

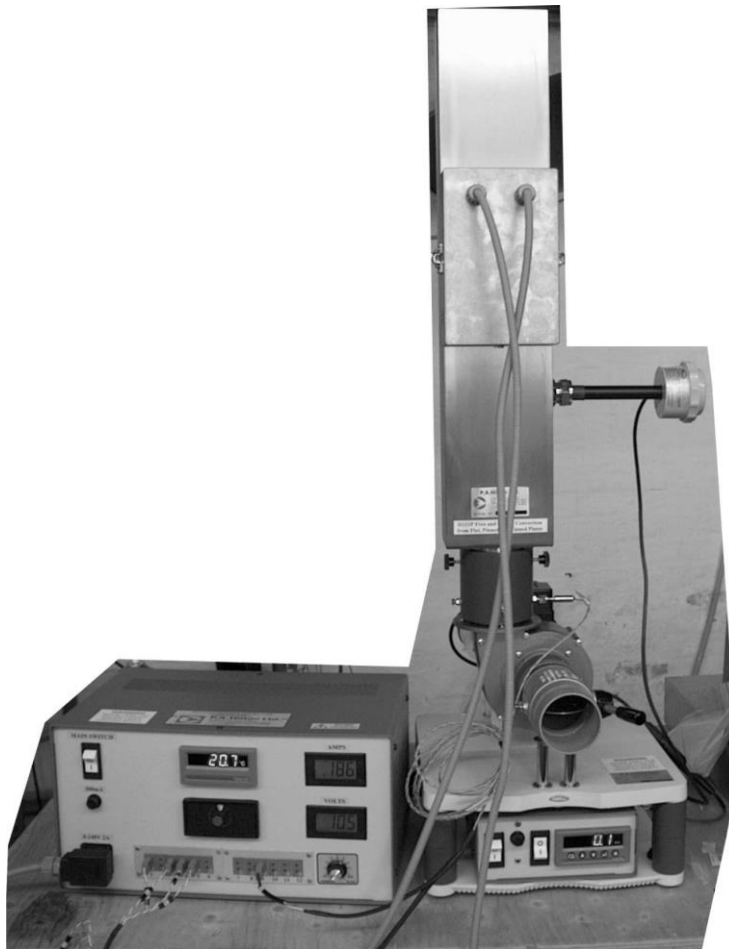
## Experiment – 8 Free And Forced Convection From Flat, Finned And Pinned Plates Experiment

### Aim of this Experiment

Free and Forced convection from Flat Finned and Pinned Plates experiments enables students to investigate heat transfer from various surfaces in free and forced convection.

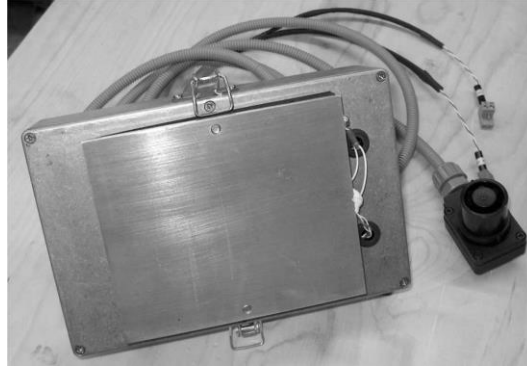
### Experimental Set – up

The H112P Free and Forced convection from Flat Finned and Pinned Plates enables students to investigate heat transfer from various surfaces in free and forced convection. The range of heated plates demonstrates the effect of extended surfaces (fins and pins) on the rate of heat transfer. The H112P is designed to be used with, and to be installed alongside, the Heat Transfer Service Unit H112.



