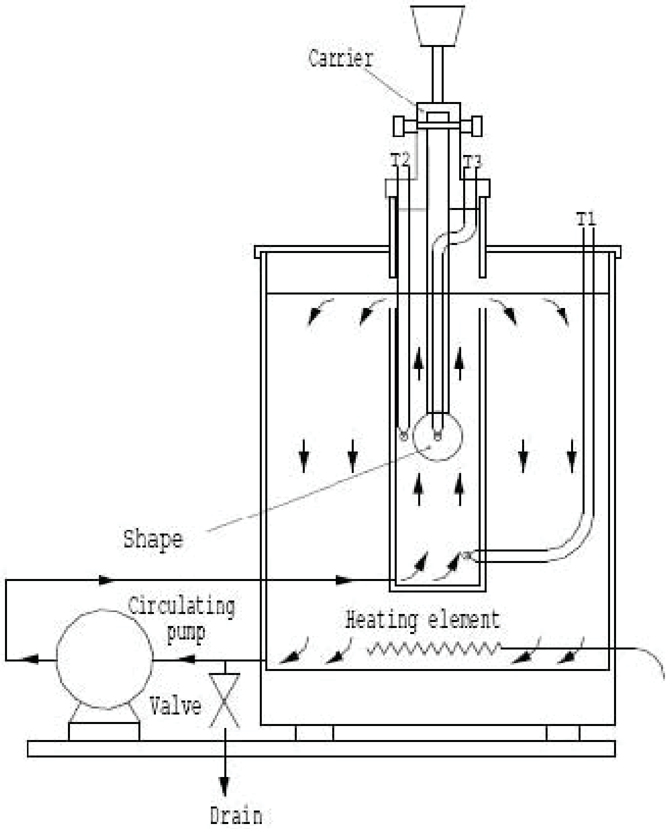


Note: The voltage control potentiometer is used to set the speed of the circulating pump on this equipment NOT the power to the heating element.

Connect the power lead from the water bath (terminated at the connection box alongside the heating tank) to an electrical supply.

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

Connect the HT10X/HT10XC service unit to the PC using the USB cable provided, and run the HT17 software. Select Exercise A.

Click on the ‘Sample’ menu from the top toolbar, and select ‘Configure…’

In the Sample Configuration menu that appears, check that Sampling Operation is set to Automatic with a Sample Interval of 1 secs and Continuous duration. Change the settings if required. Close the Sample Configuration window by selecting ‘OK’.

Place the various shapes in a suitable location where the metal bodies can stabilize at room temperature. If laboratory stands/clamps are available then the shapes can be suspended from the stands via the insulated rod attached to each shape.

Always pick up the metal shapes via the insulated rod. Heat transferred to the shape by holding in the hand will delay the stabilization of the shape at a uniform temperature.

Note: Since the water bath will take approximately 40 minute to heat to the required temperature it is suggested that this is switched on immediately as described in the Procedure section.

Theory/Background

This exercise is qualitative only and intended to show the transient/time-dependent behaviour of a system where temperature varies with time and position. This condition, referred to as unsteady-state, exists when a solid shape is immersed in the hot water and continues until the whole of the shape reaches equilibrium with the temperature of the water.

When the step change is applied a temperature gradient exists between the surface of the shape at the water temperature and the centre of the shape which is at ambient temperature. Heat flows by conduction through the shape until the whole of the shape is at the same temperature as the water.

Note: The plots of temperature versus time obtained in this exercise can be used in later exercises to perform a quantitative analysis of the unsteady state heat transfer related to the size, form and conductivity of the solid shape.

Procedure

Refer to the Operation section if you need details of the instrumentation and how to operate it.

Switch on the front Mains switch (if the panel meters do not illuminate check the RCD and any other circuit breakers at the rear of the service unit, all switches at the rear should be up).

Check that the water heater is filled with water then switch on the electrical supply to the water heater (switch on the RCD which is located on the connection box adjacent to the water heater).

Ensure that the red light is illuminated on the water heater, indicating that electrical power is connected to the unit.

Adjust the thermostat on the water heater to setting '4' and check that the red light is illuminated indicating that power is connected to the heating element.

Set the voltage to the circulating pump to 12 Volts, using the control box on the mimic diagram software screen.

Allow the temperature of the water to stabilize (monitor the changing temperature T1 on the software screen).

The water must be in the range 80 - 90 ^{o}C for satisfactory operation. If outside this range adjust the thermostat and monitor T1 until the temperature is satisfactory.

