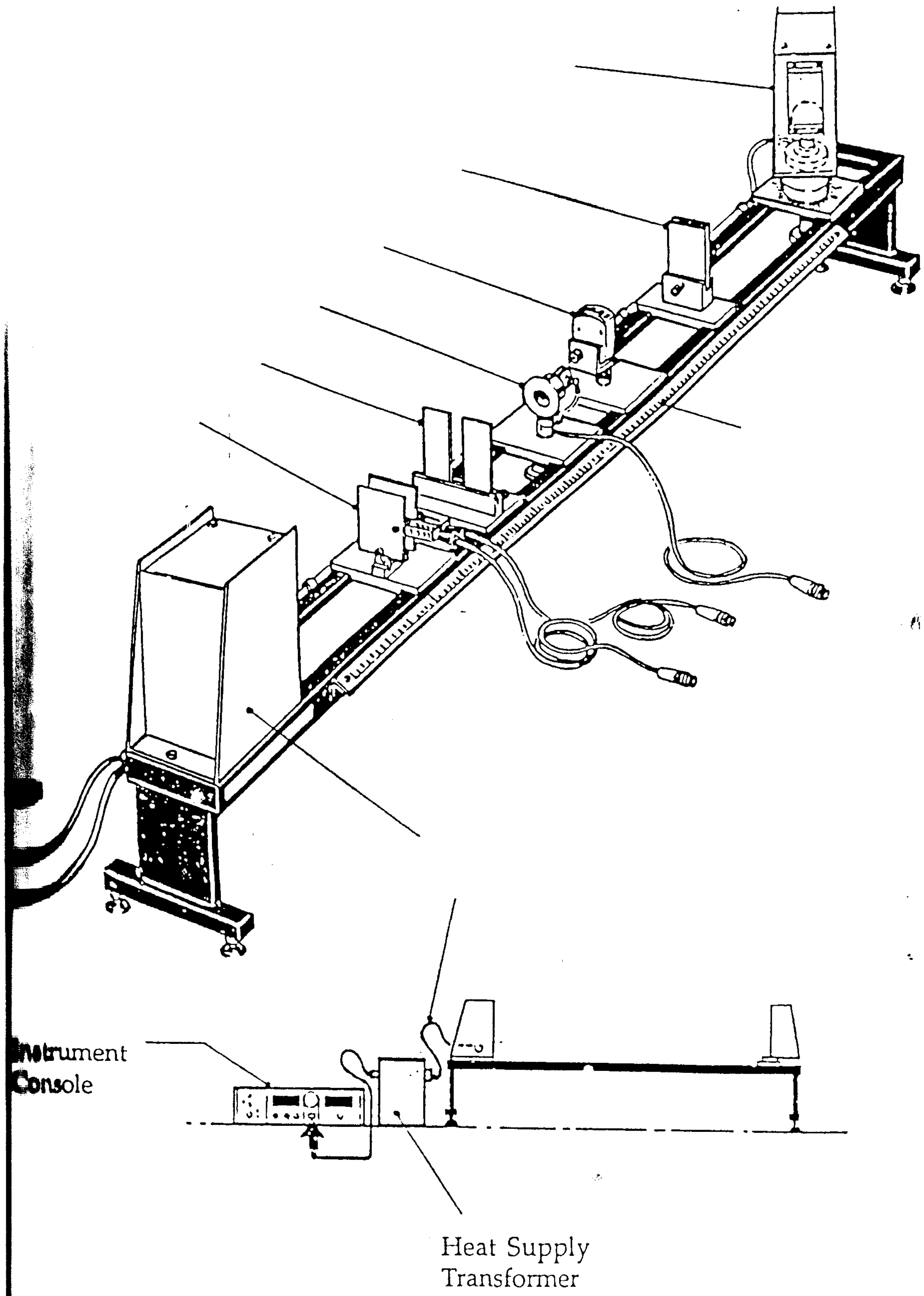
1) Place radiometer at a distance of 300 mm from heat source
2) Place aperture plate at a distance of 200mm from heat source
3) Black plate should be at 50 mm from the heat source
4) Allow the black plate temperature to stabilize at a given power level and record radiometer reading
5) Set the aperture from 60 mm to 0 in steps of 5mm. Make sure that the plates are equally spaced from the center and are securely clamped vertically.