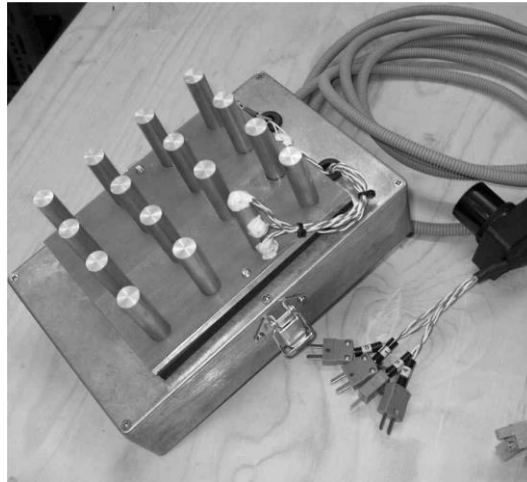
The accessory comprises a rectangular **duct (6)** mounted on the discharge of a base mounted centrifugal fan. In the middle of the duct is an **air velocity sensor (5)** that allows the air velocity within the duct to be measured and displayed (metres/second) on the **air velocity display (4)** below the base. At the centre of the duct is an aperture that allows any of the three **heated plates (8)** supplied to be installed.

A flat plate, pinned plate, or finned plate heat exchanger may be installed in the duct and secured by two toggle clamps. Each exchanger incorporates an electric heater mat rated at 100W at 240V. Each of the heated plates incorporates thermostatic protection against overheating.

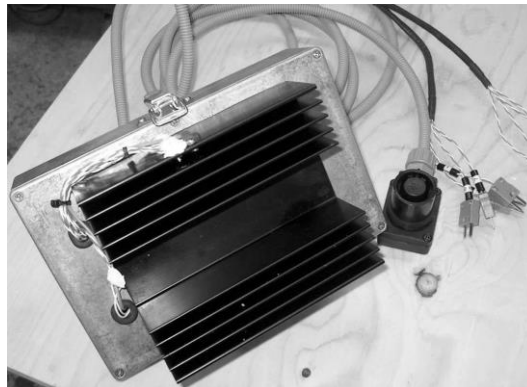


The heater surface temperature (T1) is continuously monitored and displayed by the temperature indicator when plugged in to the console.

The Pinned plate is fitted with three extra thermocouples (T2, 3 and 4) to measure the temperature of extended surfaces. T5 is furthest from the heater.



The Finned plate is fitted with three extra thermocouples (T2, 3 and 4) to measure the temperature of extended surfaces. T8 is furthest from the heater.



***Note that the T4 distance is 50mm from the heater on the Pinned Plate and 46mm from the heater on the Finned Plate.***

The T5 **air temperature (7)** sensor is located at the base of the duct and records the temperature of the air flowing over the heated plate.

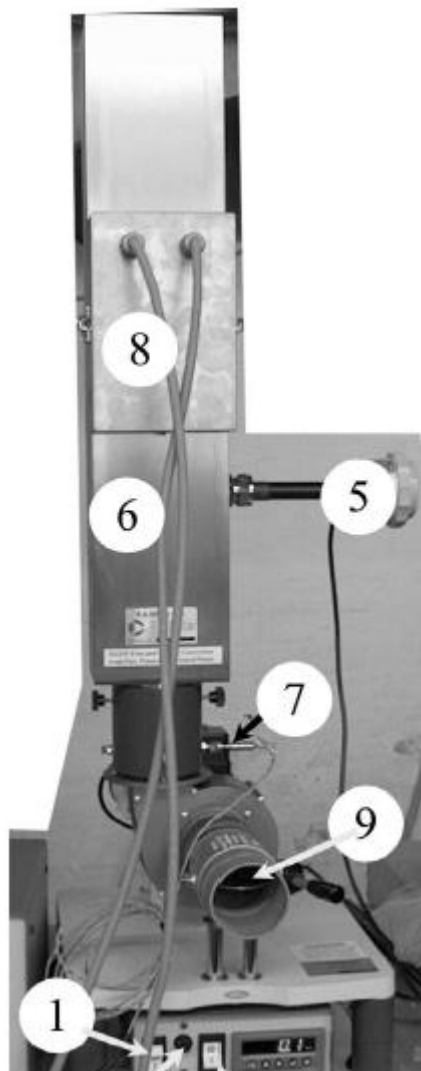
Thermocouple attachment points on the heat exchangers are protected by a covering of adhesive.

