Al-Imam Mohammad Ibn Saud Islamic University

Department of Mechanical Engineering

ME 325: HEAT TRANSFER LAB

Experiment No.1: Use of the Fourier Rate Equation

Student's Name: _____

Student ID: _____

Date experiment is conducted: _____

Date lab report is submitted: _____

Instructor's Name: _____

Prepared by:

DR. SYED MUHAMMAD FAKHIR HASANI
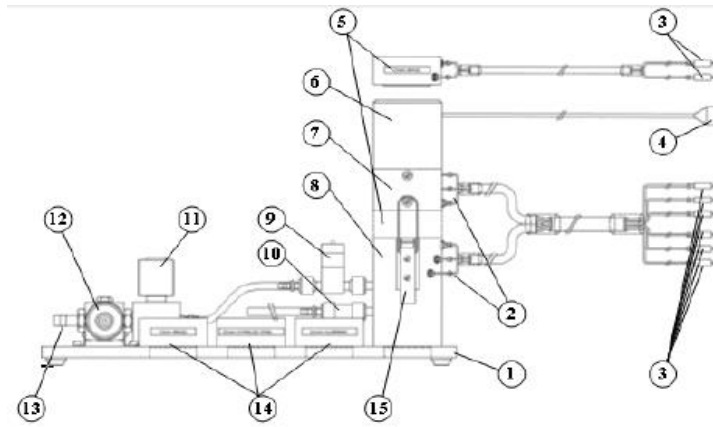
ENG. ABDULAZIZ AL-ASIRI
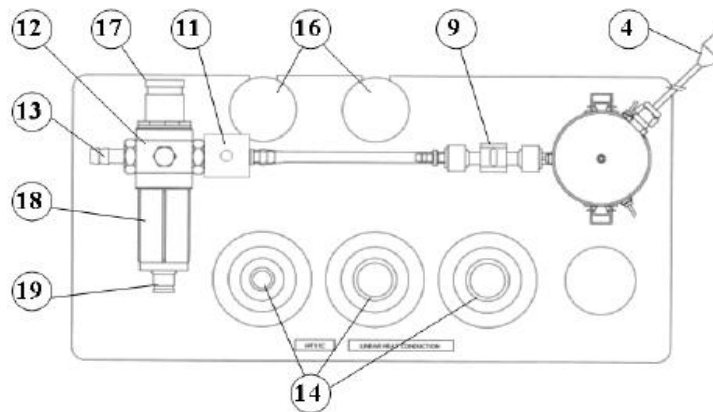
Figure 1 Side View of HT11C
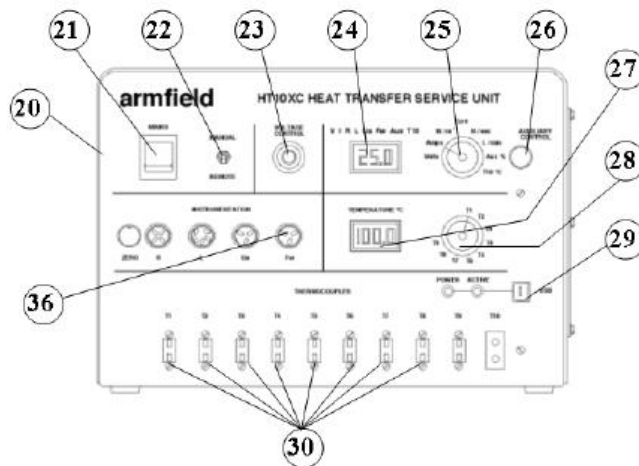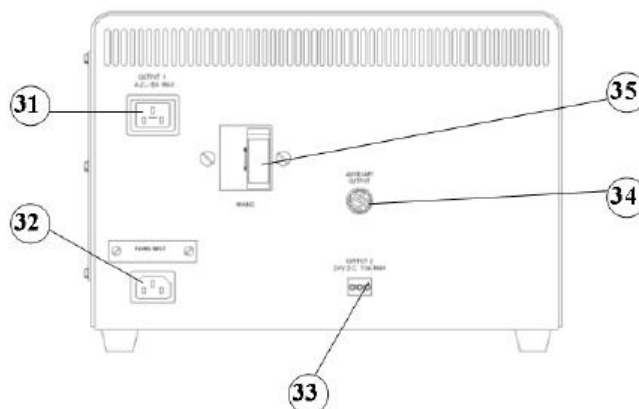

Figure 2 Top View of HT11C

Figure 3 Front View of HT10XC

Objective

To understand the use of the Fourier Rate Equation in determining rate of heat flow through solid materials for one-dimensional steady flow of heat.

Method

To demonstrate Fourier's Law for the linear conduction of heat along a simple bar, by measuring the change in temperature with distance, at different rates of heat flow through the bar and using the measurements to calculate the conductivity of the bar.

Equipment Required

Armfield Heat Transfer Service Unit HT10XC

Armfield Computer Compatible Linear Heat Conduction Accessory HT11C

PC installed with Windows

Equipment set-up

Before proceeding with the exercise, ensure that the equipment has been prepared as follows:

1) Set up the HT11C Linear Heat Conduction accessory (1) alongside the HT10XC Heat Transfer Service Unit (20).

2) Clamp the intermediate Brass section (instrumented with two thermocouples) between the heated and cooled section of the HT11C having lightly coated the mating faces with thermal paste. Take care to locate the shallow shoulders on the sections before clamping.

3) Connect the eight thermocouples on the HT11C (3) to the appropriate sockets on the front of the service unit (30). Ensure that the labels on the thermocouple leads (T1-T8) match the labels on the sockets.

4) Set the VOLTAGE CONTROL potentiometer (23) on the HT10XC service unit to minimum (anticlockwise) and the selector switch (22) to MANUAL then connect the power lead form the HT11C to the socket marked OUTPUT 2 at the rear of the service unit (33).

5) Connect the cold water flow control valve (11) to the socket marked AUXILARY OUTPUT (34) on the rear of the HT10XC console.

6) Connect the cold water flow rate sensor (9) to the socket marked Fw (36) on the front of the HT10XC console.

7) Set the AUXILIARY CONTROL knob (26) on the service unit to minimum (anticlockwise) then connect the power lead from the cold water flow control valve (11) to the AUXILIARY POWER socket on the rear of the service unit (34).

8) Ensure that a cold water supply is connected to the inlet of the pressure regulating valve on HT11C (13).

9) Ensure that the flexible cooling water outlet tube is directed to a suitable drain.

10) Ensure that the service unit is connected to an electrical supply.

11) Switch on the MAINS switch on the service unit (21).

- Connect the USB socket on the HT10XC (29) to the computer using the USB cable provided, and set the selector switch on the console (22) to REMOTE.

- If using a computer, start the HT11C software and select 'Exercise B'. The software includes full instructions on how to use the software and perform the exercise..
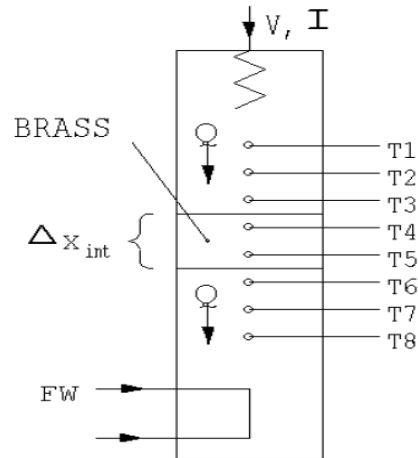
Theory/Background

Provided that the heated, intermediate and cooled sections are clamped tightly together, so that the end faces are in good thermal contact, the three sections can be considered to be one continuous wall of uniform cross section and material.
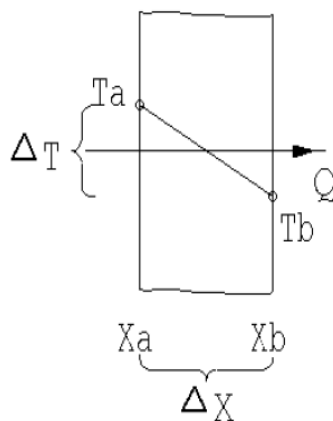
According to Fourier's law of heat conduction:

If a plane wall of thickness ΔX and area (A) supports a temperature difference (ΔT) then the heat transfer rate per unit time (Q) by conduction through the wall is found to be:

$$Q \propto A \frac{\Delta T}{\Delta x} \text{ where } \Delta x = (x_b - x_a)$$

If the material of the wall is homogeneous and has a thermal conductivity k (the constant of proportionality) then:

$$Q = -kA \frac{\Delta T}{\Delta x} \text{ where } \Delta T = (Ta - Tb)$$

It should be noted that heat flow is positive in the direction of temperature fall hence the negative sign in the equation.

For convenience the equation can be rearranged to avoid the negative sign as follows:

$$Q = kA \frac{\Delta T}{\Delta x} \text{ where } \Delta T = (Ta - Tb)$$

Note: In this exercise the HT11C is configured as a simple plane wall where k and A are constant therefore the object is to show that the Fourier equation can be used to relate Q, ΔT and ΔX.

Procedure:

1) Check that the panel displays on the service console are illuminated. If the panel displays do not illuminate check the RCD and circuit breakers at the rear of the service unit (35); all switches at the rear should be up.

2) Check that the computer software indicates IFD OK in the bottom right hand corner of the software window.

3) Turn on the cooling water. The flow rate is controlled using the control box on the software mimic diagram window. Enter a flow rate of 1.5 liters/min in thewindow and monitor it on the software screen.

4) Set the heater voltage to 12 volts. Enter the voltage in the display box for the heater or use the control box arrows.

5) Allow the HT11C to stabilize. Monitor the temperatures on the software mimic diagram screen. (If operating the equipment manually from the console, use the lower selector switch on the console to set the console display to each temperature sensor in turn).

6) When the temperatures are stable, click the icon on the computer screen to record the following: T1, T2, T3, T4, T5, T6, T7, T8, V, I, F_W.

7) Set the Heater Voltage to 17 Volts.

8) Allow the HT11C to stabilize and then repeat the above readings

Recordable Data

For this exercise the raw data is tabulated under the following headings

Data Set #	Heater Voltage 'V' (volts)	Heater Current 'I' (amperes)	TEMPERATURES (^{o}C)								Water flow rate 'F$_w$' (liters/min)
			T1	T2	T3	T4	T5	T6	T7	T8	

Constants in the experiment

For this exercise the following constants are applicable:

Distance between thermocouples T1 and T3	$x_{13} = 0.03$	(m)
Distance between thermocouples T4 and T5	$x_{45} = 0.015$	(m)
Distance between thermocouples T6 and T8	$x_{68} = 0.03$	(m)
Diameter of bar	$D = 0.025$	(m)

Note: The distance between each thermocouple is 0.015 m .The distance between thermocouple T3, T4, T5 or T6 and the end face is 0.0075 m

Calculations

For each set of readings the following calculations are performed:

Quantity	Formula	Data set			Units
		1	2	3	
Cross-sectional area of the bar	$A = \dfrac{\pi D^2}{4}$				
Heat flow (Power to heater)	$Q = V * I$				
Temp. Diff. in the heated section	$\Delta T_{hot} = T1 - T3$				
Conductivity in the heated section	$k_{hot} = \dfrac{x_{13} Q}{\Delta T_{hot} A}$				
Temp. Diff. in the intermediate section	$\Delta T_{int} = T4 - T5$				
Conductivity in the intermediate section	$k_{int} = \dfrac{x_{45} Q}{\Delta T_{int} A}$				
Temp. Diff. in the cooled section	$\Delta T_{cold} = T6 - T8$				
Conductivity in the cooled section	$k_{cold} = \dfrac{x_{68} Q}{\Delta T_{cold} A}$				

Summary of Results

Your summary of results must include the following:

1. An estimation the cumulative influence of the experimental errors on your calculated values for Q, ΔT, ΔT (hot), ΔT (int), ΔT (cold), k_{hot}, k_{int} and k_{cold} and measured values for D, $\Delta X_{(18)}$, $\Delta X_{(13)}$, $\Delta X_{(45)}$ and $\Delta X_{(68)}$.