Attach the large brass cylinder to the shape holder (insert the insulated rod into the holder and secure using the transverse pin) but do not hold the metal shape or subject it to a change in temperature. Check that the thermocouple attached to the shape is connected to T3 on the HT10X/HT10XC. Check that the thermocouple wire is located in the slot at the top of the shape holder.

Check that the temperature of the shape has stabilized (same as air temperature T2).

Switch off the electrical supply to the water bath (switch off the RCD on the connection box) to minimize fluctuations in temperature if the thermostat switches on/off.

Start continuous data logging by selecting the icon on the software toolbar.

Allow the temperature of the shape to stabilise at the hot water temperature (monitor the changing temperature T3 on the mimic diagram software screen).

When temperature T3 has stabilized, select the icon to end data logging.

Select the icon to create a new results sheet.

Switch on the electrical supply to the water bath to allow the thermostat to maintain the water temperature.

Remove the large brass cylinder from the shape holder then fit the stainless steel cylinder.

Repeat the above procedure to obtain the transient response for the stainless steel cylinder. Remember to create a new results sheet at the end, ready for the next set of results.

Remove the stainless steel cylinder from the shape holder then fit the small brass cylinder. Remember to create a new results sheet at the end, ready for the next set of results.

Repeat the above procedure to obtain the transient response for the small brass cylinder. Remember to create a new results sheet at the end, ready for the next set of results.

If time permits the response of the other shapes can be determined using the same procedure as above.

Results and Calculations

The transient behavior of the various shapes is best analysed graphically using graphs of temperature versus time which you have obtained.

Graphs can be plotted from the Graph screen of the software. Select the graph screen using the icon, then select the y=mx+c icon to open the graph configuration screen. The available results are listed on the left. Highlight the first required series (the temperature T3 for the large brass cylinder) and use the red arrow button to transfer it to 'Series on Primary Axis', then select 'OK'. The graph may be printed to a printer (if one is available) by selecting the icon To print the graph from the next set of results, first highlight the first set and use the red arrow button to transfer it back to 'Available Series' before selecting the next set as before.

You should observe the following features on the graphs obtained:

The instantaneous change in temperature T3 corresponds to the instant at which the shape is immersed in the hot water and can be taken as time = 0 seconds for each shape.

Using the large brass cylinder as a reference, the small brass cylinder stabilizes faster because the distance between the centre and the surface of the cylinder is considerably reduced.

Because the stainless steel cylinder has a lower conductivity and lower diffusivity than the brass cylinder it takes much longer to stabilize than the brass cylinder of equivalent size.

These findings are repeated if the spheres or slabs of different material are compared.

Conclusion

You have observed how, in a solid shape, temperature changes with time and position while heat flows from the hot boundary to heat the cooler material inside of the shape.

This condition of unsteady-state heat transfer exists until the temperature is constant throughout the shape; no temperature gradient exists within the shape when a condition of steady-state is achieved. The time taken for the temperature to stabilise at the centre of the shape depends on the size, form and the material of the solid shape.

Objective

Using analytical transient-temperature/heat flow charts to determine the conductivity of a solid cylinder from the measurements taken on a similar cylinder but having a different conductivity.

Method

Cylinders of the same size but different material are allowed to stabilise at room temperature then dropped into a bath of hot water. The change in temperature at the centre of one cylinder is used to determine the heat transfer coefficient for both of the cylinders. This result may then be used to determine the conductivity of the second cylinder.

Note: If results are available from Exercise A then this exercise can be completed using those results. Refer to the Theory section of this exercise followed by the Results and Calculations.

Equipment Required

HT17 Unsteady State Heat Transfer Accessory

PC running Windows™ 98 or later with available USB socket

HT10X Heat Transfer Service Unit with IFD5 option
or
HT10XC Computer Compatible Heat Transfer Service Unit

Optional Equipment

Laboratory stands with clamps.