The air velocity passing the heated plates can be varied from zero to more than 8m/s depending upon the local mains voltage and supply frequency. The **air velocity sensor(5)** is permanently mounted in the duct and connects to the console below using a line plug and socket.

The air velocity is controlled by the use of an intake **air throttle (9)**. For natural convection experiments, the fan may be switched off using the **fan switch (3)** on the H112P console.

All thermocouples terminated with a miniature plug (identified T1, and T2 to T4) for insertion into the control console sockets.

### Schematic Representation of Linear Conduction Experiment Unit



#### Key

1. Main Switch
2. Instrument Fuse
3. Fan Switch
4. Air Velocity Display (m/s)
5. Air Velocity Sensor(Hot Wire Anemometer)
6. Duct
7. T5 Air Temperature
8. Heated Plate
9. Air Throttle

## **Capabilities Of The Free and Forced Convection Unit**

1. To Demonstrate the Relationship Between Power Input and Surface Temperature in Free Convection
2. To Demonstrate the Relationship Between Power Input and Surface Temperature in ForcedConvection.
3. To Demonstrate the use of Extended Surfaces to Improve Heat Transfer From the Surface.
4. To Determine the Temperature Distribution Along an Extended Surface.

## **Operating Procedure Of Free and Forced Convection Unit**

Note that the H112P may be operated with the HC112A Data Acquisition Upgrade. With the addition of this option all data relating to the following experimental procedures may be recorded automatically and transferred to spreadsheet format for subsequent detailed analysis and calculation.

The operation of the data acquisition upgrade is detailed in a separate manual but experimental procedures are identical to those described in the following text.

### **CAUTIONS**

#### **Active Element High Temperature Protection**

Each of the heated plates (Flat, Finned and Pinned) incorporate a thermal protection thermostat. This is designed to turn off the power to the heater if the element temperature exceeds approximately 90-100°C.

This will show on the H112 console as a ZERO current demand. The mains voltage display may not show zero as the voltage is measured at the console and the thermal switch is in the heater box.

If the thermal cut out operates allow the element to cool and the thermostat will reset automatically.

#### **Hot Surfaces**

Even with the high temperature protection the heated plates can reach 100°C and this is sufficient to cause burns. NEVER touch the metal surface of the plates with bare hands when the element is plugged into the control console. Handle the plates using the plastic backing plate only. Do not place the plates on any surface that can be damaged by heat.

#### **General Notes**

Applicable to all experimental work.

Before using the Cross Flow Heat Exchanger the user should:

(i) Study the unit and schematic diagram to identify all switches and controls relating to both the H112 Heat Transfer Service Unit H112 and the Free and Forced Convection from Flat, Finned and Pinned Plates H112P Accessory.

(ii) Understand the action of the various controls. Refer to the main H112 Heat Transfer Service Unit manual.

(iii) Be aware of the Cautions regarding handling of hot surfaces.

(iv) Be aware of how to obtain stable running conditions..

## **Experiment -8.1**

### **To Demonstrate the Relationship Between Power Input and Surface Temperature in Free Convection**

#### **Aim of This Experiment**

This experiment aims to establish relations between power input and surface temperature changes during free convection.

#### **Procedure**

##### **Optionals Method**

As the rate of heat transfer in natural convection is typically very small, the time taken to reach stability can be very long and may exceed a laboratory period. For this reason two methods of demonstrating natural convection using the three plates are described below.

##### **a) Steady State Method**

If time permits, or for a student project the steady state experimental procedure may be adopted. This allows the heat transfer rate from the three heat exchangers to be compared at similar hot plate temperatures. Due to the requirement for small adjustments and the time taken to assess stability the experimental period can be long.

##### **b) Transient Method**

However for a rapid demonstration the transient method may be adopted where a fixed heat input is applied in turn to each of the three heat exchangers and the temperature rise plotted against time until the 100°C cutout point is reached.

With this method the slope of the temperature rise is an indication of the rate of heat transfer from the plate.

##### **a) Steady State Method**

The same procedure is utilised for the three types of plate, Flat, Pinned and Finned.

(i) Ensure the instrument console main switch is in the off position. Ensure the fan is switched off. For the natural convection experiments the fan will not be used.

