6.6 HT14C Laboratory Teaching Exercise D

Objective

To demonstrate that the local heat transfer coefficient varies around the circumference of a horizontal cylinder when subjected to forced convection.

Method

By subjecting a horizontal cylinder to constant conditions of forced convection and radiation (constant power input) then rotating the cylinder to measure the local differences in temperature over the surface of the cylinder (positioning thermocouple T10 at different angular positions to produce a temperature profile).

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 underside of the cylinder - at the bottom of the cylinder corresponding to the stagnation point on the cylinder, i.e. $\theta = 0$ degrees (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.

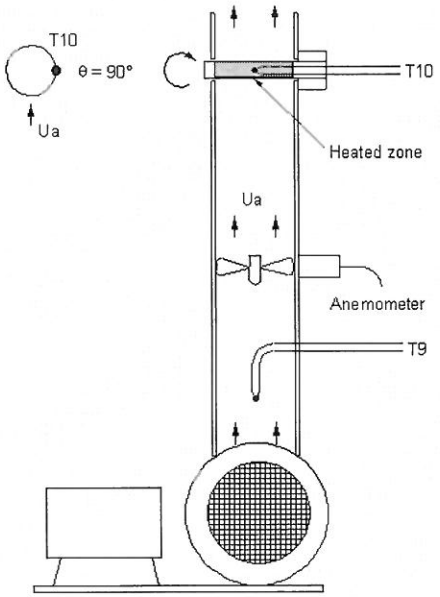
Set the manual/remote selector switch on the console to MANUAL.

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.

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 Ua on the front of the HT10X service unit.

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

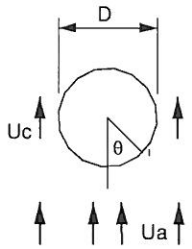
Theory/Background

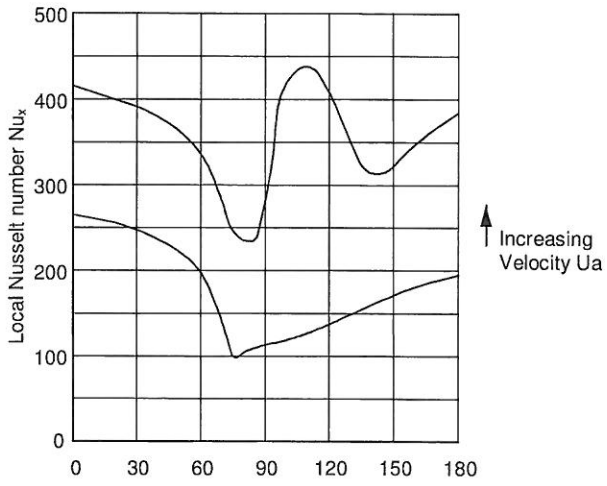
The purpose of this exercise is to demonstrate that the temperature profile around the circumference of the cylinder is not constant, i.e. the heat transfer coefficient varies according to the position on the surface of the cylinder. The cylinder is rotated to present the thermocouple at different angular positions and, after allowing the temperature profile of the cylinder to stabilise, the temperature is recorded at each angular position.

Note: Due to the relatively small size of the cylinder, the mounting arrangement of the thermocouple and the variable contact between the heating element and the inside wall of the cylinder, it is not possible to obtain values which will compare with classical results for variation of local heat transfer

coefficient around a circular cylinder. However, a variation in temperature can be shown.

The actual power supplied to the heated cylinder Qin = V I (W)





θ Angle measured from the stagnation point, degrees

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 HT10X to position Ua to indicate the air velocity in the duct.

Start the centrifugal fan by pressing the switch on the connection box.

Set the fan speed to give an air velocity of 1.0 m/s. If using the software then the fan speed can be adjusted using the control box on the mimic diagram screen. If operating the equipment manually using the HT10XC console then the fan speed can be adjusted using the AUXILIARY CONTROL knob to give a reading of 1.0 m/s on the upper panel meter.