2. A comparison of the calculated value for the thermal conductivity of Brass in the three sections at the same heat flow.

3. A comparison of the calculated value for the thermal conductivity of Brass in the three sections at different heat flows.

4. A graph of temperature (T) against position (x) along the bar with the best straight line fit through the data points. The graph should be similar to the diagram below:
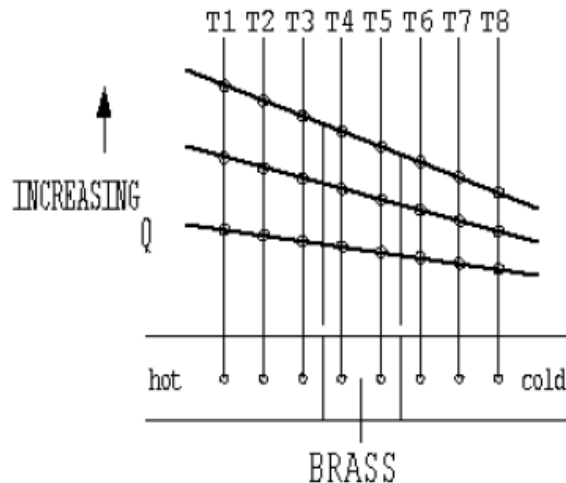
5. From the plotted graph, what conclusion can be drawn between the gradient of the line and the heat flow?

6. Calculate the average conductivity of the brass bar using the gradient of each straight line and the corresponding heat flow through the bar. Compare the value obtained with the values previously obtained for each individual section of the bar and comment on any difference.

   Note: Your results should give values in the range 110 - 128 W/m°C for the thermal conductivity of Brass, assuming no heat loss from the equipment. Since a small amount of heat loss is inevitable as the temperature of the bar increases, the calculated value for the conductivity will increase at higher operating temperatures.

Conclusions

Your conclusions must include the following:

1. How the Fourier rate equation can be used to relate temperature difference, heat flow and distance in a solid material of constant cross-sectional area and thermal conductivity. What is the effect of heat flow (Q) on temperature gradient (ΔT) across the solid material?

2. Comment on the effect of measurement accuracy and heat loss from the equipment on your calculated results and any differences between the results for each section.

Al-Imam Mohammad Ibn Saud Islamic University

Department of Mechanical Engineering

ME 325: HEAT TRANSFER LAB

Experiment No. 2: Determination of Overall Heat Transfer Coefficient and Thermal Conductivity of an unknown material using Different materials in series

Student's Name: _____

Student ID: _____

Date experiment is conducted: _____

Date lab report is submitted: _____

Instructor's Name: _____

Prepared by:
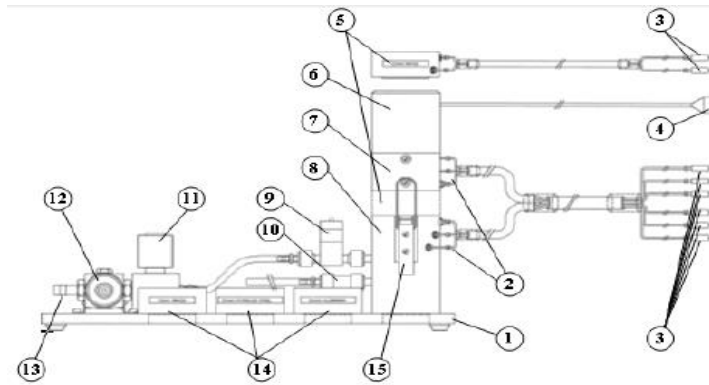
DR. SYED MUHAMMAD FAKHIR HASANI

ENG. ABDULAZIZ AL-ASIRI
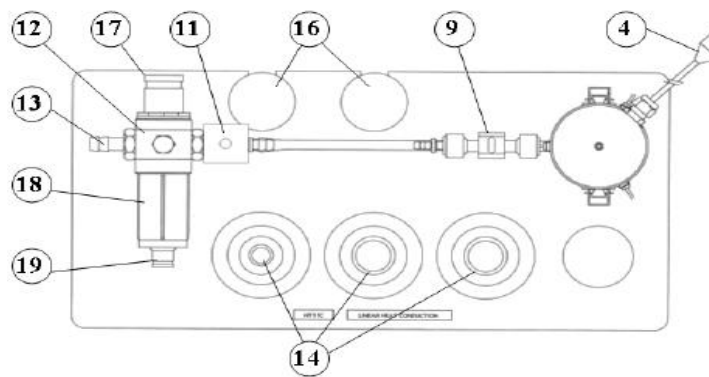
Figure 1 Side View of HT11C
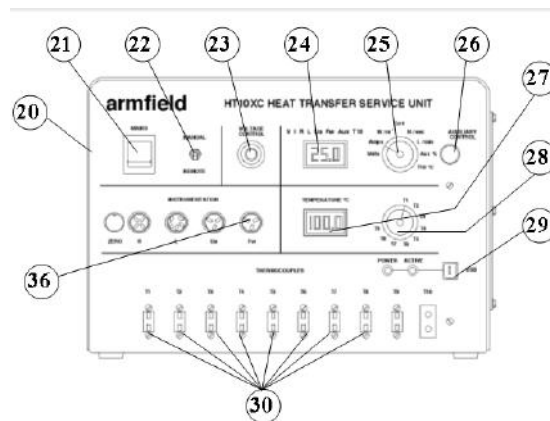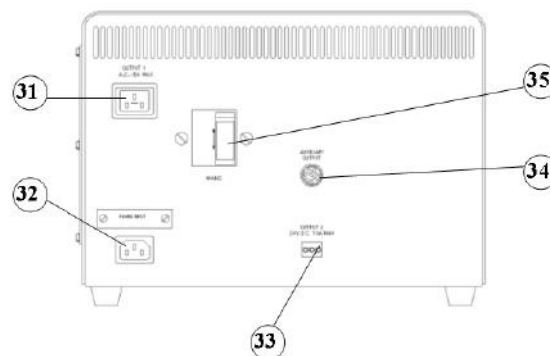

Figure 2 Top View of HT11C

Figure 3 Front View of HT10XC

Objective

To measure the temperature distribution for steady-state conduction of energy through a composite plane wall and determine the Overall Heat Transfer Coefficient and thermal conductivity of an unknown material for the flow of heat through a combination of different materials in series.

Method

By measuring the temperature distribution along a composite bar of different solid materials (conductors) for one-dimensional steady flow of heat and using the Fourier Rate Equation applied to each material to determine the Overall Heat Transfer Coefficient and the thermal conductivity of an unknown material.

Equipment Required

Armfield Heat Transfer Service Unit HT10XC.

Armfield Computer Compatible Linear Heat Conduction Accessory HT11C.

PC installed with Windows.

Equipment set-up

Before proceeding with the exercise ensure that the equipment has been prepared as follows:

1) Set up the HT11C Linear Heat Conduction accessory (1) alongside the HT10XC Heat Transfer Service Unit (20) on a suitable bench.

2) Clamp the intermediate Aluminum section (no instrumentation) between the heated and cooled section of the HT11C having lightly coated the mating faces with thermal paste. Take care to locate the shallow shoulders on the sections before clamping.
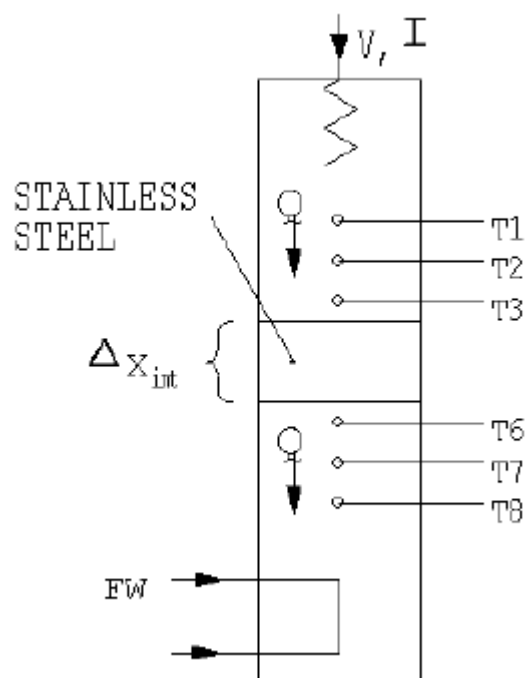
3) Connect the six thermocouples on the HT11C (3) to the appropriate sockets on the front of the service unit (30). Ensure that the labels on the thermocouple leads (T1 – T3) and (T6-T8) match the labels on the sockets.
Note: Readings from thermocouples T4 and T5 will not be used in this exercise.

4) Set the VOLTAGE CONTROL potentiometer (23) to minimum (anticlockwise) and the selector switch (22) to MANUAL then connect the heater lead from the HT11C (4) to the socket marked OUTPUT 2 at the rear of the service unit (33).

5) Connect the cold water flow control valve (11) to the socket marked AUXILARY OUTPUT (34) on the rear of the HT10XC console.

6) Connect the cold water flow rate sensor (9) to the socket marked Fw (36) on the front of the HT10XC console.

7) Set the AUXILIARY CONTROL knob (26) on the service unit to minimum (anticlockwise) then connect the power lead from the cold water flow control valve (11) to the AUXILIARY POWER socket on the rear of the service unit (34).

8) Ensure that a cold water supply is connected to the inlet of the pressure regulating valve on HT11C (13).

9) Ensure that the flexible cooling water outlet tube is directed to a suitable drain.

10) Ensure that the service unit is connected to an electrical supply.

11) Switch on the MAINS switch on the service unit (21).

12) Connect the USB socket on the HT10XC (29) to the computer using the USB cable provided, and set the selector switch on the console (22) to REMOTE.

Theory/Background

The heated, intermediate and cooled sections are clamped tightly together, so that the end faces are in good thermal contact, and create a composite bar with an Aluminum section sandwiched between two Brass sections.
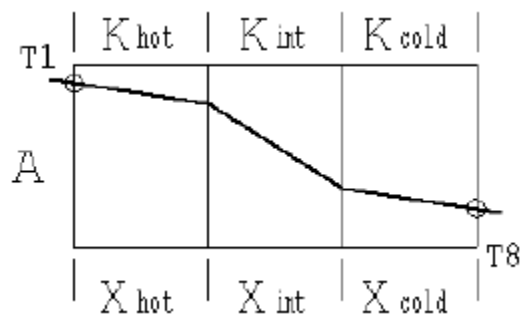
For continuity, the steady heat flow through the successive sections must be the same so Fourier's Law can be applied to the three sections as follows:

$$\frac{Q}{A} = \frac{k_{hot}\Delta T_{hot}}{x_{hot}} = \frac{k_{int}\Delta T_{int}}{x_{int}} = \frac{k_{cold}\Delta T_{cold}}{x_{cold}}$$

from which it follows that:

$$(T_1 - T_8) = (\Delta T_{hot} + \Delta T_{int} + \Delta T_{cold}) = \frac{Q}{A}(\frac{x_{hot}}{k_{hot}} + \frac{x_{int}}{k_{int}} + \frac{x_{cold}}{k_{cold}})$$

or $\quad\quad\quad \frac{Q}{A} = U(T_1 - T_8)$ where $\frac{1}{U} = \frac{x_{hot}}{k_{hot}} + \frac{x_{int}}{k_{int}} + \frac{x_{cold}}{k_{cold}} = R$

where U is the Overall Heat Transfer Coefficient and 1/U is the resistance to heat flow R.