Equipment Setup

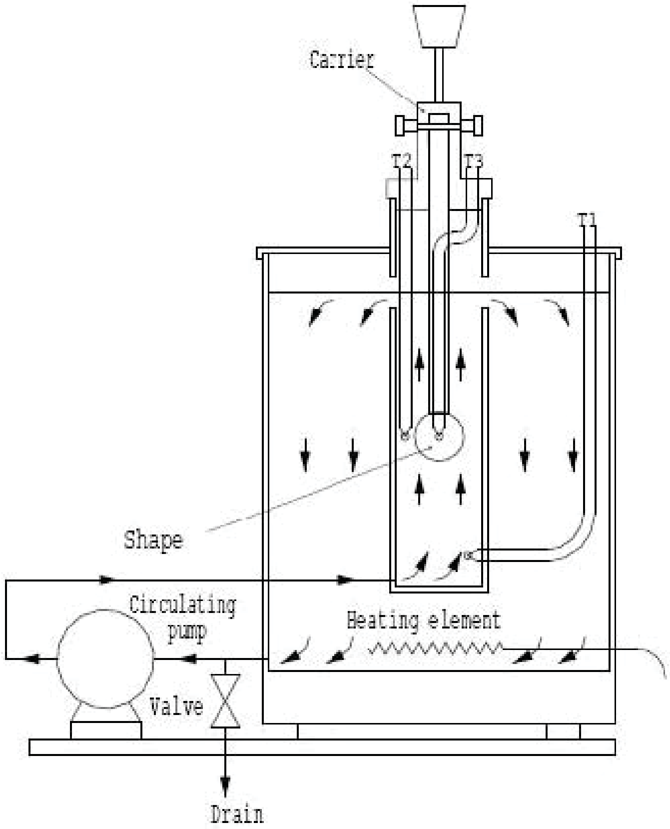
Before proceedings with the exercise ensure that the equipment has been prepared as follows:

Locate the hot water bath of the HT17 Unsteady State Heat Transfer accessory alongside the HT10X/HT10XC Heat Transfer Service Unit on a suitable bench.

Ensure that the lid of the hot water bath is fitted and the inlet at the base of the flow duct is connected to the outlet of the circulating pump using flexible tubing.

Ensure that the drain valve on the water bath is closed then fill the bath with clean water until the level is coincident with the centre of the holes in the vertical flow duct as shown in the diagram below.

Connect thermocouple T1 from the flow duct inside the water bath (lead exits via a grommet in the lid of the water bath) to socket T1 on the front of the HT10X/HT10XC service unit.



Connect thermocouple T2 on the shape holder to socket T2 on the front of the HT10X/HT10XC service unit.

Connect thermocouple T3 inside the large brass shape to socket T3 on the front of the HT10X/HT10XC service unit.

Set the VOLTAGE CONTROL potentiometer to minimum (anticlockwise) and the selector switch to MANUAL then connect the power lead from the circulating pump alongside the water heating tank to the socket marked Output 2 at the rear of the service unit.

Note: The voltage control potentiometer is used to set the speed of the circulating pump on this equipment NOT the power to the heating element.

Connect the power lead from the water bath (terminated at the connection box alongside the heating tank) to an electrical supply.

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

Connect the HT10XC service unit to the PC using the USB cable provided, and run the HT17 software. Select Exercise B.

Click on the 'Sample' menu from the top toolbar, and select 'Configure…'

In the Sample Configuration menu that appears, check that Sampling Operation is set to Automatic with a Sample Interval of 1 secs and Continuous duration. Change the settings if required. Close the Sample Configuration window by selecting 'OK'.

Place the various shapes in a suitable location where the metal bodies can stabilise at room temperature. If laboratory stands/clamps are available then the shapes can be suspended from the stands via the insulated rod attached to each shape.

Always pick up the metal shapes via the insulated rod. Heat transferred to the shape by holding in the hand will delay the stabilisation of the shape at a uniform temperature.

Note: Since the water bath will take approximately 40 minute to heat to the required temperature it is suggested that this is switched on immediately as described in the Procedure.

Theory/Background

Analytical solutions are available for temperature distribution and heat flow as a function of time and position for simple solid shapes which are suddenly subjected to convection with a fluid at a constant temperature. A typical chart is included below which is constructed for a long cylinder of radius b where the whole of the surface is suddenly subjected to a change in temperature (the effect of the end faces is considered to be negligible).

To use the charts it is necessary to evaluate appropriate dimensionless parameters as follows:

$\theta = \dfrac{T(r,t) - T_\infty}{T_i - T_\infty}$ = dimensionless temperature

$Bi = \dfrac{hb}{k}$ = Biot number

$\tau = \dfrac{\alpha t}{b^2}$ = dimensionless time or Fourier number

Where

α = Thermal diffusivity of the cylinder ($m^2 s^{-1}$)

h = Heat transfer coefficient ($Wm^{-2}\,{}^oC^{-1}$)

k = Thermal conductivity of the cylinder ($Wm^{-1}\,{}^oC^{-1}$)

t = Time since step change (seconds)

T(0,t) = Temperature at centre of cylinder (=T3 at time t) (${}^oC$)

Ti = Initial temperature of cylinder (T3 at t=0) (${}^oC$)

T_∞ = Temperature of water bath (T1) (${}^oC$)

b = Radius of cylinder (m)

r = Radial position within the cylinder (at axis r = 0) (m)

Since the flow of water vertically upwards through the duct is constant for all of the measurements, the heat transfer coefficient h will remain constant for each shape.