(ii) If the flat (pinned or finned) plate is not in position, open the toggle clamps. Replace with the flat (pinned or finned) plate and close the toggle clamps. Note that with the plate heat exchanger the power leads exit from the top of the plates. Refer to the diagram on page 1

(iii) No air velocity will be measurable under natural convection conditions unless specialised instrumentation is available.

(iv) Switch on the main switch and set the heater voltage to minimum.

The objective with the steady state method is to obtain the same T<sub>1</sub> surface temperature on each of the heat exchangers and determine the steady state power input required to achieve this. From factory tests under "typical" conditions the following heat inputs were required to maintain T<sub>1</sub> (approximately) 100°C

	Flat Plate	Pinned Plate	Finned Plate
$\dot{Q}$ (Watts) for 100°C	22	50	90
Voltage V for $\dot{Q}$ input	$\sqrt{22 \times R}$	$\sqrt{53 \times R}$	$\sqrt{90 \times R}$

Where  $R$  is the electrical resistance (Ohms) of the heater element. The nominal resistance of the standard heater is 529 Ohms. The actual figure can be checked by calculating the resulting measured  $V$  (volts) and  $I$  (current) to the heater and calculating

$$\dot{Q} = V \times I$$

The best technique is to set the voltage input to maximum and monitor  $T_1$  on the digital temperature indicator. When  $T_1$  approaches 100°C, reduce the voltage to the appropriate level for the plate heat exchanger in use.

(v) When the temperature  $T_1$  has stabilised (this may take 10's of minutes) record the actual temperature  $T_1$ , the actual voltage  $V$  and the ambient air temperature  $T_9$ . If either the Finned or Pinned plates are in position the pin temperatures ( $T_2, T_3, T_4$ ) or fin temperatures ( $T_2, T_3, T_4$ ) may be recorded.

(vi) Before removing the heat exchanger from the duct turn on the fan and cool the heat exchanger.

**Note that this cooling procedure may be used to quickly demonstrate to students the increased heat transfer coefficient due to forced convection if the voltage setting is left at the natural convection condition and the fan turned on to give maximum flow.  $T_1$  will be seen to rapidly fall from the natural convection condition.**

(vii) Finally reduce the heater voltage to zero and allow to cool before removing the plate from the tunnel and replacing with one of the alternative plates.

### Procedure b) Transient Method

The same procedure is utilised for the three types of plate, Flat, Pinned and Finned.

(i) Ensure the instrument console main switch is in the off position. Ensure the fan is switched off. For the natural convection experiments the fan will not be used.

(ii) If the flat (pinned or finned) plate is not in position, open the toggle clamps retaining the plate in the tunnel and remove the existing plate from the tunnel. Replace with the flat (pinned or finned) plate and close the toggle clamps. Note that with the plate heat exchangers the power leads exit from the top of the plates.

(iii) No air velocity will be measurable under natural convection conditions unless specialised instrumentation is available.

(iv) Switch on the main switch and set the heater voltage to minimum. The objective with the transient method is to apply the same heat input to all three heat exchangers and record the rise in  $T_1$  temperature with time. Factory tests have shown that under a 100W input is acceptable and allows sufficient time for data to be collected. The voltage  $V$  required for 100W input is

$$V = \sqrt{100 \times R}$$

Where  $R$  is the electrical resistance (Ohms) of the heater element. The nominal resistance of the standard heater is 529 Ohms.

The actual figure can be checked by calculating the resulting measured V (volts) and I (current) to the heater and calculating

$$\dot{Q} = V \times I$$

v) Record the starting surface temperature T1, air stream temperature T2 and, if the pinned or finned heat exchangers are in use record the pin (T2, T3, T4) or fin (T2, T3, T4) temperatures. Select a suitable time interval for recording data that is achievable (say 10-15 second intervals). Note that it may be beneficial for more than one student to be involved in data collection and recording.