Observation Sheet

Black Plate temperature =

Aperture, mm	60	55	50	45	40	35	30	25	20	15	10	5	0
Radiometer reading W/m^2													

Comment on the relation between aperture size and radiometer reading. Draw a graph of Radiometer reading vs. aperture size.



THERMAL RADIATION APPARATUS

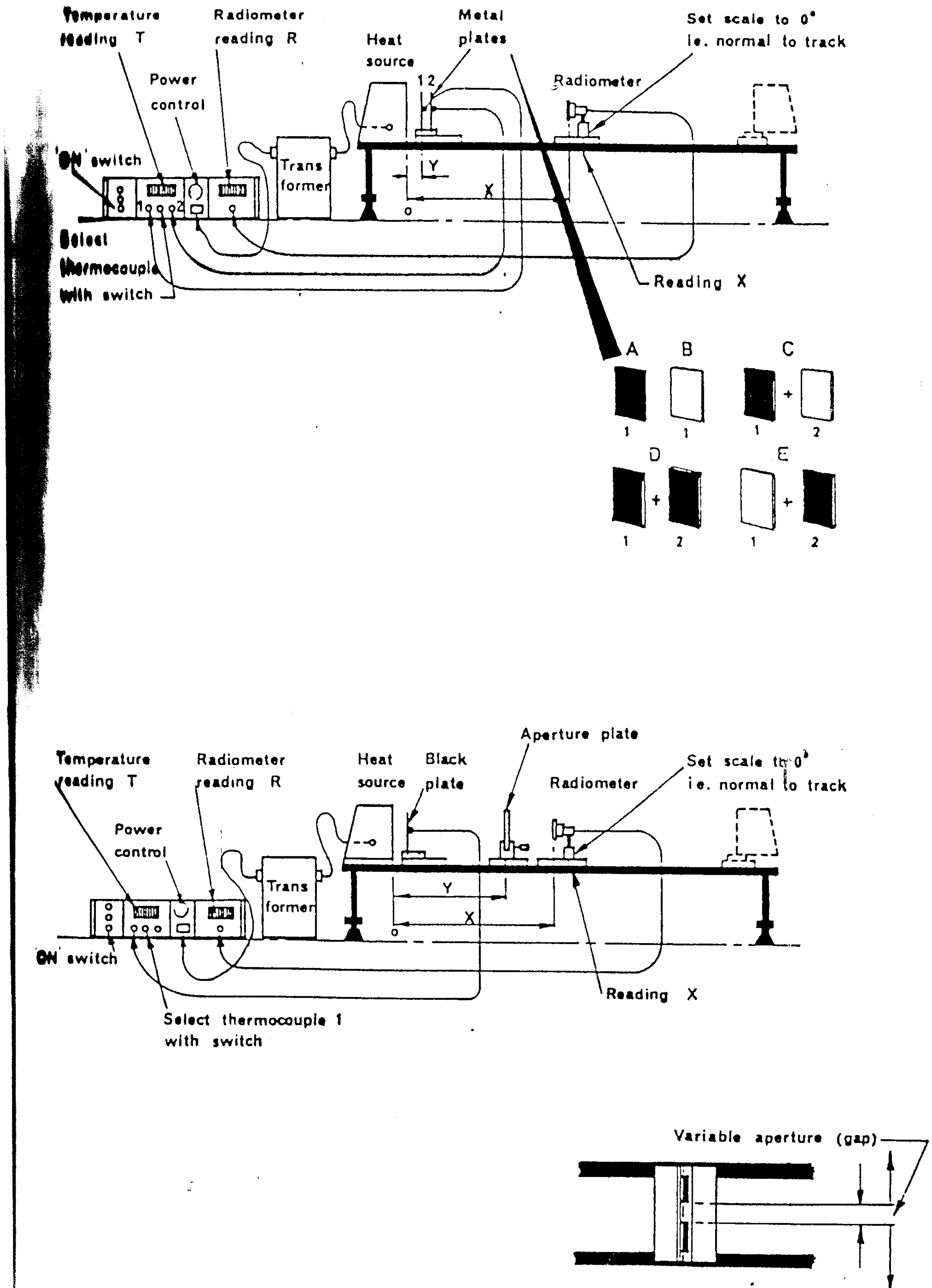

Temperature reading T
Radiometer reading R
Metal plates
Heat source
Set scale to 0°
i.e. normal to track
Power control
Radiometer
'ON' switch
Trans former
Y
X
Select thermocouple with switch
Reading X
A
B
C
D
E
Temperature reading T
Radiometer reading R
Heat source
Black plate
Aperture plate
Radiometer
Set scale to 0°
i.e. normal to track
Power control
'ON' switch
Select thermocouple 1 with switch
Reading X
Variable aperture (gap)