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 can be controlled using the control box on the mimic diagram. If operating the accessory manually 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.

Allow the HT14C to stabilise. 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 then select the icon on the top software toolbar to record the following:

Position Ua, T9, T10, V, I.

If operating the accessory manually then record these values from the HT10XC console, using the panel meters/switches to display each required value.

Rotate the cylinder by 30 degrees.

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

Enter the cylinder angle on the mimic diagram.

Allow the HT14C to stabilise then repeat the above readings.

Continue to rotate the cylinder in steps of 30 degrees until the thermocouple is located on the top of the cylinder, i.e. $\theta = 180$ degrees. Remember to create a new results sheet and enter the new cylinder angle each time.

Adjust the fan speed to give an air velocity of 5 m/s then repeat the above procedure. If using the software then remember to create a new results sheet first.

After taking readings set the Voltage Control to zero before switching off the fan.

Results and Calculations

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

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

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

Plot graphs of surface temperature T10 versus angular position from the stagnation point θ for each setting of the air velocity Ua.

Observe that the temperature varies over the surface of the cylinder. Since the heat transfer coefficient is related to the surface temperature (demonstrated in the previous exercises) the local heat transfer coefficient must vary over the surface of the cylinder.

Conclusions

The heat transfer coefficient Hf_m used in the calculation of heat transfer from a surface is an average value for the surface. The local heat transfer coefficient varies according to the location on the surface.

Note: Exercise HT14CE may be carried out on the completion of this exercise.

6.7 HT14C Laboratory Teaching Exercise E

PROJECT WORK

Designing a model to demonstrate heat transfer by combination of convection and radiation to its surroundings

An interesting project for students who have completed the previous training exercises is to build and test a heat transfer model of their own design.

The HT10XC service unit provides the necessary power supplies and instrumentation to operate such a model. Provided that the model is constructed with the following principles it can be connected directly to the HT10XC service unit for evaluation:

The heater must operate from a 24 VDC electrical supply at a maximum current of 9 Amps (216 Watts maximum). The size of the model must be restricted to allow a sufficiently high surface temperature to be achieved with this power input. The heater should be arranged to provide uniform heating over the entire surface of the model.

A model to demonstrate free convection combined with radiation is to be recommended as the model can be simply located on the bench and not involve modifications to the centrifugal fan/duct on the HT14C.

If it is required to build a model to demonstrate forced convection with radiation then the model should include a simple extension to the top of the existing duct. The existing heated cylinder should be removed to prevent disturbance to the air flow. Alternatively, an independent source of moving air could be provided.

Any heated model may become extremely hot in operation and must be adequately protected to prevent injury without impeding the convection and radiation of heat from the surface of the model.

The thermocouples must be type K and terminated with a miniature thermocouple plug where temperatures are less than 133°C or a standard thermocouple plug where temperatures will exceed 133°C (maximum operating temperature 500°C). To provide a reliable measurement of the surface temperature, the thermocouple must be attached rigidly to the surface or buried just beneath the surface in a hole or a trough. A mineral insulated thermocouple is recommended as the thermocouple must remain isolated from the metalwork of the heater. The thermocouple used to measure the surface temperature of the model should be located at the centre of the surface to minimise edge effects.

Typical projects might include:

Combined natural convection and radiation from flat plates:

- Horizontal - heated surface facing upwards
- Horizontal - heated surface facing downwards
- Vertical

Effect of rod cross section:

Solid cylindrical rods of the same material but different diameters. The rod should be heated internally along its entire length.