**If the optional HC112A Data Acquisition system is available then all parameters may be recorded simultaneously at 10 second intervals or less with ease.**

(vi) Set the heater voltage to the required value and begin recording (all) the temperatures at the set interval. Once the surface temperature reaches the 100°C value the high temperature cut out will operate and the experiment can be concluded. Before removing the heat exchanger from the duct turn on the fan and cool the heat exchanger. Note that this cooling procedure may be used to quickly demonstrate to students the increased heat transfer coefficient due to forced convection if the voltage setting is left at the natural convection condition and the fan turned on to give maximum flow. T1 will be seen to rapidly fall from the natural convection condition.

### Sample Test Results

Sample No.	T1	T2	T3	T4	T5	T6	T7	T8	V	I
	°C	°C	°C	°C	°C	°C	°C	°C	Volts	Amps
1	30.9	28.4	25.9			24.5	21.9	20.1	88	0.098
2	41.1	36.9	32.7			29.7	25.5	22.2	117	0.129
3	64.3	58.3	48.4			41.7	33.8	27.2	164	0.184
4	89.3	77.5	65.6			55	42.9	32.6	203	0.226
Distance from T1	0.000	0.015	0.030	—	—	0.045	0.060	0.075	—	—



## Experiment -8.2

### To Demonstrate the Relationship Between Power Input and Surface Temperature in Forced Convection

#### Aim of This Experiment

This experiment aims to establish relations between power input and surface temperature changes during forced convection.

#### Procedure

undertake steady state experimental procedures within a reasonable time period as the plates will stabilise relatively quickly.

The same procedure is utilised for the three types of plate, Flat, Pinned and Finned.

(i) Ensure the instrument console main switch is in the off position. Ensure the fan is switched off.

(ii) If the flat (pinned or finned) plate is not in position, open the toggle clamps. Replace with the flat (pinned or finned) plate and close the toggle clamps. Note that with the plate heat exchangers the power leads exit from the top of the plates.

(iii) Note that the flat plate will have the minimum blockage effect upon the air stream and the pinned plate will have the maximum. Hence it will not be possible to achieve the same maximum air velocity reading (fan at full speed) with the pinned plate in position as with the flat plate in position. If direct comparison between finned, pinned and flat plate performance is required then it would be beneficial to test the pinned plate first in order to establish the maximum possible velocity reading  $U$ . Then the remaining plates can be tested under similar or lower air flow conditions.

(iv) Switch on the **main switch (1)** and set air velocity to a low value by closing the **air throttle (9)**. Increase the heater power to a suitable level such that  $t_s$  ( $T_1$ ) does not exceed  $100^\circ\text{C}$ . Allow the temperatures to stabilise and then record the surface temperature  $t_s$  ( $T_1$ ), the heater supply voltage  $V$ , heater current  $I$  and the air velocity  $U$ .

(v) Maintain the heater voltage at the same condition and then increase the air velocity by opening the **air throttle (9)**. Once again allow the temperatures to stabilise and repeat the readings. Repeat the procedure at increasing air velocity if required.

(vi) For direct comparison repeat the procedure for the three plates under similar heat input conditions and at similar velocities.

## Sample Test Results

Heater Used :- Pinned Plate

Atmospheric Pressure =  $1.013 \times 10^5 \text{ kNm}^{-2}$

Sample No.	1	2	3	4	5	6
Time t/s						
Heater Volts V	242	242				
Heater Current I (Amps)	0.362	0.364				
Heater Power $V \times I$ Watts	87.84	88.08				
Ambient $t_a$ (T5)/°C	21.0	21.0				
Flat Plate $t_s$ (T1)/°C						
Pinned Plate $t_s$ (T1)/°C	52.1	43.4				
Pinned Plate T2/°C	52.0	43.4				
Pinned Plate T3/°C	47.7	39.5				
Pinned Plate T4/°C	47.5	39.3				
Finned Plate $t_s$ T1/°C						
Finned Plate T2/°C						
Finned Plate T3/°C						
Finned Plate T4/°C						
Surface-Air Temperature Difference ( $t_s - t_a$ ) / K						
Duct Air Velocity U m/s	6.8	10.1				

## Experiment -8.3

### To Demonstrate The use of Extended Surfaces To Improve Heat Transfer From the Surface.

#### Aim of This Experiment

This experiment aim to proof importance of using extended surfaces to improve heat transfer from the surface.