Procedure

1) Turn on the cooling water. The flow rate is controlled using the control box on the software mimic diagram window. Enter a flow rate of 1.5 liters/min and monitor it on the software window.

2) Set the heater voltage to 9 volts. Enter the voltage in the display box for the heater, or use the control box arrows.

3) Allow the HT11C to stabilize. Monitor the temperatures on the software mimic diagram screen. (If operating the equipment manually from the console, use the lower selector switch on the console to set the console display to each temperature sensor in turn).

4) When the temperatures are stable record the following: When the temperatures are stable, select the icon to record the following: T1, T2, T3, T6, T7, T8, V, I, Fw.

5) Set the Heater Voltage to 12 Volts.

6) Allow the HT11C to stabilize then repeat the above readings.

Recordable Data

For this exercise the raw data is tabulated under the following headings

Data Set #	Heater Voltage 'V' (volts)	Heater Current 'I' (amperes)	TEMPERATURES (°C)								Water flow rate 'Fw' (liters/min)
			T1	T2	T3	T4	T5	T6	T7	T8	
						X	X				

					X	X			
					X	X			

Constants in the experiment

For this exercise the following constants are applicable:

Distance between thermocouple T1 and the hotface	$x_{hot} = 0.0375$	(m)
Distance between hotface and coldface	$x_{int} = 0.030$	(m)
Distance between the coldface and thermocouple T8	$x_{cold} = 0.0375$	(m)
Diameter of bar	$D = 0.025$	(m)

Calculations

For each set of readings the following calculations are performed:

Quantity	Formula	Data set			Units
		1	2	3	
Cross-sectional area of the bar	$A = \dfrac{\pi D^2}{4}$				
Heat flow (Power to heater)	$Q = V * I$				
Hot face temperature	$T_{hotface} = T3 - \dfrac{(T2 - T3)}{2}$				
Cold face temperature	$T_{coldface} = T6 + \dfrac{(T6 - T7)}{2}$				
Temp. Diff. in the intermediate section (specimen)	$\Delta T_{int} = T_{hotface} - T_{coldface}$				

Conductivity in the intermediate section (specimen)	$k_{int} = \dfrac{x_{int} Q}{\Delta T_{int} A}$				
Temp. Diff. in the hot section	$\Delta T_{hot} = T1 - T_{hotface}$				
Conductivity of material in hot section	$k_{hot} = \dfrac{x_{hot} Q}{\Delta T_{hot} A}$				
Temp. Diff. in the cold section	$\Delta T_{cold} = T_{coldface} - T8$				
Conductivity of material in cold section	$k_{cold} = \dfrac{x_{cold} Q}{\Delta T_{cold} A}$				
Overall resistance to heat flow 'R'	$\dfrac{1}{U} = \dfrac{x_{hot}}{k_{hot}} + \dfrac{x_{int}}{k_{int}} + \dfrac{x_{cold}}{k_{cold}} = R$				
Overall heat transfer coefficient	(1) $U = \dfrac{1}{R}$ (2) $U = \dfrac{Q}{A*(T1\text{-}T8)}$				

Notes:

The distance between each thermocouple is 0.015m

The distance between thermocouple T3 or T6 and the end face is 0.0075m

The results of conductivity of the Brass sections (k_{hot} and k_{cold}) should be approximately 121 W/m°C

The conductivity of the Aluminum section (k_{int}) should be approximately 180 W/m°C

Summary of Results

Your summary of results must include the following:

1. An estimation of the cumulative influence of the experimental errors on your calculated values for Q, ΔT_{18}, R and U and measured values for, x_{hot}, x_{in}, x_{cold} and D.

2. A comparison the two values obtained for the Overall Heat Transfer Coefficient U and U= 1/R and comment on any difference in the values obtained.

3. A comparison of the calculated value of thermal conductivity of Aluminum (k_{Al}) to its value available in literature (k_{Al}=180 W/m°C)

4. A graph of temperature against position along the bar and draw the best straight line through the points for the heated section and cooled section. Extrapolate each line to the joint with the intermediate section then join these two points to give the gradient through the intermediate section. Your graph should be similar to the diagram below:
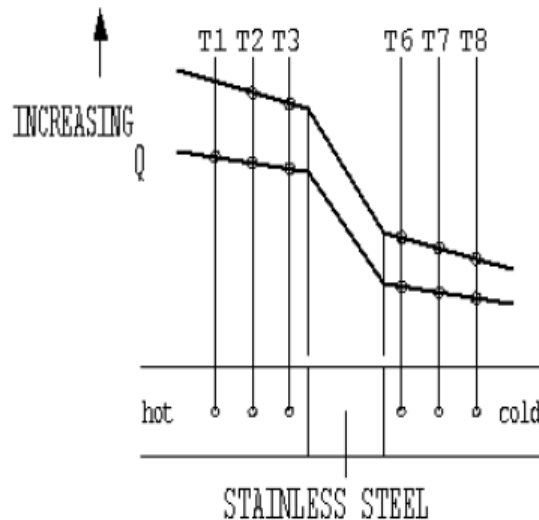
5. What observation can you make about the temperature gradient in the Aluminum (intermediate) section?

6. Your results should give values of approximately 180 W/m°C for the thermal conductivity of Aluminum, assuming no heat loss from the equipment. As a small amount of heat loss is inevitable as the temperature of the bar increases, the calculated value for the conductivity will increase at higher operating temperatures.

7. What was the effect of varying the heater power (heat flow through the composite bar)?

Conclusions

Your conclusions must include the following:
1. How the Fourier rate equation can be used to determine the Overall Heat Transfer Coefficient and the thermal conductivity of an unknown material using heat flow through a composite plane wall of constant cross sectional area but differing thermal conductivity.

2. Comment on the effect of measurement accuracy and heat loss from the equipment on your calculated results and any differences between the calculated results and those available in the literature.

8

Al-Imam Mohammad Ibn Saud Islamic University

Department of Mechanical Engineering

ME 325: HEAT TRANSFER LAB

Experiment No. 3: Use of the Fourier Rate Equation for Radial Conduction and determination of thermal conductivity

Student's Name: _____

Student ID: _____

Date experiment is conducted: _____

Date lab report is submitted: _____

Instructor's Name: _____

Prepared by:

DR. SYED MUHAMMAD FAKHIR HASANI
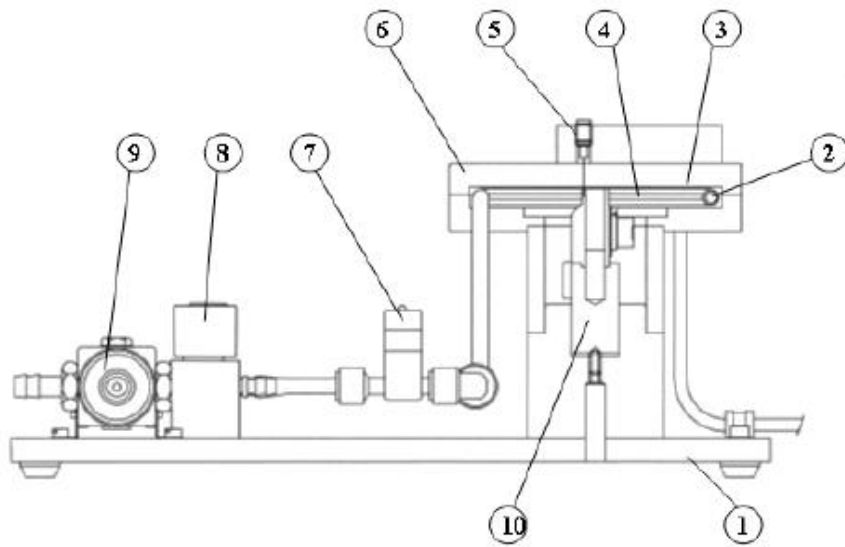
ENG. ABDULAZIZ AL-ASIRI

Figure 1 Front View of HT12C Computer Compatible Radial Heat Conduction Accessory
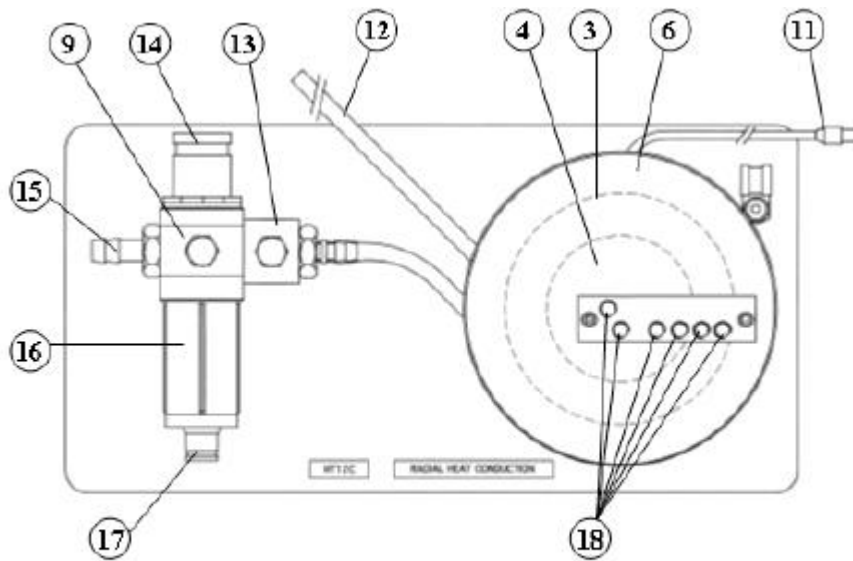

Figure 2 Top View of HT12C Computer Compatible Radial Heat Conduction Accessory
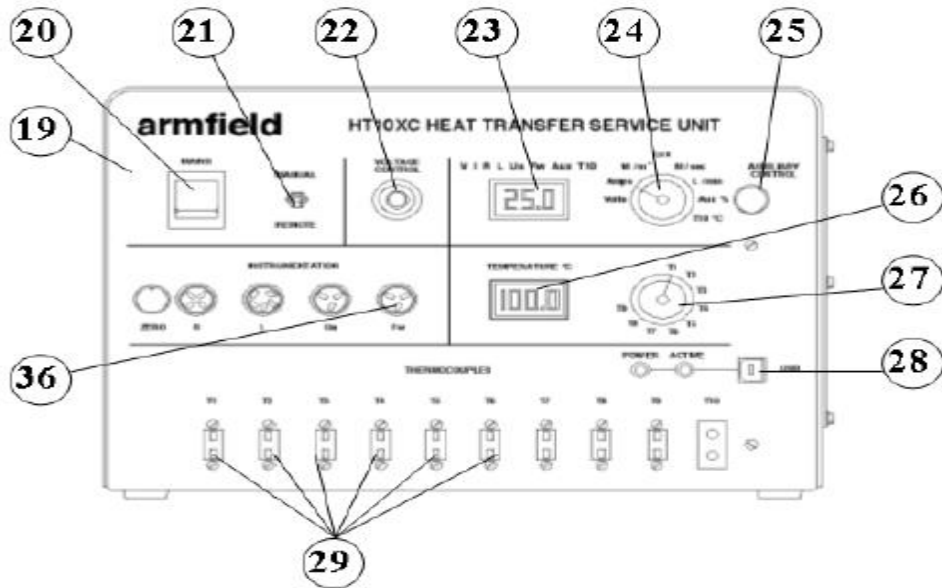
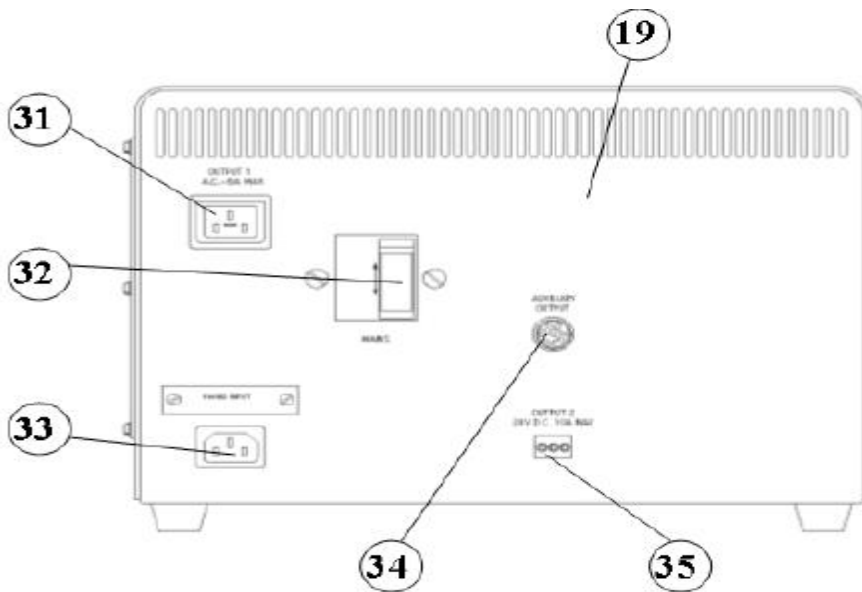Figure 3 Front View of HT10XC Heat Transfer Service Unit

Figure 4 Rear View of HT10XC Heat Transfer Service Unit

Objective

To understand the use of the Fourier Rate Equation in determining the rate of heat flow for steady-state conduction of energy through the wall of a cylinder (radial energy flow) and using the equation to determine the constant of proportionality (the thermal conductivity k) of the disk material.