Effect of shape:

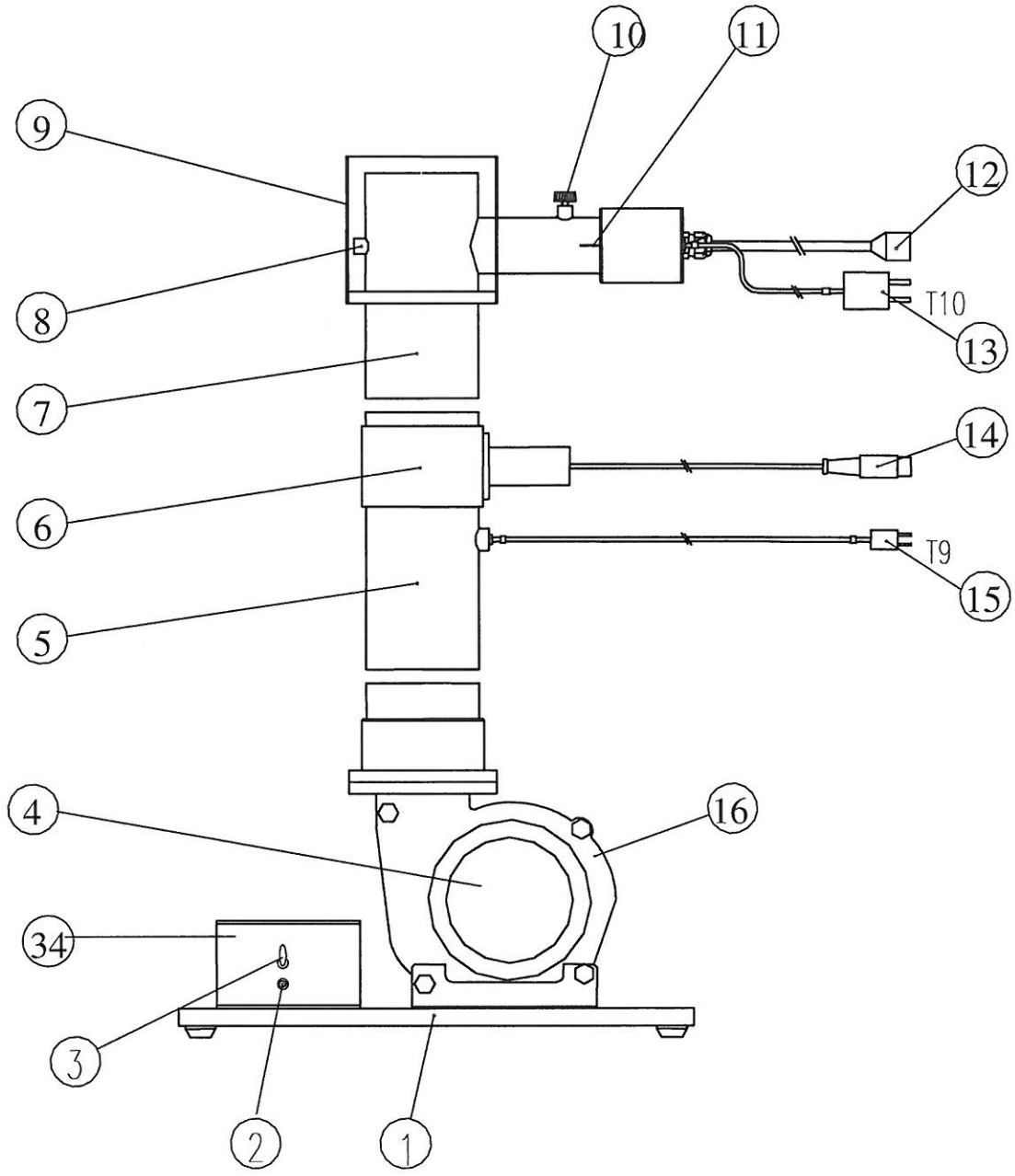
Solid surfaces having different shapes of cross section, e.g. rectangular section, square section. The section should be heated internally along its entire length.

Where appropriate, any of the exercises HT14CA, HT14CB, HT14CC or HT14CD might be applied to the project model constructed by the student.