#### Procedure

The following procedure may be undertaken either in natural convection conditions (fan not operating) or in forced convection conditions. In both cases the use of extended surfaces does increase the rate of heat transfer. However as demonstrated in experiment No 1 the time taken to achieve stable temperatures when investigating natural convection can be considerable. Therefore a forced convection experiment is described as follows.

The same procedure is utilised for the three types of plate, Flat, Pinned and Finned.

- (i) Ensure the instrument console main switch is in the off position. Ensure the fan is switched off. For the natural convection experiments the fan will not be used.
- (ii) If the flat (pinned or finned) plate is not in position, open the toggle clamps retaining the plate in the tunnel and remove the existing plate from the tunnel. Replace with the flat (pinned or finned) plate and close the toggle clamps. Note that with the plate heat exchanger the power leads exit from the top of the plates.
- (iii) Note that the flat plate will have the minimum blockage effect upon the air stream and the pinned plate will have the maximum. Hence it will not be possible to achieve the same maximum velocity reading (with the **air throttle (9)** fully open) with the pinned plate in position as with the flat plate in position. If direct comparison between finned, pinned and flat plate performance is required then it would be beneficial to test the pinned plate first in order to establish the maximum possible velocity reading  $U$ . Then the remaining plates can be tested under similar or lower air flow conditions.
- (iv) Switch on the **main switch (1)** and set the air speed to a low value by closing the **air throttle**
- (9). Increase the heater power to a suitable level such that  $t_s$  ( $T_1$ ) does not exceed  $100^\circ\text{C}$ . Allow the temperatures to stabilise and then record the surface temperature  $t_s$  ( $T_1$ ), airstream temperature  $t_a$  ( $T_5$ ), the heater supply voltage  $V$  and the air velocity reading  $U$  m/s.
- (v) Maintain the heater voltage at the same condition and then increase the air velocity by opening the **air throttle (9)** Once again allow the temperatures to stabilise and repeat the readings. Repeat the procedure at increasing air velocity if required.
- (vi) For direct comparison repeat the procedure for the three plates under similar heat input conditions and at similar velocities.

## Sample Test Results

Heater Used :- Finned Plate

Atmospheric Pressure =  $1.013 \times 10^5 \text{ kNm}^{-2}$

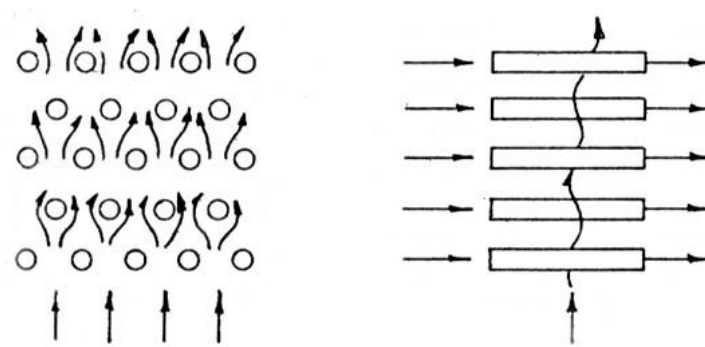
Sample No.	1	2	3	4	5	6
Time t/s						
Heater Volts V	242	242				
Heater Current I (Amps)	0.370	0.371				
Heater Power $V \times I$ Watts	89.54	89.78				
Ambient $t_a$ (T5)/°C	20.0	20.0				
Flat Plate $t_s$ (T1)/°C						
Pinned Plate $t_s$ (T1)/°C						
Pinned Plate T2/°C						
Pinned Plate T3/°C						
Pinned Plate T4/°C						
Finned Plate $t_s$ T1/°C	42.1	35.5				
Finned Plate T2/°C						
Finned Plate T3/°C						
Finned Plate T4/°C						
Surface-Air Temperature Difference $(t_s - t_a)$ / K	22.1	15.5				
Duct Air Velocity U m/s	6.7	10.3				

## Theory of Experiments

If a flat surface is heated to a temperature above that of its surroundings heat will be transferred from it by means of convection and radiation. The amount of heat apportioned to each method of heat loss will depend upon the temperature of the surface and its emissivity.