Fig 3.1

EG 605 ME
Heat Transfer

Lab 4

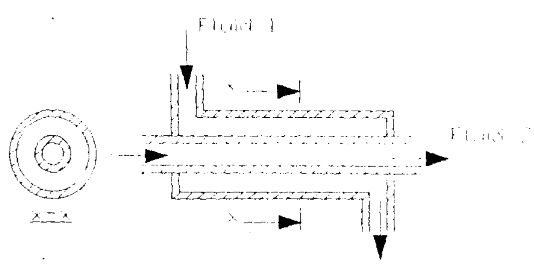
itle: Concentric Tube Heat Exchanger

bjective:

he objective of this experiment is:
) to study the working principle of parallel flow heat exchanger
) to study the working principle of counter flow heat exchanger
) to study effect of fluid temperatures on counter flow heat exchanger performance
) to study effect of fluid flow rates on counter flow heat exchanger performance

troduction

at exchangers are usually classified according to the configuration of fluid flow paths rough the heat exchanger and according to their construction. According to fluid flow ths, heat exchangers are classified as:
) parallel flow heat exchanger
) counter flow heat exchanger, and
) cross flow heat exchanger
parallel flow heat exchangers, both the hot and cold fluids flow in the same direction. In unter flow heat exchangers, the flow of two fluids in mutually opposite direction and in oss flow heat exchangers, the flow of two fluids is in mutually perpendicular direction. at exchangers may be constructed in various designs with the above mentioned flow nfigurations. Concentric tube heat exchanger is one of such designs in which one fluid ows through outer tube and the other flows through the inner concentric tube as shown figure.



The flow of fluids can be either in same direction or in opposite direction (i.e. parallel or counter flow of fluids). Concentric tube heat exchangers are usually used for liquids only. If the difference in heat transfer coefficients of the two fluids is too large (as in the case of air and water), this type of heat exchanger is not used since the heat transfer area is not large.

Relevant Equations:

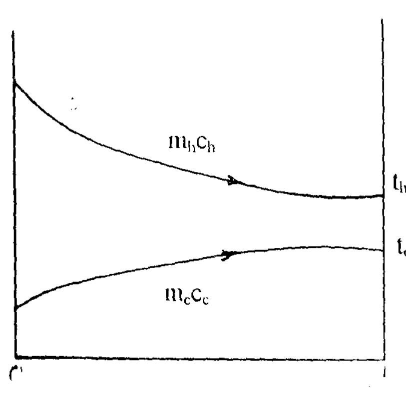
According to the laws of thermodynamics, the heat given off by the hot fluid must be equal to heat gained by cold fluid if there are no losses.

$$m_h c_h \Delta t_h = q = m_c c_c \Delta t_c \qquad (1)$$

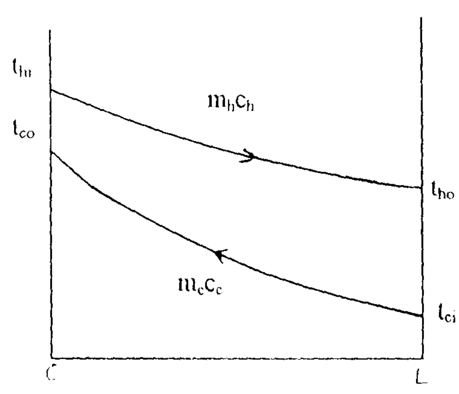
Where, m = mass (kg)
C = sp. Heat (kJ/kg.K)
Δt = temperature difference, (K)
subscripts c and h = cold and hot respectively

From equation (1) it is obvious that if $m_c c_c > m_h c_h$ then, $\Delta t_h > \Delta t_c$, i.e, the fluid with minimum value of (mc) has to undergo a larger temperature change Δt otherwise energy balance will be violated. This means the maximum possible heat transfer is always given by the product of minimum (mc) and maximum temperature difference in the heat exchanger. The effectiveness of heat exchanger is given by :

$$\epsilon = \frac{\text{actual heat transfer}}{\text{maximum possible heat transfer}} = \frac{m_c c_c \Delta t_c \text{ or } (m_h c_h \Delta t_h)}{(mc)_{\min}(t_{hi} - t_{ci})} \qquad (2)$$