Equipment Required

HT10XC Heat Transfer Service Unit

HT12C Computer Compatible Radial Heat Conduction Accessory

PC installed with Windows

Method

By measuring the change in temperature between the inside radius (heated) and outside radius (cooled) of the disk at different rates of heat flow through the disk.

Equipment set-up
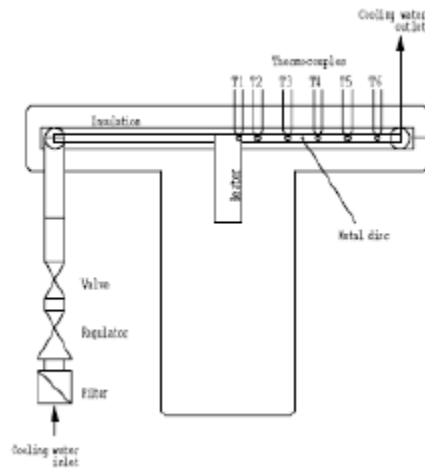
1) Place the HT12C Radial Heat Conduction accessory (1) alongside the HT10XC Heat Transfer Service Unit (19).

2) Connect the six thermocouples on the HT12C (18) to the appropriate sockets on the front of the service unit HT10XC (29). Ensure that the labels on the thermocouple leads (T1 - T6) match the labels on the sockets.

3) On the console, set the VOLTAGE CONTROL potentiometer (22) to minimum (anticlockwise) and the REMOTE/MANUAL selector switch (21) to MANUAL, then connect the heater lead from the HT12C (11) to the socket marked Output 2 at the rear of the service unit (35).

4) Connect the cold water flow control valve (13) to the socket marked AUXILIARY CONTROL (34) on the HT10XC console.

5) Connect the cold water flow rate sensor (7) to the socket marked Fw (36) on the HT10XC console

6) switch on the console (21) back to REMOTE.

7) Ensure that a cold water supply is connected to the inlet of the pressure regulating valve on HT12C (15). The water supply should be on.

8) Ensure that the flexible cooling water outlet tube is directed to a suitable drain.

9) Ensure that the service unit is connected to an electrical supply.

Theory/Background
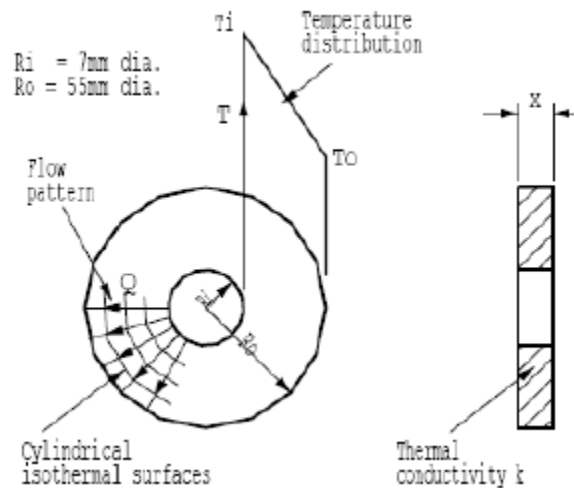
When the inner and outer surfaces of a cylinder are each at a different uniform temperature, heat flows radially through the wall of the cylinder.

The disk can be considered to be constructed as a series of successive layers as shown in the figure above.

From continuity considerations the radial heat flow through each of the successive layers in the wall must be constant if the flow is steady but since the area of the successive layers increases with radius, the temperature gradient must decrease with radius.

If a concentric layer (of thickness dR and radius R from the centre) in the wall of the cylinder is considered, the area of heat flow is $2\pi R$ for a unit length of cylinder.

The temperature gradient normal to the axis of the cylinder is dT/dR.

According to Fourier's law:

$Q = - 2\pi R k (dT/dR) L$

Since Q is independent of R, integration gives:

$Q \ln(R6/R1) = - 2\pi k (T6 - T1) L$ for heat flow through a unit length of the cylinder

(where R1 is the inside radius with corresponding temperature T1 and R6 is an outer radius corresponding to temperature T6).

Considering a cylinder of length x and rearranging the equation to eliminate the -ve sign gives:

$$Q = 2\pi \times k \frac{(T1 - T6)}{\ln(R6/R1)}$$

rearranging the equation gives:

$$k = \frac{Q * \ln(R6/R1)}{2\pi X * (T1\text{-}T6)}$$

The heat flow path in the HT12C consists of a cylinder 3.2 mm long (thickness of disk x) with inside radius R1 = 7 mm (where thermocouple T1 is located) and outer radius R6 = 50 mm (where thermocouple T6 is located).

The object of this exercise is to determine the conductivity of the disk material from measurements of temperature difference and heat flow through the cylindrical disk.

Procedure

1) Switch on the MAINS switch (21). (If the panel meters do not illuminate check the RCD at the rear of the service unit (35), the switch should be up.)

2) Check that the software indicates IFD OK in the bottom right hand corner of the software window on the computer screen.

3) Set the water flow rate to 1.5 liters/min in the control box on the mimic diagram on the computer screen.

4) Set the Heater Voltage to 12 Volts on the computer screen using the control box on the mimic diagram. If operating the equipment manually using the HT10XC console, set the upper display selector switch to V (volts) and observe the upper display panel while adjusting the AUXILIARY CONTROL knob.

5) Allow the HT12C to stabilize. Monitor the temperatures on the mimic diagram. If using the console, monitor the temperatures using the lower selector switch/meter (27/26).

6) When the temperatures are stable, Click the (GO) icon in the software window to save the set of results, or manually record the following if using the console:

7) T1, T2, T3, T4, T5, T6, V, I, Fw*

8) Set the heater voltage to 17 volts.

9) Allow the H12C to stabilize then repeat the above readings.

10) Set the Heater Voltage to 24 Volts.

11) Allow the HT12C to stabilize then repeat the above readings.

Recordable Data

For this exercise the raw data is tabulated under the following headings:

Data Set #	Heater Voltage 'V' (volts)	Heater Current 'I' (amperes)	TEMPERATURES (^{o}C)						Water Flow rate 'Fw' (liters / min)
			T1	T2	T3	T4	T5	T6	

Constants in the experiment

Radius where thermocouple T1 is located	R1 = 0.007	(m)
Radius where thermocouple T6 is located	R6 = 0.050	(m)
Thickness of disk (cylinder length)	x = 0.0032	(m)

Calculations

For each set of readings the following calculations are performed:

Quantity	Formula	Data set			Units
		1	2	3	
Heat flow (Power to heater)	Q=V * I				
Conductivity of the cylindrical disk material	$k=\dfrac{Q*\ln(R6/R1)}{2\pi X*(T1\text{-}T6)}$				

Summary of Results

Your summary of results must include the following

1. An estimation of the cumulative influence of the experimental errors on your calculated values for Q and k and measured values for R1, R6 and x.

2. Your results should give an approximate value of 125 W/m^{o}C for the thermal conductivity of Brass disk.

3. Compare the values obtained for the Thermal Conductivity of Brass at different settings of heat flow through the specimen.

4. Calculate the thermal conductivity of the Brass disk using two different radii and corresponding temperatures. Compare the value obtained with the original value at the same heat flow based on the maximum radial distance and the maximum temperature difference i.e. the values at R1,T1 and R6, T6. .

5. Plot a log/linear graph of radius on the logarithmic axis and temperature on the linear axis then draw the best straight line through the points. The result should be a straight line similar to the diagram below:
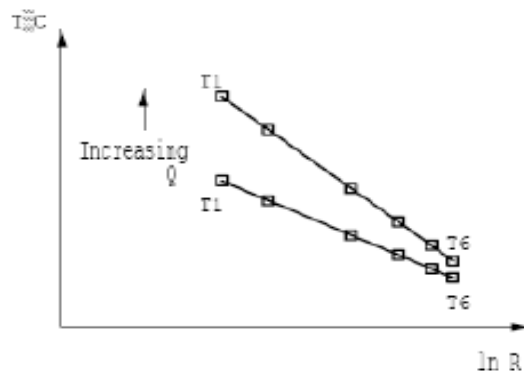
6. What observation do you make about the temperature profile as a function of the radial distance R? What is the effect of radial heat flow Q on the temperature gradient dT/d(ln R)?

Conclusions

Your conclusions must include the following:

1. How the Fourier rate equation can be applied to the radial flow of heat through a thick walled cylinder and how the conductivity of the material can be determined from the knowledge of the radial heat flow through the disk, the thickness of the disk and the change in temperature between two different radii in the disk.

2. Comment on the effect of measurement accuracy and heat loss from the equipment on your calculated results and any differences between the calculated results and those available in the literature.