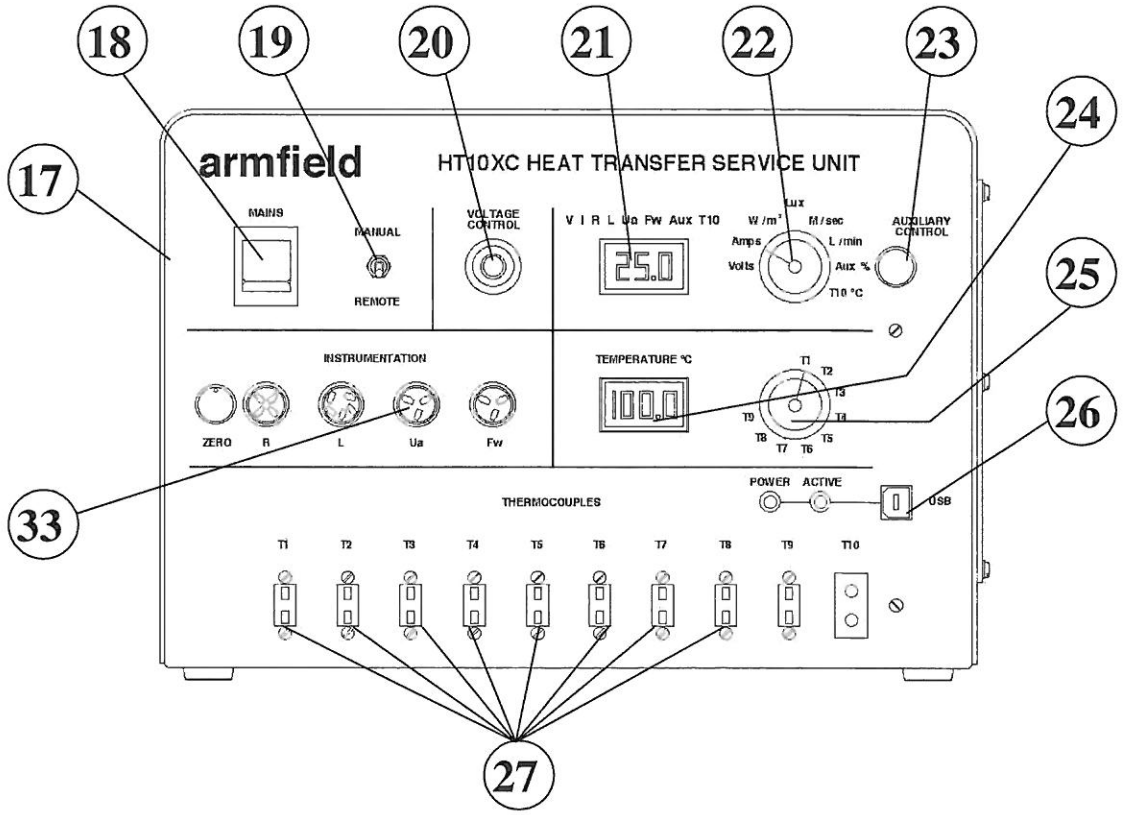
7 APPENDIX A: INSTALLATION GUIDE

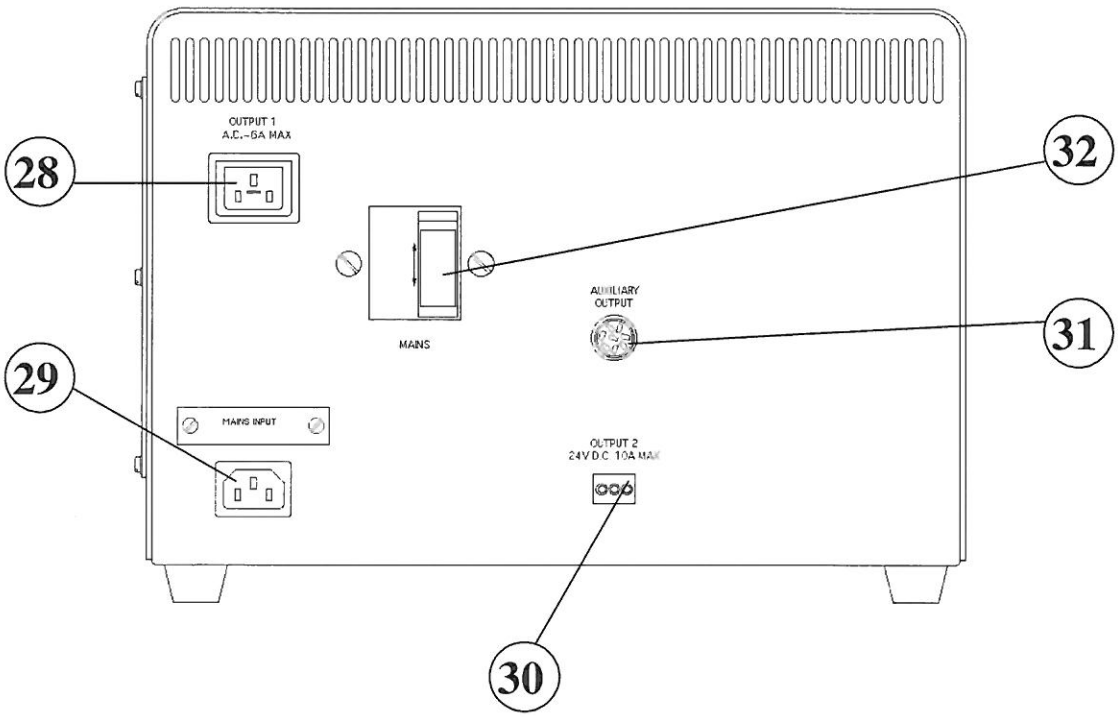
HT14C Installation Guide

The HT14C 'Combines Convection and Radiation' accessory must be used in conjunction with the HT10XC 'Heat Transfer Service Unit'. This Installation Guide assumes that the HT10XC has already been installed according to the guide included with the HT10XC manual.



Front view of HT14C





HT10XC Service Unit

Refer to the drawings on pages 2 and 3.

1. The apparatus should be carefully unpacked and the components checked against the Advice Note.

2. The HT14C 'Combined Convection and Radiation' accessory is supplied with the section of duct removed from the fan for convenience in shipping.

3. Carefully remove the packing then place the PVC baseplate, incorporating the centrifugal fan, on a suitable bench with the protective guard on the fan inlet facing forwards.

4. Remove the three fixing screws from the PVC flange at the fan outlet. Locate the lower duct section (5) on the outlet of the centrifugal fan (16) with the anemometer cable (14) exiting to the right hand side.

5. Carefully align the PVC flanges on the duct and the fan outlet, then fix the duct to the fan outlet by replacing the three fixing screws.

6. Locate the upper duct section (7) on the lower duct section with the boss for the heater assembly facing to the right hand side. Insert the upper duct section into the body of the anemometer (6) taking care not to damage the blades of the impeller. Carefully align the fixing holes then fix the upper duct to the anemometer body by replacing the three fixing screws. Carefully insert the heater assembly into the boss on the side of the upper duct section ensuring that the tip of the heated cylinder (8) is located in the hole on the opposite side of the duct. Rotate the heater assembly until the black dot on the insulated cover is aligned with the index mark (11) on the boss then tighten the securing screw (10) to retain the heater assembly.

7. Temperature Sensors (type k thermocouples)
   - Connect the miniature thermocouple plug from temperature sensor T9 in the duct wall to the socket marked T9 (27) on the front of the service unit.

   - Connect the standard thermocouple plug from temperature sensor T10 attached to the wall of the heated cylinder to the socket marked T10 (27) on the front of the service unit.

8. DC Power to heating element.
   - Set the Heater Voltage potentiometer (20) on the front of the service unit to zero (release the clamp and turn the adjusting knob fully anticlockwise).

   - Set the remote/manual selector switch (19) to the MANUAL position.