Parallel flow arrangement



Counter flow arrangement

In order to simplify heat transfer analysis for heat exchangers, log mean temperature difference is introduced which is also denoted by LMTD. It is given by,

$$MTD = \frac{\Delta T_0 - \Delta T_L}{\ln\left(\frac{\Delta T_0}{\Delta T_L}\right)} \qquad (3)$$

at transfer in the heat exchanger can then be given by:

$$AU(LMTD) \qquad (4)$$

re, A – heat transfer area
U – Overall heat transfer coefficient

of the four quantities in equation (4) are known, the other one can be easily

y setup:

ent used for this lab is the 'concentric tube heat exchanger made by P.A. Hilton
quipment is shown in figure 4-1.

of hot water at a temperature up to 80 °C is maintained in a storage tank (1) at
f the apparatus by two heating elements (2). The temperature of the water is
d by a sensor (4) adjacent to the tank outlet. The controller is mounted on the
el (9). Water is continuously recirculated through the tank by a pump (6) and
) within the tank assist in mixing to promote a consistent temperature at the tank

r for the exchanger is taken from the pump discharge and passes through the
e of the concentric tube arrangement (13) before returning to the tank for
g. Flow through this circuit is regulated by a control valve (18) and indicated on a
ter (19). Thermometers (15) and (17) installed at the inlet and outlet of the
or hot water circuit indicate respective water temperatures. A thermometer (10)
d in the top branch of the exchanger indicates the temperature of the water in the
ater circuit at the mid-point of the circuit.
water for the exchanger is supplied from an external source to the outer annulus of
oncentric tube arrangement via an inlet (21) and valve arrangement (16). Flow
ugh this circuit is regulated by a control valve (20) and indicated on a flowmeter (23).
r heating in the exchanger the cold water leaves via an outlet (22). Temperatures
ough the cold water circuit are indicated on three thermometers (12 and 14) , parallel
r counter flow configurations may be obtained by appropriate setting of the valeves (16).
Valves (11) at the top of the exchanger permit air to be bled from the system and facilitate
drainage. There is a drain valve (24) which permits the storage tank to be drained.

Safety considerations:

1) Make sure that the water at the outlet is properly drained to avoid spillage of water on the floor.
2) Make sure that the valves are opened/closed properly to set the required path of water.
3) Do not touch the hot water tank on the back of the equipment to avoid burns.

Laboratory Procedure:

1) Remove the cover of the water storage tank on the back of the equipment and fill the tank with clean water to within 75 mm of the top (the vent hole in the right hand return pipe should remain exposed).
2) Connect the cold water inlet to source of cold water using flexible tubing.
3) Connect the cold water outlet to a suitable drain using flexible pipe.
4) Set the selector valves for parallel or counter flow arrangemnets.
5) Connect the electrical mains lead to fused mains supply and switch ON.
6) Close the vent valve at the top of heat exchanger after venting it.
7) Press the setpoint membrane key of the temperature controller to view the setpoint. While pressing the setpoint key press the 'lower' or 'raise' key to set the temperature at 65 °C.
8) Allow time for the water to reach the setpoint.
9) Set the required flow rate by turning the valves before cold/hot water flow meters.
10) Take readings of temperatures at inlet, mid point and outlet of cold and hot water.
11) Turn the mains switch OFF.
12) Shut down the cold water supply.
13) Let the cold water drain completely.

Observation Sheet:

Useful data:

Tube outer diameter = 15 x 0.7 mm
Shell outer diameter = 22 x 0.9 mm
Insulation thickness = 20 mm
Heat transfer area = 0.067 m^2

1. Parallel and Counter flow heat exchanger characteristics:

	Qc (LPM)	Qh (LPM)	t_{hi}, °C	t_{hmid}, °C	t_{ho}, °C	t_{ci}, °C	t_{cmid}, °C	t_{co}, °C
Parallel	1	2	65	43	3[illegible]	18	2[illegible]	30
Counter	1	2	65	44	27	[illegible]	25	31

Draw temperature vs. Length graph for both arrangements. Calculate Cmin, Cmax, effectiveness, and U factor. Comment on the results.