Al-Imam Mohammad Ibn Saud Islamic University

Department of Mechanical Engineering

ME 325: HEAT TRANSFER LAB

Experiment No. 5: Contribution of convective and radiative coefficients to total heat transfer

Student's Name: _____

Student ID: _____

Date experiment is conducted: _____

Date lab report is submitted: _____

Instructor's Name: _____

Prepared by:

DR. SYED MUHAMMAD FAKHIR HASANI
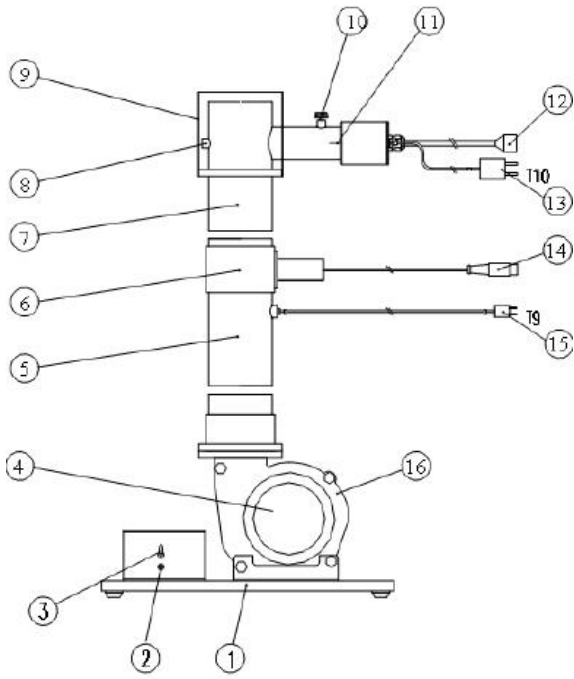
ENG. ABDULAZIZ AL-ASIRI
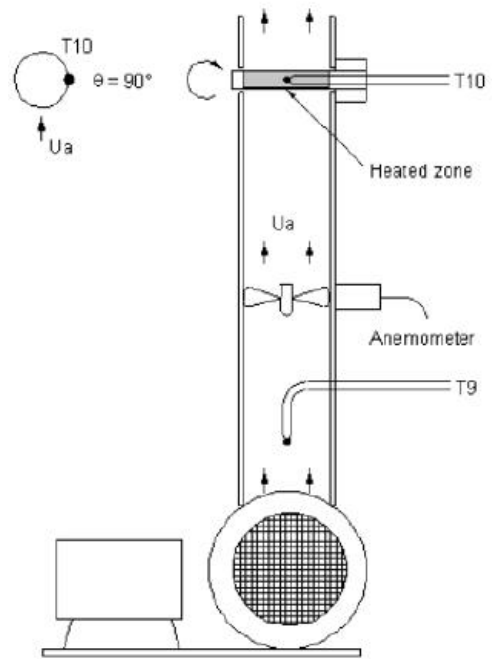
Figure 1 Front View of HT14C
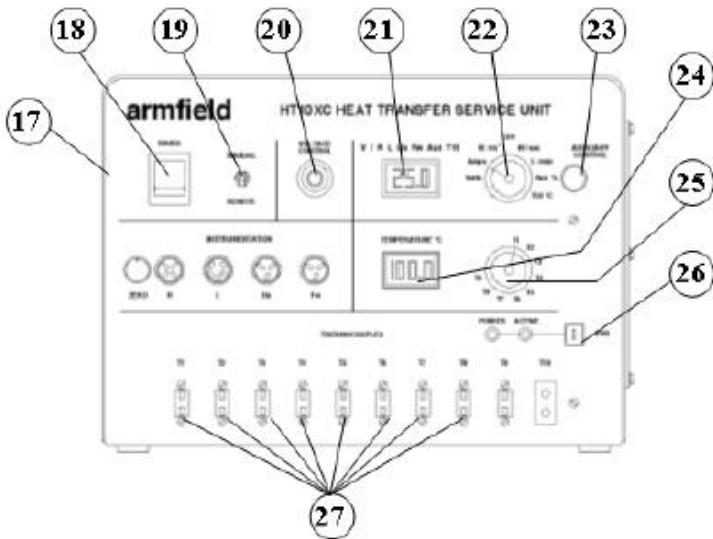

Figure 2 Side View of HT14C
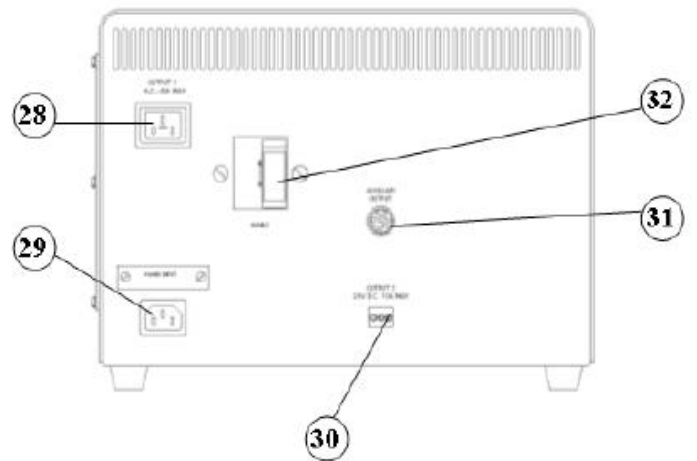

Figure 3 Front View of HT10XC

Figure 4 Rear View of HT10XC

Objective

To compare the contribution of heat transfer by convection with heat transfer by radiation and to show from the measurements the domination of the convective heat transfer coefficient H_c at low surface temperatures and the domination of the radiation heat transfer coefficient H_r at high surface temperatures.

Method

By measuring the temperature on the surface of a horizontal cylinder subjected to heat loss by combined natural convection and radiation. Compare the relative heat loss contributions of convection and radiation.

Equipment Required

Armfield Computer Compatible Heat Transfer Service Unit HT10XC

Armfield Combined Convection and Radiation Accessory HT14C

PC installed with Windows

Equipment set-up

1) Place the HT14C Combined Convection and Radiation accessory alongside the HT10XC Heat Transfer Service Unit on a suitable bench.

2) Ensure that the horizontal cylinder is located at the top of the metal duct with the thermocouple located on the side of the cylinder. (The cylinder can be rotated by releasing the thumb screw on the top of the mounting arrangement. Ensure that the thumb screw is securely tightened after adjustment.)

3) Connect the thermocouple attached to the heated cylinder to socket T10 on the front of the service unit.

4) Connect the thermocouple located in the vertical duct to socket T9 on the service unit.

5) Set the manual/remote selector switch on the console to MANUAL.

6) Set the VOLTAGE CONTROL potentiometer to minimum (anticlockwise) and the selector switch to MANUAL then connect the power lead from the heated cylinder on HT14C to the socket marked Output 2 at the rear of the service unit.

7) Ensure that the service unit is connected to an electrical supply.

8) Connect the HT10XC console to the PC via the USB socket, ensure that the manual/remote selector switch on the console is set to REMOTE, and run the HT14C software Exercise B.

Theory/Background

When a horizontal cylinder, with its surface at a temperature above that of its surroundings, is located in stationary air then heat loss from the cylinder will be a combination of natural convection to the air (air surrounding the cylinder becomes less dense and rises when it is heated) and radiation to the surroundings.

Note: Heat loss due to conduction is minimized by the design of the equipment and measurements mid way along the heated section of the cylinder can be assumed to be unaffected by conduction at the ends of the cylinder. Heat loss by conduction would normally be included in the analysis of a real application.

The heat transfer contributions due to natural convection and radiation can be determined as follows:

Total heat loss from the cylinder	$Q_{tot} = Q_c + Q_r$ where:
Heat loss due to natural convection	$Q_c = H_c A_s (T_s - T_a)$ and
Heat loss due to radiation	$Q_r = H_r A_s (T_s - T_a)$
Heat transfer area (surface area)	$A_s = (\pi d L)$

The heat transfer coefficients H_c and H_r can be calculated using the following relationships

$$H_c = 1.32 \frac{(T_s - T_a)^{0.25}}{d}$$ [Source: Heat Transmission by McAdams, 3rd ed. McGraw Hill, NY, 1959]

$$H_r = \sigma \varepsilon F \frac{(T_s^4 - T_a^4)}{(T_s - T_a)}$$

where:

σ = Stefan Boltzmann constant (= 5.67 x 10^{-8} Wm^{-2}K^{-4})

ε = Emmisivity of surface (=0.95)

F = Radiation View Factor (=1.0)

T_s = Surface temperature of cylinder (K)

T_a = Ambient temperature (K)

Actual power supplied to the heated cylinder Q_{in} = V I (Watts)

Procedure

1) Switch on the front Mains switch (if the panel meters do not illuminate check the RCD at the rear of the service unit, the switch should be up).

2) Set the Heater Voltage to 5 Volts. If using the HT14C software, adjust the heater setting using the control box on the mimic diagram screen. If operating the accessory manually using the console then set the heater voltage by adjusting the VOLTAGE CONTROL potentiometer to give a reading of 5 Volts on the top panel meter with the selector switch set to position V.

3) Allow the HT14C to stabilize. If using the software then monitor the surface temperature of the cylinder T10 on the mimic diagram screen. If operating the accessory manually then monitor T10 using the lower selector switch/meter on the console.

- When the temperatures are stable select the (GO) icon on the top software toolbar to record the following: T9, T10, V, I.

4) Set the Heater Voltage to 8 Volts.
5) Allow the HT14C to stabilize then repeat the above readings.
6) Set the Heater Voltage to 12 Volts.
7) Allow the HT14C to stabilize then repeat the above readings.
8) Set the Heater Voltage to 15 Volts.
9) Allow the HT14C to stabilize then repeat the above readings.
10) Set the Heater Voltage to 20 Volts.
11) Allow the HT14C to stabilize then repeat the above readings.

CAUTION: Do not set the heater voltage in excess of 20 Volts when operating the cylinder in natural convection (no forced airflow). The life of the heating element will be considerably reduced if operated at excessive temperature.

Recordable Data

Measured Quantity	Units	Data Set #1	Data Set #2	Data Set #3	Data Set #4	Data Set #5
Heater Voltage (V)	Volts					
Heater Current (I)	Amps					
Upstream Air Temp. (T9)	°C					
Upstream Air Temp. (T9)	K					
Cylinder Surface Temp. (T10)	°C					
Cylinder Surface Temp. (T10)	K					

Constants in the Experiment

For this exercise the following constants are applicable:

Diameter of cylinder *d* = 0.01 (m)

Heated length of cylinder *L* = 0.07 (m)

Calculations

For each set of readings the the following calculations are performed:

Heater Surface Area $(A_s) = \pi dL =$

Quantity	Formula	Units	Data Sets				
			1	2	3	4	5
Heat Flow (Power to Heater	$Q_{in}=V\,I$						
Natural convection heat transfer coefficient	$H_c = 1.32\dfrac{(T_s - T_a)^{0.25}}{d}$						
Radiation heat transfer coefficient	$H_r = \sigma\varepsilon F\dfrac{(T_s^4 - T_a^4)}{(T_s - T_a)}$						
Heat transferred by natural convection	$Q_c=H_c\,A_s\,(T_s - T_a)$						
Heat transferred by radiation	$Q_r=H_r\,A_s\,(T_s - T_a)$						
Total heat transferred	$Q_{tot} = Q_c + Q_r$						

Summary of Results

Your summary of results must include the following:

1. An estimation of the cumulative influence of the experimental errors on your calculated values for A_s, H_c, H_r, Q_c, Q_r, Q_{tot} and Q_{in} and measured values for T9, T10, L and D.

2. A comparison of the calculated heat transfer due to convection Q_c with the calculated heat transfer due to radiation Q_r by plotting graphs of H_c and H_r against the surface temperature $T_s = T_{10}+273$

   Your graph should be similar to the diagram below:
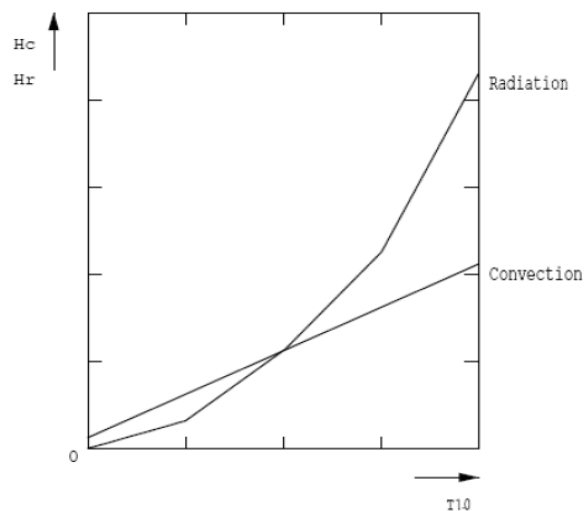
Conclusions

Your conclusions must include the following:

1. How natural convection and radiation affect the total heat loss from a hot surface.
2. How the temperature difference between the hot surface and ambient air/ surroundings affect the convective, radiative and total heat transfer values.
3. What conclusions can you draw from the above graph?