   - Connect the power lead (12) from the heated cylinder inside the duct of the HT14C to the variable DC outlet socket marked OUTPUT 2 (30) at the rear of the service unit.

9. Anemometer
   - Connect the electrical lead from the anemometer (14) to the socket marked Ua (33) on the front of the service unit.

10. Mains Power to Centrifugal Fan
    - The centrifugal fan is mains operated but derives its supply from the HT10XC service unit. Before connecting the fan for the first time ensure that the label on the cable attached to the fan agrees with the local electrical supply and agrees with the label attached to the mains input lead on the HT10X service unit.
    - Connect the power lead from the fan connection box (34) on the HT14C to the mains outlet socket marked OUTPUT 1 (28) at the rear of the service unit.

11. Control Signal to Centrifugal Fan
    - The control signal for the centrifugal fan is transmitted via a cable from the fan connection box (34) on the HT14C. This cable should be connected to the socket marked AUXILUIARY OUTPUT (31) at the rear of the service unit.

12. Software (optional)
    - The HT14C includes Windows™ based software that allows remote operation of the accessory from any compatible PC running Windows™ 98, 2000 or XP. The PC should have an available USB port and be situated within cable length of the HT10XC.
    - The software MUST be installed on the PC BEFORE connecting to the HT10XC console, to ensure that Windows locates the correct driver when the console is connected.
    - To install the software, insert the CD provided into the CD or DVD drive of the PC (If autorun is disabled, select 'Run...' from the 'Start' menu and type' 'D:/setup.exe' where 'D' is the letter designation of your CD drive). Follow the instructions on the screen. Restart the PC when instructed.
    - A USB socket (26) on the right hand side of the HT10XC service unit front panel allows the voltage signals from each of the measurements to be connected to the USB port of the PC using the supplied USB cable.
    - Once the software has been installed and the HT10XC connected to the PC, check that both USB indicator lights on the HT10XC console are illuminated.

13. Ensure that the mains on/off switch (18) on the front of the service unit is in the OFF position.

14. Ensure that Heater Voltage potentiometer (20) on the front of the service unit is set to zero (release the clamp and turn the adjusting knob fully anticlockwise).

15. Ensure that the adjacent manual/remote selector switch (19) is set to the MANUAL position.

16. Ensure that the mains electrical supply is connected and switched on.

17. Ensure that the RCD/RCCB (32) at the rear of the service unit is in the ON (up) position.

18. Set the mains on/off switch (18) on the service unit front panel to the ON position.

19. Observe that both digital panel meters (21, 24) are illuminated (as no power is supplied to the accessory at this stage the temperature display should indicate approximately ambient temperature).

20. Set the temperature selector switch (25) to position T10 to indicate the surface temperature of the heated cylinder. Check that the temperature indicated (24) is approximately ambient temperature.

21. Set the top measurement selector switch (22) to position V to indicate the voltage supplied to the element inside the heated cylinder. Adjust the Heater Voltage potentiometer (20) to give a reading of approximately 10 Volts on the display (ensure that the clamp on the side of the knob is released before turning the knob).

22. Check that the reading of temperature T10 gradually increases. Check that temperature T10 stabilises in free convection (no flow of air through the duct). Check that the temperature T9 indicates ambient temperature inside the duct by setting the temperature selector switch (25).

23. Turn on the centrifugal fan by pressing the switch (3) on the connection box. The actual air velocity can be read directly on the top panel meter (21) with the selector switch (22) set to position Ua. Adjust the fan speed using the AUXILIARY CONTROL knob (23) to give an air velocity of 4.5 metres/sec

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.

24. Turn off the power to the heater by setting the potentiometer to zero.

25. Allow the cylinder to cool then press the fan switch (3) to turn off the cooling air.

The basic operation of the 'Combined Convection and Radiation' accessory and 'Heat Transfer Service Unit' has been confirmed. Refer to the section Operation section in this manual (page 3-1) for further information.