2. Water temperature variation in Counter flow heat exchanger

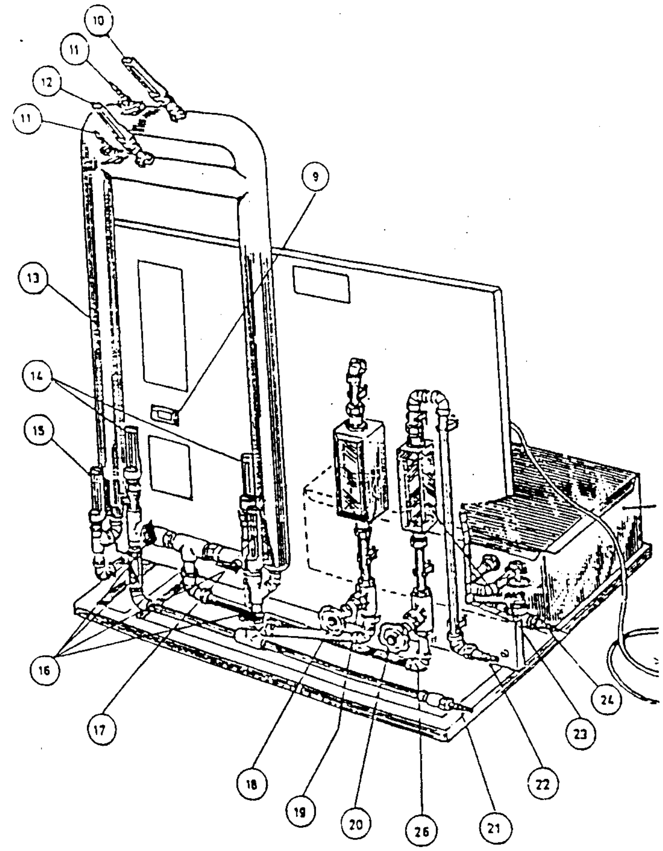
Qc (LPM)	Qh (LPM)	t_{hi}, °C	t_{hmid}, °C	t_{ho}, °C	t_{ci}, °C	t_{cmid}, °C	t_{co}, °C
1	2	50					
1	2	55					
1	2	60					
1	2	65					

Draw temperature vs. Length graph. Calculate Cmin, Cmax, effectiveness, and U factor for the cases of lowest and highest temperatures of hot water. Comment on the results.

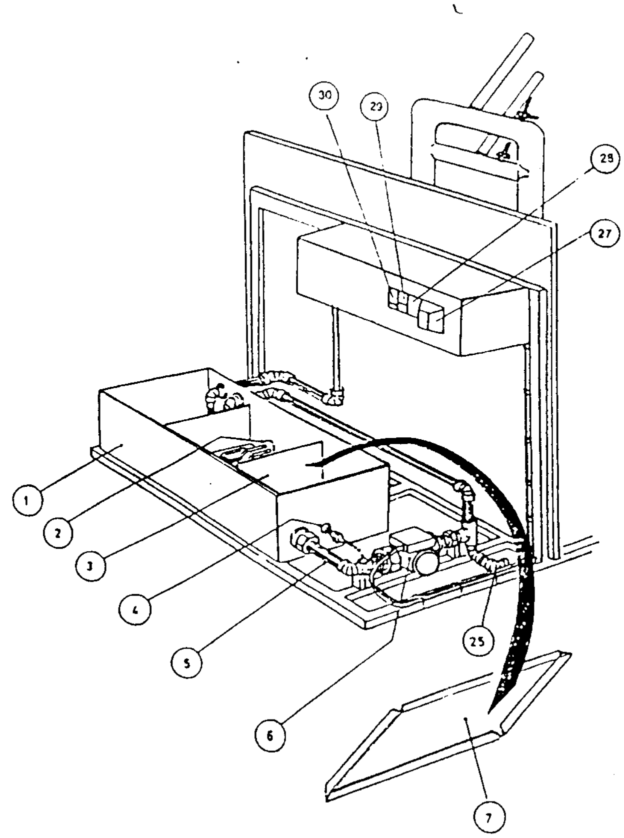
3. Water flow rate variation in Counter flow heat exchanger

Qc (LPM)	Qh (LPM)	t_{hi}, °C	t_{hmid}, °C	t_{ho}, °C	t_{ci}, °C	t_{cmid}, °C	t_{co}, °C
2	1	65					
2	2	65					
2	3	65					
2	4	65					

Draw temperature vs. Length graph. Calculate Cmin, Cmax, effectiveness, and U factor for the cases of lowest and highest flow rates of hot water. Comment on the results.