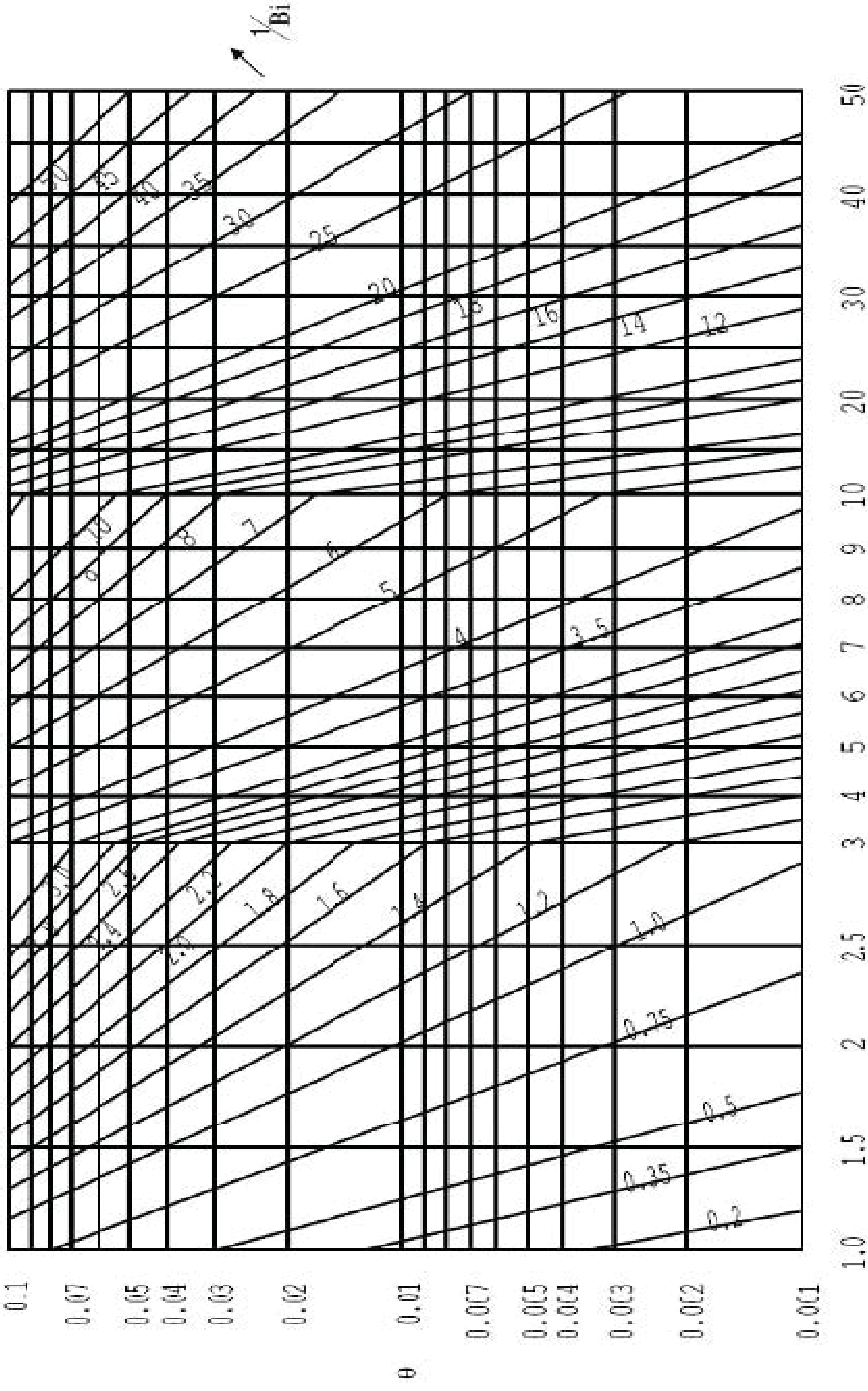


Chart for Long Cylinder

Procedure

Refer to the Operation section in the HT17 instruction manual if you need details of the instrumentation and how to operate it.

Switch on the front Mains switch (if the panel meters do not illuminate check the RCD and any other circuit breakers at the rear of the service unit, all switches at the rear should be up).

Check that the water heater is filled with water then switch on the electrical supply to the water heater (switch on the RCD which is located on the connection box adjacent to the water heater).