Al-Imam Mohammad Ibn Saud Islamic University

Department of Mechanical Engineering

ME 325: HEAT TRANSFER LAB

Experiment No. 6: Forced Convection Heat Transfer

Student's Name: _____

Student ID: _____

Date experiment is conducted: _____

Date lab report is submitted: _____

Instructor's Name: _____

Format developed by:

DR. SYED MUHAMMAD FAKHIR HASANI
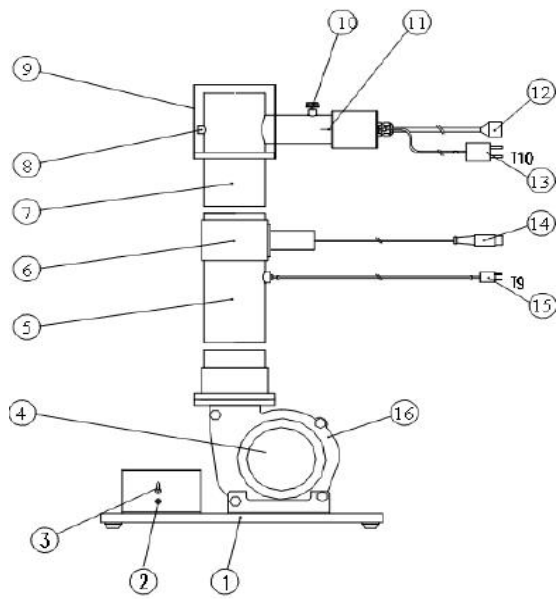
ENG. ABDULAZIZ AL-ASIRI

Figure 1 Front View of HT14C
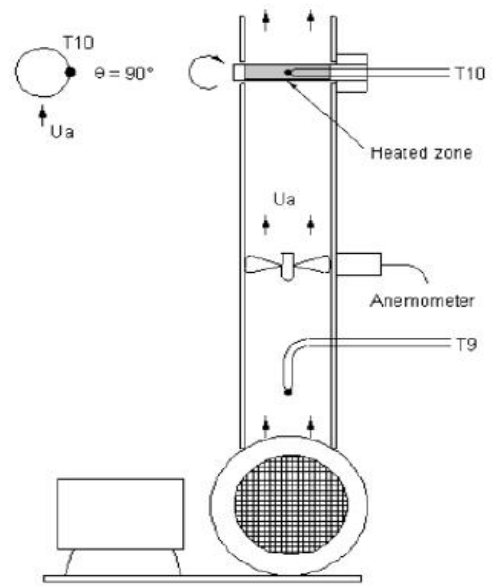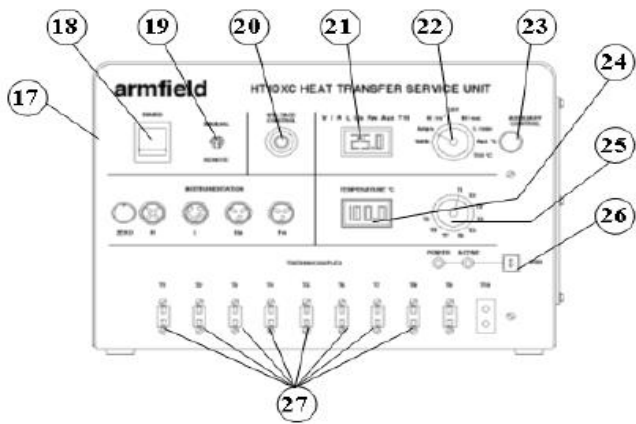

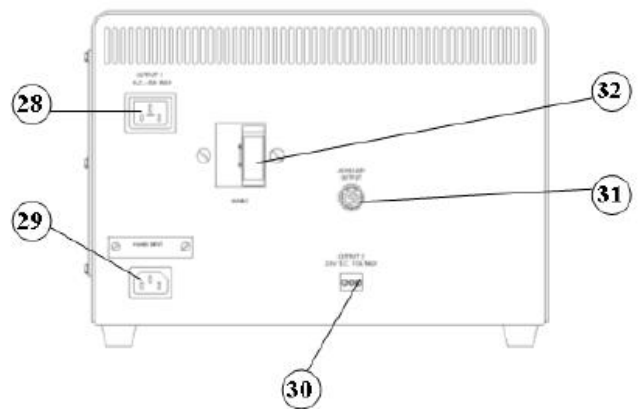Figure 2 Side View of HT14C

Figure 3 Front View of HT10XC

Figure 4 Rear View of HT10XC

Objective

To study forced convection heat transfer from the surface of a hot cylinder by varying the air velocity.

To demonstrate the relationship between air velocity and surface temperature for a cylinder subjected to forced convection.

Method

The temperatures on the surface of a horizontal cylinder subjected to heat loss by combined radiation and forced convection are measured and then compared with the results obtained from a theoretical analysis.

Equipment Required

HT14C Combined Convection and Radiation Accessory

HT10XC Computer Compatible Heat Transfer Service Unit

PC installed with Windows

Equipment set-up

1) Place the HT14C Combined Convection and Radiation accessory alongside the HT10XC Heat Transfer Service Unit on a suitable bench.
2) Ensure that the horizontal cylinder is located at the top of the metal duct with the thermocouple located on the side of the cylinder (the cylinder can be rotated by releasing the thumb screw on the top of the mounting arrangement. Ensure that the thumb screw is securely tightened after adjustment).
3) Connect the thermocouple attached to the heated cylinder to socket T10 on the front of the service unit.
4) Connect the thermocouple located in the vertical duct to socket T9 on the service unit.
5) Set the manual/remote selector switch on the console to MANUAL.
6) Set the VOLTAGE CONTROL potentiometer to minimum (anticlockwise) and the selector switch to MANUAL, then connect the power lead from the heated cylinder on HT14C to the socket marked Output 2 at the rear of the service unit.
7) Ensure that the service unit is connected to an electrical supply.
8) Connect the HT10XC console to the PC via the USB socket, ensure that the manual/remote selector switch on the console is set to REMOTE, and run the HT14C software Exercise C.
9) Connect the main lead from the fan (terminated at the connection box alongside the fan) to the socket marked Output 1 at the rear of the HT10XC service unit.
10) Connect the lead from the anemometer in the vertical duct to the socket marked Ua on the front of the HT10XC service unit.

Theory/Background

In free/natural convection the heat transfer rate from a surface is limited by the small movements of air which are generated by changes in the density of the air as the air is heated by the surface. In forced convection the air movement can be greatly increased resulting in improved heat transfer rate from a surface. Therefore a surface subjected to forced convection will have a lower surface temperature than the same surface subjected to free convection, for the same power input.

If a surface, at a temperature above that of its surroundings, is located in moving air at the same temperature as the surroundings then heat will be transferred from the surface to the air and the surroundings. This transfer of heat will be a combination of forced convection to the air (heat is transferred to the air passing the surface) and radiation to the surroundings. A horizontal cylinder is used in this exercise to provide a simple shape from which the heat transfer can be calculated.

Note: Heat loss due to conduction is minimized by the design of the equipment and measurements mid way along the heated section of the cylinder can be assumed to be unaffected by conduction at the ends of the cylinder. Heat loss by conduction would normally be included in the analysis of a real application.

Total heat loss from the cylinder	$Q_{tot} = Q_{fm} + Q_{rm}$ where:
Heat loss due to forced convection	$Q_f = Hf_m \, A \, (T_s - T_a)$ and
Heat loss due to radiation	$Q_r = Hr_m \, A \, (T_s - T_a)$
Heat transfer area	$A = (\pi \, D \, L)$

The heat transfer coefficients Hf_m due to forced convection and Hr_m due to radiation can be calculated using the following relationships:

$$Hr_m = \sigma \varepsilon F \frac{\left(Ts^4 - Ta^4\right)}{\left(Ts - Ta\right)}$$

σ = Stefan Boltzmann constant (= 5.67×10^{-8} Wm^{-2} K^{-4})

ε = Emissivity of surface (=0.95)

F = Radiation View Factor (=1 for this geometry)

Ts = Surface temperature of cylinder (K)

Ta = Ambient temperature (K)

$$Hf_m = \frac{k}{D} Nu_m$$

(Wm-2K-1)

where:

k = conductivity of the air (Wm^{-1}K^{-1})

D = diameter of the cylinder (m)

Nu_m = Average Nusselt number (Dimensionless)

An empirical formula can be used to calculate the value for Nu_m as follows:

$$Nu_m = 0.3 + \frac{\left(0.62\,Re^{0.5}\,Pr^{0.33}\right)}{\left[1+\left(\frac{0.4}{Pr}\right)^{0.66}\right]^{0.25}}\left(1+\left(\frac{Re}{282000}\right)^{0.5}\right)$$

(dimensionless)

where:

Re = Reynolds number = Uc D / v (dimensionless)
Pr = Prandtl number for air (dimensionless)
Uc = Corrected air velocity (m/s)

Corrected air velocity Uc = 1.22 Ua (m/s)

(The cylinder causes a blockage in the duct resulting in a local increase in the air velocity.)

Values for k, v and Pr depend on the temperature of the air and can be found using the table included in the HT14C teaching manual.

The actual power supplied to the heated cylinder Q_{in} = V I (W)

Procedure

1) Switch on the front Mains switch (if the panel meters do not illuminate check the RCD at the rear of the service unit, the switch should be up).
• If controlling the accessory manually using the console then set the upper selector switch on HT10XC to position Ua to indicate the air velocity in the duct.
2) Start the centrifugal fan by pressing the switch on the connection box. Set the fan to give an air flow rate of 0.5 m/s. If using the software then the fan speed may be set using the control box on the mimic diagram screen. If operating the accessory manually then the fan speed may be adjusted using the AUXILIARY CONTROL knob to give a reading of 0.5 m/s on the top panel meter with the selector switch set to m/s.
3) Set the Heater Voltage to 20 Volts. If using the software then the heater may be controlled using the control box on the mimic diagram screen. If operating the accessory manually using the HT10XC console then adjust the VOLTAGE CONTROL potentiometer to give a reading of 20 Volts on the top panel meter with the selector switch set to position V.

4) Allow the HT14C to stabilize. If using the software then monitor the temperature T10 on the mimic diagram screen. If operating the accessory manually then monitor the surface temperature of the cylinder T10 using the lower selector switch/meter on the HT10XC console.
5) When the temperatures are stable select the (GO) icon on the top toolbar to record the following: Ua, T9, T10, V, I.
- If operating the accessory manually then record these values from the HT10XC console using the display meters/switches to select each required value.
- Adjust the fan to give an air velocity of 1.0 m/s.
6) Allow the HT14C to stabilize then repeat the above readings.
7) Repeat the above procedure changing the air velocity in steps of 1.0 m/s until the air velocity is 7.0 m/s.