FRONT VIEW



REAR VIEW

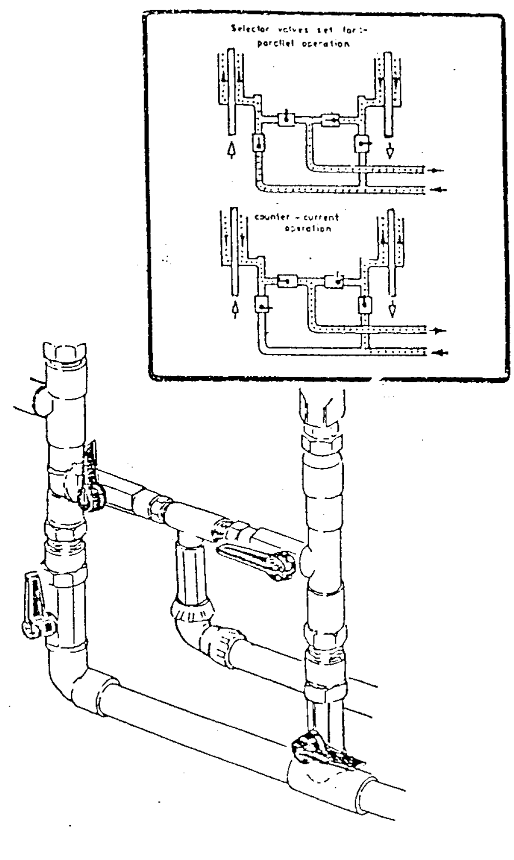


Fig 4-1

It is very difficult to analytically solve convective heat transfer problems and almost all problems are solved using experimentally establishea empirical correlations. Some of commonly used empirical correlations for flow across cylinders are as follows.

1. Raithby and Eckert correlation

$$Nu = C_1 Re^{C2} \qquad (1)$$

For air and $5000<Re<50000$, $C_1 = 0.148$; $C_2 = 0.633$

2. Hilpert correlation

$$Nu = C\, Re^n\, Pr^{1/3} \qquad (2)$$

For air and $4000<Re<40000$, $C = 0.193$; $n = 0.618$

3. Eckert and Drake correlation

$$Nu = 0.25\, Re^{0.6}\, Pr^{0.38}, \qquad \text{For air and } 1000< Re <200000 \qquad (3)$$

From Newton's law of cooling, we know that the rate of transmission of heat from element (cylinder) to air is given by:

$$q = h A (T- T_A) \qquad (4)$$

In a period of time dt, the fall in temperature dT is given by:

$$-qdt = m\,c\,dT \qquad (5)$$

From eq. 4 and 5, eliminating q,

$$\frac{-dT}{(T - T_A)} = \frac{hA}{mc} dT \qquad (6)$$

Where,
T = cylinder surface temperature, K
T_A= air temperature, K
A = effective surface area of cylinder, m
h = convective heat transfer coefficient, W/m^2K
m = mass of cylinder, kg
c = sp. heat of cylinder material (i.e. copper), J/kg.K

Integrating equation 6, we get,

$$\ln(T - T_A) - \ln(T_0 - T_A) = -\frac{hAt}{mc} \quad (7)$$

Where, T_0 = temperature of cylinder at time t =0

It is obvious that equation 7 is a linear equation and it suggests that a plot of $\ln(T-T_A)$ against t should yield a straight line of slope -(hA/mc) and since the other factors in this expression are known, the heat transfer coefficient h may be calculated. In practice, it is more convenient to plot $\log_{10}(T-T_A)$ vs. t. Since, ln N = 2.3026 $\log_{10}$ N, the heat transfer coefficient is related to the slope M of this line by the expression:

$$h = -2.3026\frac{mc}{A}M \quad (8)$$

The velocity of air is calculated from the velocity head upstream which is given by:

$$V_1 = 237.3\sqrt{\frac{H.T_A}{p_A}} \text{ (m/s)} \quad (9)$$

Where,

H = velocity head in cm of H_2O
p_A = ambient pressure, N/m^2
T_A = absolute temperature, K

The velocity passing through the cylinder is then given by:

$$V = \frac{D}{(D-d)}V_1 \quad (10)$$

Where,

D = diameter of air flow channel, m
d = diameter of cylinder, m

Laboratory Setup

The apparatus used for this lab is Plint and Partners' 'Cross-flow heat exchanger" intended for the study of heat transfer phenomena associated with flow past cylindrical tubes arranged either in isolation or in banks of various configurations.

