

HT14 COMBINED CONVECTION AND RADIATION

6.5 HT14C Laboratory Teaching Exercise C

Objective

To determine the effect of forced convection on heat transfer from the surface of a cylinder at varying air velocities and surface temperatures.

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

Method

By measuring the temperature on the surface of a horizontal cylinder subjected to heat loss by radiation and forced convection in combination then comparing the results with those obtained from a theoretical analysis.

Equipment Required

HT10XC Computer Compatible Heat Transfer Service Unit
HT14 Combined Convection and Radiation Accessory

Equipment set-up

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

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

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).

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

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

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

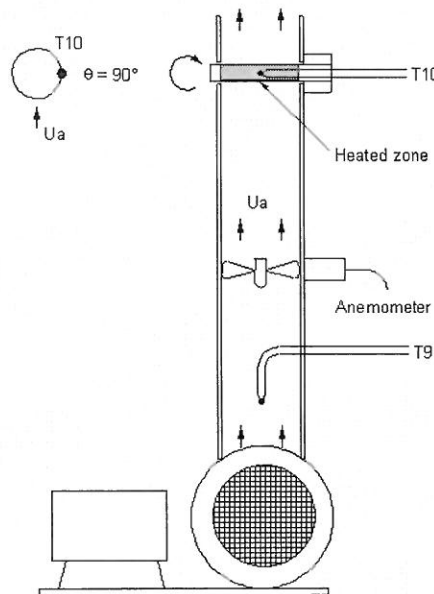
Set the VOLTAGE CONTROL potentiometer to minimum (anticlockwise) and the selector switch to MANUAL then connect the power lead from the heated cylinder on HT14C to the socket marked Output 2 at the rear of the service unit.

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

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If using the HT14C software, check that the HT10XC console is connected 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.

If operating the accessory manually then leave the console selector switch set to MANUAL.



Connect the mains lead from the fan (terminated at the connection box alongside the fan) to the socket marked Output 1 at the rear of the HT10X service unit.

Connect the lead from the anemometer in the vertical duct to the socket marked U_a on the front of the HT10X service unit.

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

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

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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 minimised 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	$Q_{\text{tot}} = Q_{\text{fm}} + Q_{\text{rm}}$ 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:

$$Hr_m = \sigma \xi F \frac{(T_s^4 - T_a^4)}{(T_s - T_a)} \quad (\text{Wm}^{-2}\text{K}^{-1})$$

where:

σ = Stefan Boltzmann constant ($\sigma = 56.7 \times 10^{-9} \text{ Wm}^{-2}\text{K}^{-4}$)

ξ = Emmisivity of surface

T_s = Surface temperature of cylinder (K)

T_a = Ambient temperature (K)

$$Hf_m = \frac{k}{D} Nu_m \quad (\text{Wm}^{-2}\text{K}^{-1})$$

where:

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

D = diameter of the cylinder (m)

Num = Average Nusselt number (Dimensionless)

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

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

From SW Churchill and M Bernstein "A Correlating Equation for Forced Convection from Gases and Liquids to a Circular cylinder in crossflow". Journal of Heat Transfer, 99:300-306 (1977).

Where:

$Re = \text{Reynolds number} = U_c D / \nu$ (dimensionless)

$Pr = \text{Prandtl number for air}$ (dimensionless)

$U_c = \text{Corrected air velocity}$ (m/s)

Corrected air velocity $U_c = 1.22 U_a$ (m/s)

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

Values for k , ν 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

Refer to the Operation section (page 3-1) 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 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 U_a to indicate the air velocity in the duct.

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.

NOTE for HT14 Users:


If using the HT14 accessory instead of the HT14C, the air velocity is adjusted by manually rotating the disc in front of the fan. The fan on the HT14 may not be operated using the console or the software.

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

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CONTROL potentiometer to give a reading of 20 Volts on the top panel meter with the selector switch set to position V.

Allow the HT14C to stabilise. 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.

When the temperatures are stable select the  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.

If using the software then select the  icon to create a new results table.

Allow the HT14C to stabilise then repeat the above readings.

Repeat the above procedure changing the air velocity in steps of 1.0 m/s until the air velocity is 7.0 m/s.

Results and Calculations

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

Heater Voltage	V	Volts
Heater Current	I	Amps
Upstream air temperature	T9	(°C)
Surface temperature of cylinder	T10	(°C)
Air velocity in the duct	Ua	(m/s)

You should also estimate and record the experimental errors for these measurements.

For this exercise the following constants are applicable:

Diameter of cylinder	$d = 0.01$	(m)
Length of cylinder	$L = 0.07$	(m)

For each set of readings the derived results are tabulated under the following headings:

Heat flow (Power to heater)	Q_{in}	=	(Watts)
Heat transfer area	A_s	=	(m ²)
Corrected air velocity	U_c	=	(m/s)

Heat transfer coefficient (forced convection) H_{f_m}	=	($Wm^{-2}K^{-1}$)
Heat transfer coefficient (radiation) H_{r_m}	=	($Wm^{-2}K^{-1}$)
Heat transfer by natural convection Q_f	=	(W)
Heat transfer by radiation Q_r	=	(W)
Total heat transferred Q_{tot}	=	(W)

Estimate the cumulative influence of the experimental errors on your calculated values for U_c , A_s , H_{f_m} , H_{r_m} , Q_f , Q_r , Q_{tot} and Q_{in} and measured values for U_a , T_9 , T_{10} , L and x .

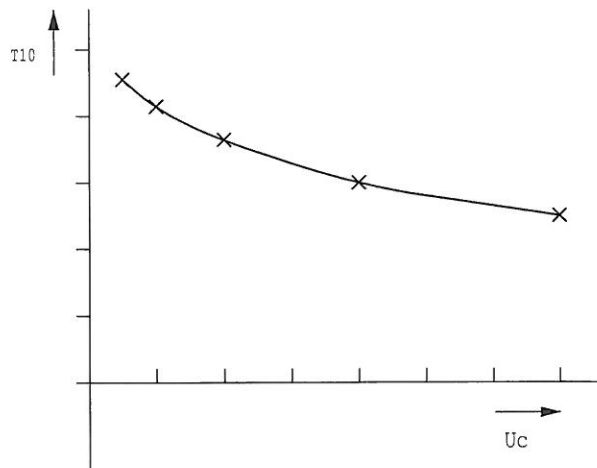
Compare the theoretical value obtained for Q_{tot} with the measured value for Q_{in} and explain any difference in the two values.

Compare the calculated heat transfer due to forced convection Q_f and radiation Q_r .

Plot a graph of surface temperature T_{10} against corrected air velocity U_c . Your graph should be similar to the diagram below:

Observe that the surface temperature of the cylinder reduces as the air velocity increases for a fixed heat input Q_{in} .

Observe that the surface temperature reduces more rapidly at low air velocities and reduces more slowly at high air velocities.



Conclusions

You have demonstrated how the heat transfer from a heated surface to its surroundings is a combination of forced convection and radiation (the effect of conduction must also be included where relevant) when the surface is located in a moving air stream.

For equilibrium, heat input to a surface must equal the heat transferred from the surface to its surroundings. Since heat transfer from a surface increases

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with the velocity of the air, increased air velocity past a surface results in a decrease in the temperature of the surface.

The calculation of the heat transfer coefficient $h_{f,m}$ for forced convection involves the use of empirical equations which are specifically related to heat transfer from a horizontal cylinder. Empirical equations are available for other classical shapes which will allow a theoretical analysis to be performed.

The effect of air velocity forced convection on surface temperature.

Note: Exercise HT14CD should be carried out on the completion of this exercise.