Recordable Data

Record the data in the following table

Measured Quantity	Units	Data Set							
		1	2	3	4	5	6	7	8
Heater Voltage (V)	Volts								
Heater Current (I)	Amps								
Air Velocity (Ua)	m/s								
Corrected Air Velocity (Uc=1.22*Ua)	m/s								
Upstream Air Temp. (T9)	°C								
Upstream Air Temp. (T9)	K								
Cylinder Surface Temp. (T10)	°C								
Cylinder Surface Temp. (T10)	K								

Constants in the experiment

For this exercise the following constants are applicable:

Diameter of cylinder D = 0.01 (m)

Length of cylinder L = 0.07 (m)

Calculations

For each set of readings the the following calculations are performed:

Heater Surface Area (A$_s$) = πDL =

Heat Flow (Power to Heater) 'Q$_{in}$' = V I

Quantity	Formula	Units	Data Sets							
			1	2	3	4	5	6	7	8
Corrected air velocity (U$_C$)	U$_C$ = 1.22 * U$_a$									
Reynolds number (Re)	Re = Uc D / ν (Table in Appendix)									
Prantdl number (Pr)	Table in Appendix									
Nusselt number (Nu$_m$)	Empirical eqn. given in theory section									
Forced convection heat transfer coefficient	$Hf_m = \dfrac{k}{D} Nu_m$ (Table in Appendix)									
Radiation heat transfer coefficient	$Hr_m = \sigma \varepsilon F \dfrac{(T_s^4 - T_a^4)}{(T_s - T_a)}$									
Heat transferred by natural convection	Q$_f$=Hf$_m$ A$_s$ (T$_s$ – T$_a$)									
Heat transferred by radiation	Q$_r$=Hr$_m$ A$_s$ (T$_s$ – T$_a$)									
Total heat transferred	Q$_{tot}$ = Q$_f$ + Q$_r$									

Summary/Discussion of Results

Your summary/discussion of results must include the following:

1. Estimate the cumulative influence of the experimental errors on your calculated values for U$_c$, A$_s$, Hf$_m$, Hr$_m$, Q$_f$, Q$_r$, Q$_{tot}$ and Q$_{in}$ and measured values for Ua, T9 and T10.
2. Compare the theoretical value obtained for Q$_{tot}$ with the measured value for Q$_{in}$ and explain any difference in the two values.
3. Compare the calculated heat transfer due to forced convection Q$_f$ and radiation Q$_r$.
4. Plot a graph of surface temperature T10 against corrected air velocity Uc. Your graph should be similar to the diagram below:
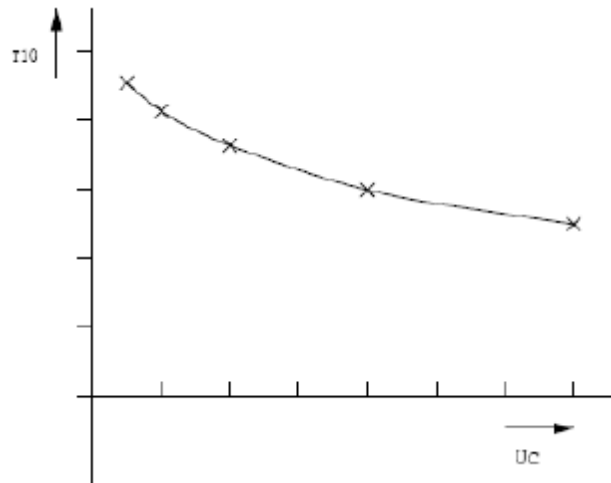
5. Plot a graph of Hf_m and Hr_m versus corrected air velocity U_C.
6. Discuss what happens to the surface temperature of the cylinder as the air velocity increases for a fixed heat input Q_{in}.
7. Explain why the surface temperature decreases more rapidly at low air velocities and less rapidly at high air velocities.
8. Discuss the possible sources of error in the experiment.

Conclusions

Your conclusions must include the following:

1. How the forced convection and radiation heat transfer affect the total heat transfer.
2. How the air velocity affect the surface temperature and the total heat transfer.
3. How the air velocity affect the respective convective and radiative contributions to total heat transfer.

Appendix

Table of physical properties for air at atmospheric pressure

T_{film}(K)	ν (m^{2}s^{-1})	k (Wm^{-1}K^{-1})	Pr (dimensionless)
300	1.684×10^{-5}	0.02624	0.708
350	2.076×10^{-5}	0.03003	0.697
400	2.590×10^{-5}	0.03365	0.689
450	3.171×10^{-5}	0.03707	0.683
500	3.790×10^{-5}	0.04038	0.680
550	4.434×10^{-5}	0.04360	0.680
600	5.134×10^{-5}	0.04659	0.680

Al-Imam Mohammad Ibn Saud Islamic University

Department of Mechanical Engineering

ME 325: HEAT TRANSFER LAB

Experiment No. 8: The Stefan-Boltzmann Law

Student's Name: _____

Student ID: _____

Date experiment is conducted: _____

Date lab report is submitted: _____

Instructor's Name: _____

Format developed by:

DR. SYED MUHAMMAD FAKHIR HASANI

ENG. ABDULAZIZ AL-ASIRI

Objective

To demonstrate the validity of the Stefan Boltzmann Law by showing that the intensity of radiation varies as the fourth power of the source temperature (T_o).

Method

By measuring the thermal radiation received by the radiometer at a fixed distance from the heat source with the source at different surface temperatures.

Equipment Required

HT13 Laws of Radiant Heat Transfer and Radiant Heat Exchange accessory
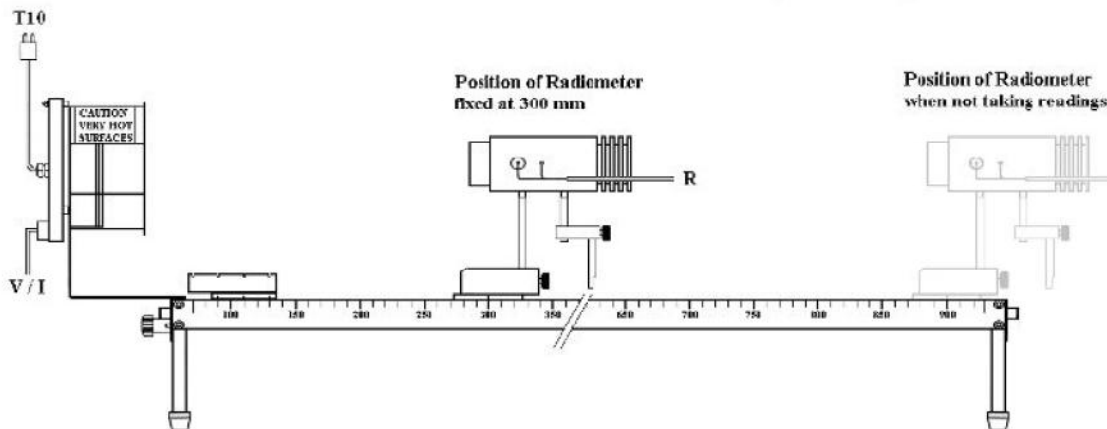
HT10XC Computer Compatible Heat Transfer Service Unit

PC installed with Windows

Note: If required, the black heated plate may be sooted to ensure that the surface finish has an emissivity close to unity. The plate should be masked using cardboard then held above a candle and moved around until the surface is uniformly covered with soot.

The heated plate may be used unsooted but the emissivity will be slightly less than unity.

Equipment Setup

Before proceeding with the exercise ensure that the equipment has been prepared as follows:

Place the HT13 'Laws of Radiant Heat Transfer and Radiant Heat Exchange' accessory alongside the HT10XC Heat Transfer Service Unit. If not already fitted, attach the heated plate to the left hand end of the track. Ensure the bracket is located on the dowels then secure it using the thumb screw. Attach the radiometer to the right hand carriage using the front mounting rod and secure it using the thumb screw. Position the carriage with the radiometer at a distance of 900mm from the heated plate. Connect the lead from the radiometer to the socket marked R on the front of the HT10XC service unit. Allow the radiometer to stabilize at room temperature (reading on top panel meter steady with selector switch set to position R) then adjust the zero potentiometer (adjacent to the socket marked R on the front of HT10XC) until the reading on HT10XC is zero. Connect the thermocouple on the heated plate to the socket marked T10 on the front of the service unit.

1. Connect the thermocouple on the polished plate to the socket marked T9 on the front of the service unit and place the plate in a suitable location adjacent to the equipment where it will not be subjected to sources of radiation (the plate will be used to provide a measurement of the ambient temperature of the surroundings Ta).

2. Set the VOLTAGE CONTROL potentiometer to minimum (anticlockwise) and the manual/remote selector switch to MANUAL then connect the power lead from the heated plate on the HT13 to the socket marked OUTPUT 2 (HT10XC) at the rear of the service unit.

3. Ensure that the service unit is connected to an electrical supply.

Theory

The Stefan-Boltzmann Law states that for a black body:

$$q_b = \sigma \, (Ts^4 - Ta^4)$$

where:

q_b = Energy emitted by unit area of a black body surface (Wm^{-2})

σ = Stefan Boltzmann constant (= $5.67 \times 10^{-8} \, Wm^{-2}K^{-4}$)

Ts = Surface temperature of heated plate (K)

Ta = Temperature surroundings including radiometer (K)

If the distance between the heat source and the radiometer is fixed then the reading on the radiometer will be related to the radiation emitted from the plate by a constant factor F. ($F=q_b/R$). This factor F should remain constant if the Stefan Boltzmann relationship is satisfied, i.e. q_b is related to the fourth power of the temperatures.

Procedure

CAUTION: The heat source used in this exercise will become extremely hot in operation. Take care not to burn yourself on the hot surfaces.

1. Switch on the front Mains switch. (If the panel meters do not illuminate check the RCD at the rear of the service unit, the switch should be up.)

2. If operating the equipment remotely from a PC, check that the PC is connected to the HT10XC console via the USB socket. Set the manual/remote selector switch to REMOTE. Check that the USB indicator lights on the console are both lit, and run the HT13 software. (if operating the equipment manually using the HT10XC console then leave the selector switch set to MANUAL).

3. Set the Heater Voltage to 4 Volts. If operating remotely using a PC then set the heater voltage using the control box on the software mimic diagram screen. If operating manually from the HT10XC console then adjust the VOLTAGE CONTROL potentiometer to give a reading of 4 Volts on the top panel meter with the selector switch set to position V.

4. Allow the HT13 to stabilize. If operating with a PC then monitor temperature T10 on the software screen. If operating manually using the HT10XC console then monitor temperature T10 using the lower selector switch/meter. When the temperature of the plate is almost stable, move the radiometer to a position 300 mm away from the plate (move the carriage, do not hold the radiometer body).

5. Allow the radiometer to stabilize (approximately 90 seconds). Monitor temperature T10 and radiometer R on the software screen (or, if operating manually, monitor T10 using the lower selector switch/meter and the radiometer R using the upper selector switch/meter).

6. When T10 and R are stable select the 'Go' icon on the software toolbar to record the following:

   Temperature of heated plate T10 ($^{\circ}$C)

   Temperature of surroundings T9 ($^{\circ}$C)

   Radiometer reading R (m)

7. If operating the equipment manually using the HT10XC console then use the upper and lower selector switches to display each required variable, and manually record the values.

8. Move the radiometer away from the heated plate to the far end of the track (to avoid heating of the radiometer body). Set the Heater Voltage to 8 Volts. Wait for the temperature of the plate T10 to stabilize then move the radiometer back to the 300mm position.

9. Allow the reading from the radiometer to stabilize then record T10 and R.

10. Repeat the procedure, increasing the voltage to the heated plate in steps of 4 Volts until the Heater Voltage is set to 24 Volts. (The radiometer must be moved away from the

heat source and returned to the 300mm position for each reading to avoid heating of the radiometer body.)

11. After taking the last reading move the radiometer to the far end of the track (away from the heated plate) and set the Heater Voltage to zero.

CAUTION: As the heat source will be extremely hot following operation DO NOT attempt to remove it from the end of the track until it has cooled sufficiently.

Recordable Data

Dimensionless radiometer correction factor 'C' =

Note: A calibration factor is supplied with the radiometer to give improved accuracy of results. Each radiometer reading can be corrected as follows:

C = 30.12/calibration factor

Corrected radiometer reading R_c (Wm^{-2}) = R . C

Assume C = 1 if correction factor is not available.