Ensure that the red light is illuminated on the water heater indicating that electrical power is connected to the unit.

Adjust the thermostat on the water heater to setting '4' and check that the red light is illuminated indicating that power is connected to the heating element.

Set the voltage to the circulating pump to 12 Volts using the voltage control box on the mimic diagram software display.

Allow the temperature of the water to stabilise (monitor the changing temperature T1).

The water must be in the range 80 - 90 ^{o}C for satisfactory operation. If outside this range adjust the thermostat and monitor T1 until the temperature is satisfactory.

Attach the large brass shape to the holder (insert the insulated rod into the holder and secure using the transverse pin) but do not hold the metal shape or subject it to a change in temperature. Check that the thermocouple attached to the shape is connected to T3 on the HT10X/HT10XC. Check that the thermocouple wire is located in the slot at the top of the shape holder.

Check that the temperature of the shape has stabilised (same as air temperature T2).

Switch off the electrical supply to the water bath (switch off the RCD on the connection box) to minimise fluctuations in temperature if the thermostat switches on/off).

Start continuous data logging by selecting the  icon on the software toolbar.

Allow the temperature of the shape to stabilise at the hot water temperature (monitor the changing temperature T3 on the mimic diagram software screen).

When temperature T3 has stabilised, select the  icon to end data logging.

Select the  icon to create a new results sheet.

Switch on the electrical supply to the water bath to allow the thermostat to maintain the water temperature.

Remove the large brass cylinder from the shape holder then fit the stainless steel cylinder.

Repeat the above procedure to obtain the transient response for the stainless steel cylinder. Remember to create a new results sheet afterwards ready for the next set of results.

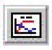
Remove the stainless steel cylinder from the shape holder then fit the small brass cylinder.

Repeat the above procedure to obtain the transient response for the small brass cylinder.

If time permits the response of the other shapes can be determined using the same procedure as above. These additional results can be used in exercise HT17C.

Results and Calculations

Determine the value for h using the result obtained for the brass cylinder as follows:

Plot the first graph using the Graph screen of the software. Select the graph screen using the  icon, then select the icon to open the graph configuration screen. The available results are listed on the left. Highlight the first required series (the temperatures T2 and T3 for the large brass cylinder) and use the red arrow button to transfer them to 'Series on Primary Axis', then select 'OK'. The graph may be printed to a printer (if available) by selecting the  icon.

Establish where t = 0 (i.e. T2 step changes from room temperature to T_∞

Choose a point on the temperature/time plot for the brass cylinder and measure the corresponding values of temperature T3 and time t. (the point should be close to the final temperature e.g. 2 or 3 degrees away from the final temperature).

Calculate θ knowing Ti (T3 at t=0), T_∞ , and T3 ie. T(r=0, t)

Calculate τ knowing α, t and b (assume α = 3.7 x 10^{-5} $m^2 s^{-1}$ for brass)

Read value for 1/Bi on chart using the calculated values for θ and τ

Calculate h knowing Bi, b and k (assume k = 121 $Wm^{-1}\,{}^{o}C^{-1}$ for brass)

This value of h will be the same for the stainless steel cylinder since the size, shape, surface finish and water velocity are constant.

Plot the graph for the stainless steel cylinder: first highlight the results for the brass cylinder and use the red arrow button to transfer them back to 'Available Series'. Then select the results for the stainless steel cylinder from the available series, and transfer them to the primary Y-axis. Select 'OK', then print the graph (if a printer is available).

Choose a point on the temperature/time plot for the stainless steel cylinder and measure the corresponding values of temperature T at time t. (the point should be close to the final temperature e.g. 2 or 3 degrees away from he final temperature).

Calculate θ knowing Ti (T3 at t=0), T_∞ , and T3 i.e. T(r=0, t)

Calculate τ knowing α, t and b (assume α = 0.6 x 10^{-5} $m^2 s^{-1}$ for stainless steel)

Read value for 1/Bi on chart using the calculated values for θ and τ

Calculate k knowing Bi, b and h (use the calculated value for h obtained using results from the brass cylinder. The typical value of k for stainless steel is $25 Wm^{-1} {}^{o}C^{-1}$)

Conclusion

You have experienced the use of analytical transient-temperature/heat flow charts to analyse the temperature changes between the surface and the centre of a solid cylinder.

Relevant dimensionless parameters are used to effect the analysis.

Note: The use of charts, as demonstrated in this exercise, is restricted to simple regular shapes with constant thermal properties. Where bodies have an irregular shape or the surface is not maintained at a uniform temperature then the problems must be solved using a numerical approach such as finite-difference or finite element methods.