The apparatus consists of a transparent perspex working section through air may be drawn by a centrifugal fan. Perspex rods may be inserted into the working section with their axes at right angles to the direction of flow, thus simulating a typical cross flow heat exchanger.

One of the spaces provided in the working section for the rods is occupied by an element consisting of a rod of pure copper approximately 10 cm in length carried between tow extension rods of fabric-based plastic compound. Arrangements are made for heating this copper element in isolation from the working section, replacing it in the section and then recording its rate of cooling as indicated by a thermocouple embedded at its center. A semi-logarithmic plot of rate of cooling together with a knowledge of the thermal capacity and surface area of the copper then permits a direct calculation of the heat transfer coefficient between the copper element and the air flowing past it. The other spaces provided are used to simulate a tube bank using dummy perspex rods.

The element is heated by withdrawing it from the working section and placing it in a cylindrical electric heater. The heater is supplied with current at a low voltage which can raise the temperature of the element to a maximum of 80°C. The element temperature is indicated by a chart recorder. The chart recorder records the temperature difference between the hot junction embedded in the element and a cold junction in the air stream at the inlet to the working section. The initial temperature of the air is indicated by a mercury-in-glass thermometer at the air inlet.

A centrifugal fan draws the air through the bellmouth. After the working section, the air enters the honeycomb flow-straightner intended to prevent the transmission of swirl from the fan to working section. The fan discharges to a graduated throttle valve by means of which the air velocity through the apparatus may be regulated.

Associated static tappings are provided so that the velocity head may be recorded by means of the manometer. The velocity distribution upstream of the tube bank is sensibly constant and may be established by a single measurement of the static wall pressure downstream of the bellmouth.

The thermocouple in the element and at the air inlet are of copper and constantan type.

Safety considerations

The cylindrical element after heating may have a temperature of up to 80 °C. Handle with care to avoid burns (do not touch the copper surface).

Laboratory Procedure

1) Connect the chart recorder to appropriate power supply
2) Set the chart speed to 10mm/min
3) Calibrate the chart recorder for a suitable scale
4) Connect the power supply mains of cross flow apparatus and turn the power ON
5) Turn the heater ON
6) Insert the copper element into the heater
7) Watch the copper element temperature rise in the chart up to about 70°C (about 2.4 mV corresponds to about 70 °C)
8) Set the air flow rate to 20% of full-flow by adjusting the damper at the air outlet duct
9) Turn on the fan

10) Remove the copper element from the heater and insert into the central hole of the working section
11) Watch the element cool down to ambient temperature (i.e. 0 mV on the chart)
12) Turn the fan off
13) Repeat process 6 onwards for up to 100% air flow in a step of 20% each time.

Observation Sheet

Useful data

Width of working section	12.5 cm
Height of working section	12.5 cm
Diameter of elements	1.25 cm
Transverse pitch of elements	2.5 cm
Longitudinal pitch of elements	1.875 cm

Data related to cross-flow apparatus:

Throttle opening %	H, cm H_2O	V, m/s	Re	Slope M	Nu
20%					
40%					
60%					
80%					
100%					

Data related to chart recorder:

t, sec	Thermocouple mV	$T-T_A$, °C	$\log_{10}(T-T_A)$, °C

- From chart, find $(T-T_A)$ using thermocouple data sheet and laws of thermocouple. Draw a graph $\log_{10}(T-T_A)$ vs. time t for each value of throttle opening
- Find slope M from the graph

- Calculate h using equations 8 for each value of throttle opening
- Calculate Re for each value of throttle opening
- Calculate Nu for each value of throttle opening
- Draw a graph Nu vs. Re using the above data
- Draw graphs Nu vs. Re for equations 1, 2 and 3
- How does your experiment compare with the other three graphs ?