Quantity	Units	Data set					
		1	2	3	4	5	6
Heater Voltage (V)	volts						
Heater current (I)	amps						
Temperature of heated plate (Ts)	(T10) °C						
Temperature of surroundings (Ta)	(T9) °C						
Distance from the heated plate (x)	meters						
Radiometer reading (R)	Wm^{-2}						

Calculations

$\sigma = 5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$

Quantity	Formula	Data Set					
		1	2	3	4	5	6
Temperature of heated plate (Ts) (K)	T10 +273						
Ts^4 $(K)^4$	$(T10+273)^4$						
Temperature of surroundings (Ta) (K)	T9 +273						
Ta^4 $(K)^4$	$(T9+273)^4$						
Net Blackbody radiation flux($q_b{}''$) (Wm^{-2})	$\sigma\ (Ts^4 - Ta^4)$						
Corrected radiometer reading (Wm^{-2})	R_c						
Fraction of radiation flux received at radiometer 'F' – (dimensionless)	$q_b{}''/R_c$						

Discussion/Summary of Results

Your discussion/summary of results must include the following:

1. An Estimation of the cumulative influence of the experimental errors on your calculated values for Ts^4, Ta^4, $q_b{}''$ and F.

2. A Comparison of the value obtained for F at different surface temperatures of the heated black plate and comment on the validity of the Stefan Boltzmann relationship.

Conclusion

Conclusion must include an statement indicating the validity of the Stefan Boltzmann Law within the experimental constraints and the fact that small experimental errors in the measurements become significant when raised to the fourth power.

Al-Imam Mohammad Ibn Saud Islamic University

Department of Mechanical Engineering

ME 325: HEAT TRANSFER LAB

Experiment No. 9: Emissivity of Radiating Surfaces

Student's Name: _____

Student ID: _____

Date experiment is conducted: _____

Date lab report is submitted: _____

Instructor's Name: _____

Format developed by:

DR. SYED MUHAMMAD FAKHIR HASANI

ENG. ABDULAZIZ AL-ASIRI

Objective

To determine the emissivity of radiating surfaces with different finishes, namely polished and grey (silver anodized) compared with matt black.

Method

By comparing the thermal radiation received by the radiometer from target plates with different surface finishes which are heated by radiation from the heat source.

Equipment Required

- HT13 Laws of Radiant Heat Transfer and Radiant Heat Exchange accessory
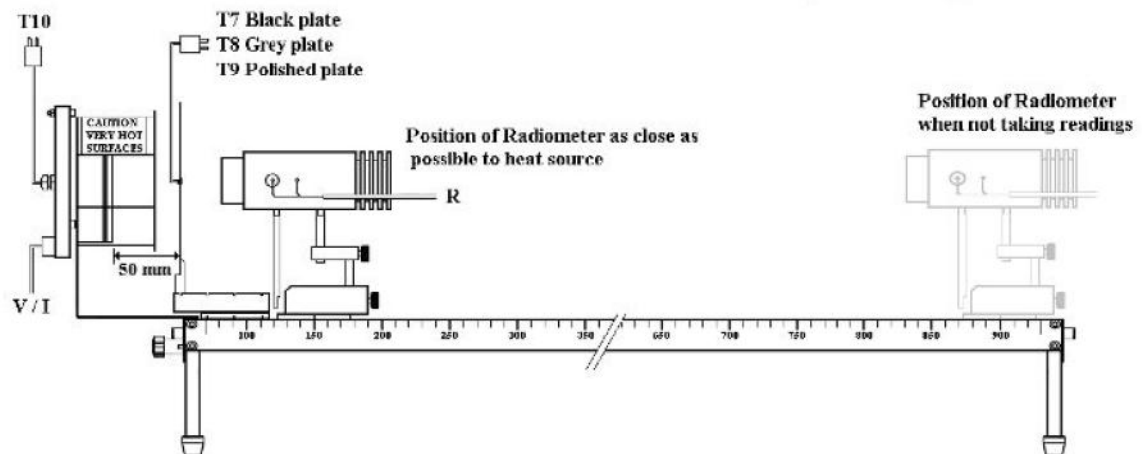
- HT10XC Computer Compatible Heat Transfer Service Unit

Note: If required, the black plate used for this demonstration may be sooted to ensure that the surface finish has an emissivity close to unity. The plate should be held above a candle and moved around until the surface is uniformly covered with soot.

The plate may be used unsooted but the emissivity will be slightly less than unity.

- PC installed with Windows software.

Equipment Setup

Before proceeding with the exercise ensure that the equipment has been prepared as follows:

1. Place the HT13 'Laws of Radiant Heat Transfer and Radiant Heat Exchange' accessory alongside the HT10XC Heat Transfer Service Unit.

2. If not already fitted, attach the heated plate to the left hand end of the track. Ensure the bracket is located on the dowels then secure it using the thumb screw.

3. Attach the radiometer to the right hand carriage using the rear mounting rod and secure it using the thumb screw.

4. Position the carriage with the radiometer at a distance of 900mm from the heated plate. Connect the lead from the radiometer to the socket marked R on the front of the HT10XC service unit. Allow the radiometer to stabilize at room temperature (reading on top panel meter steady with selector switch set to position R) then adjust the zero potentiometer (adjacent to the socket marked R on the front of HT10XC) until the reading on HT10XC is zero.Connect the thermocouple on the heated plate to the socket marked T10 on the front of the service unit.

5. Attach the plate holder to the left hand carriage and position the carriage with the left hand index mark 70 mm from the heated plate.

6. Locate one of the blackened plates in the left hand slot of the plate holder (closest to the heated plate).

7. Connect the thermocouple on the blackened plate to the socket marked T7 on the front of the service unit.

8. Connect the thermocouple on the polished plate to the socket marked T9 on the front of the service unit and place the plate in a suitable location adjacent to the equipment where it will not be subjected to sources of radiation (the plate will be used to provide a measurement of the ambient temperature of the surroundings Ta).

9. Set the VOLTAGE CONTROL potentiometer to minimum (anticlockwise) and the selector switch to MANUAL then connect the power lead from the heated plate on the HT13 to the socket marked OUTPUT 2 (HT10XC) at the rear of the service unit.

10. Ensure that the service unit is connected to an electrical supply.

Theory

The Stefan-Boltzmann Law states that:

$q_b{}'' = \varepsilon\, F\, \sigma\, (Ts^4 - Ta^4)$ where ε is the emissivity of the radiating surface and $\varepsilon=1$ for a black body.

The view factor F can be determined using the blackened plate

where $\varepsilon \approx 1$ and $F = q_b{}''/R$

then for the non-black plates: $\varepsilon = \dfrac{R_{pc}}{\sigma(T_p^4 - T_a^4)F}$

where:

$q_b'' =$ Energy emitted by unit area of a black body surface (Wm^{-2})

$q_n'' =$ Energy emitted by unit area of a non-black body surface (Wm^{-2})

$\sigma =$ Stefan Boltzmann constant ($\sigma = 5.67 \times 10^{-8}$ Wm^{-2}K^{-4})

$T_s =$ Surface temperature of black body (K)

$T_a =$ Temperature of radiometer and its surroundings (K)

$T_p =$ Surface temperature of metal plate (K)

$\varepsilon =$ Emissivity of radiating surface (Dimensionless)

$R =$ Reading from radiometer (Wm^{-2})

$F =$ View factor (Dimensionless)

Procedure

1. Switch on the front Mains switch. (If the panel meters do not illuminate check the RCD at the rear of the service unit, the switch should be up.)

2. If operating the equipment remotely from a PC, check that the PC is connected to the HT10XC console via the USB socket. Set the manual/remote selector switch to REMOTE. Check that the USB indicator lights on the console are both lit, and run the HT13 software. (if operating the equipment manually using the HT10XC console then leave the selector switch set to MANUAL).

3. Set the Heater Voltage to 20 Volts. If operating remotely using a PC then set the heater voltage using the control box on the software mimic diagram screen. If operating manually from the HT10XC console then adjust the VOLTAGE CONTROL potentiometer to give a reading of 20 Volts on the top panel meter with the selector switch set to position V.

4. Allow the HT13 to stabilize. If using a computer then monitor the temperatures T7 and T10 on the software screen. If operating the equipment manually using the HT10XC console then monitor temperatures T10 and T7 using the lower selector switch/meter. When the temperature T7 of the blackened metal plate is almost stable, move the radiometer as close as possible to the heated plate (move the carriage, do not hold the radiometer body).

5. Allow the radiometer reading to stabilize for approximately 90 seconds. If using the computer then monitor temperature T7 and the radiometer output R on the software screen. If operating the equipment manually then monitor T7 on the HT10XC console using the lower selector switch/meter, monitor the radiometer R using the upper selector switch/meter.

6. When T7 and R are stable select the 'Go' icon on the software toolbar to record the following:

   Temperature of heat source (constant) T10 (^{o}C)
   Temperature of surroundings (constant) T9 (^{o}C)
   Temperature of blackened plate T7 (^{o}C)
   Radiometer reading R (Wm^{-2}K^{-4})

7. If operating the equipment manually then use the upper and lower selector switches to display each required variable on the console, and record the values.
8. Move the radiometer away from the blackened plate to the far end of the track (to avoid heating of the radiometer body).

9. Carefully remove the hot blackened plate taking care not to burn yourself. Place the plate in a safe location.

10. Place the grey plate (anodized aluminum) in the left hand slot of the plate carrier then connect the thermocouple to socket T8 on the HT10XC.

11. Allow the HT13 to stabilize. If using a computer then monitor the temperatures T8 and T10 on the software screen. If operating the equipment manually, then monitor temperatures T10 and T8 using the console selector switches/displays. When the temperature of the grey metal plate is almost stable, move the radiometer as close as possible to the heated plate (move the carriage, do not hold the radiometer body).

12. Allow the radiometer reading to stabilize then record T10, T8 and R.

13. After taking the last reading move the radiometer to the far end of the track (away from the heated plate) and set the Heater Voltage to zero.

CAUTION: As the heat source will be extremely hot following operation DO NOT attempt to remove it from the end of the track until it has cooled sufficiently.

Recordable Data

Heater voltage (V) =   Heater Current (I) =

Quantity	Units	Exp. with black plate	Exp. with grey plate
Temperature of the heated plate	^{o}C	T10 =	T10 =
Temperature of surroundings (T_a)	^{o}C	T9 =	T9 =
Temperature of the black plate (T_s)	^{o}C	T7 =	------
Temperature of the grey plate (T_p)	^{o}C	------	T8 =
Distance from the heated plate (x)	meters		
Radiometer reading	Wm^{-2}	R_b =	R_p =

Calculations

Note: Each reading using the radiometer can be corrected as follows:

Radiometer correction factor C (Dimensionless)

Corrected radiometer reading (= R.C) R_c (Wm^{-2})

Note: A calibration factor is supplied with the radiometer to give improved accuracy of results. Assume C = 1 if correction factor is not available.

C = 30.12/calibration factor

$\sigma = 5.67 \times 10^{-8}$ Wm^{-2}K^{-4}

Quantity	Formula	
Temperature of black plate (Ts) ~ K	T7 +273	
$Ts^4 \sim (K)^4$	$(T7+273)^4$	
Temperature of surroundings (Ta) ~ K	T9 +273	
$Ta^4 \sim (K)^4$	$(T9+273)^4$	
Net Blackbody radiation flux($q_b^{''}$) ~ Wm^{-2}	$\sigma\,(Ts^4 - Ta^4)$	
Corrected radiometer reading for black plate ~ Wm^{-2}	R_{bc}	
Fraction of radiation flux received at radiometer 'F' ~ (dimensionless)	$q_b^{''}/R_{bc}$	
Temperature of black plate (Tp) ~ K	T8 +273	
$Tp^4 \sim (K)^4$	$(T8+273)^4$	
Corrected radiometer reading for grey plate ~ Wm^{-2}	R_{pc}	
Emissivity of grey plate	$\varepsilon = \dfrac{R_{pc}}{\sigma(T_p^4 - T_a^4)F}$	

Discussion and Summary of Results

Estimate the cumulative influence of the experimental errors on your calculated values for F, Tp and ε.

Observe that the temperature of the heat source changes when plates of different emissivity are placed in front of it. Explain the changes in the temperature of the heat source.

Conclusion

The emissivity of the grey plate is found to be _____