Assuming the surface is not at elevated temperatures the majority of heat will be lost due to convection caused by a local increase in buoyancy adjacent to the surface causing an upward flow. For a simple flat plate the amount of heat lost will be small due to the low heat transfer coefficient.

In order to increase the rate of heat transfer one method is to extend the surface by the addition of conducting fins or pins.



Various tube and fin layouts have been devised in order to improve the efficiency heat exchangers and thereby reduce the physical size for a given heat transfer rate. However, the objective of all of the arrangements is to promote turbulence in the fluid flowing across the extended surfaces.

This turbulence may be increased by raising the stream velocity by means of a fan or pump. Alternatively, the tube layout may be changed in order to maximise turbulence. This is achieved by ensuring that each row of tubes is positioned such that turbulence induced by the preceding row is incident upon the next row. Hence a cascade effect is produced such that the degree of turbulence increases with the depth of the tube bundle.

Alternatively the surface may be increased by the use of fins rather than pins. These can result in lower aerodynamic drag and enhanced heat transfer rates. An area where this may be important for example is in an aero engine.

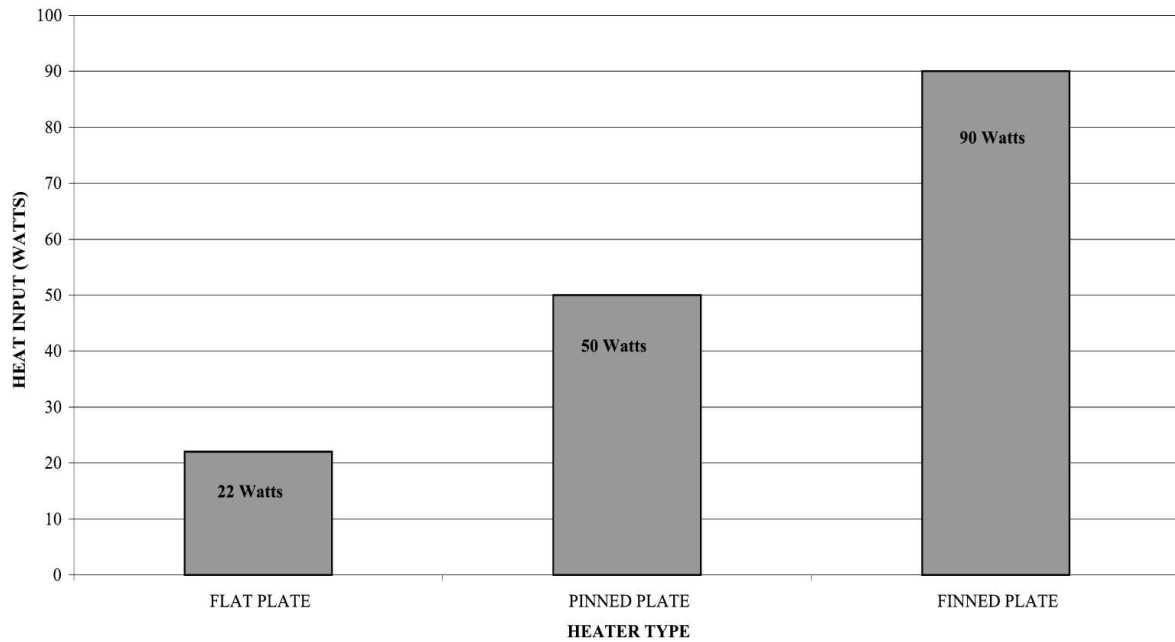
The optional Free and Forced Convection from Flat, Finned and Pinned Plates H112P allows students to compare flat, pinned and finned plates in a graphic form. For vocational and undergraduate students the demonstrations can be undertaken without prior knowledge of the theory in order to aid understanding.

## Appendix – I Symbols and Units

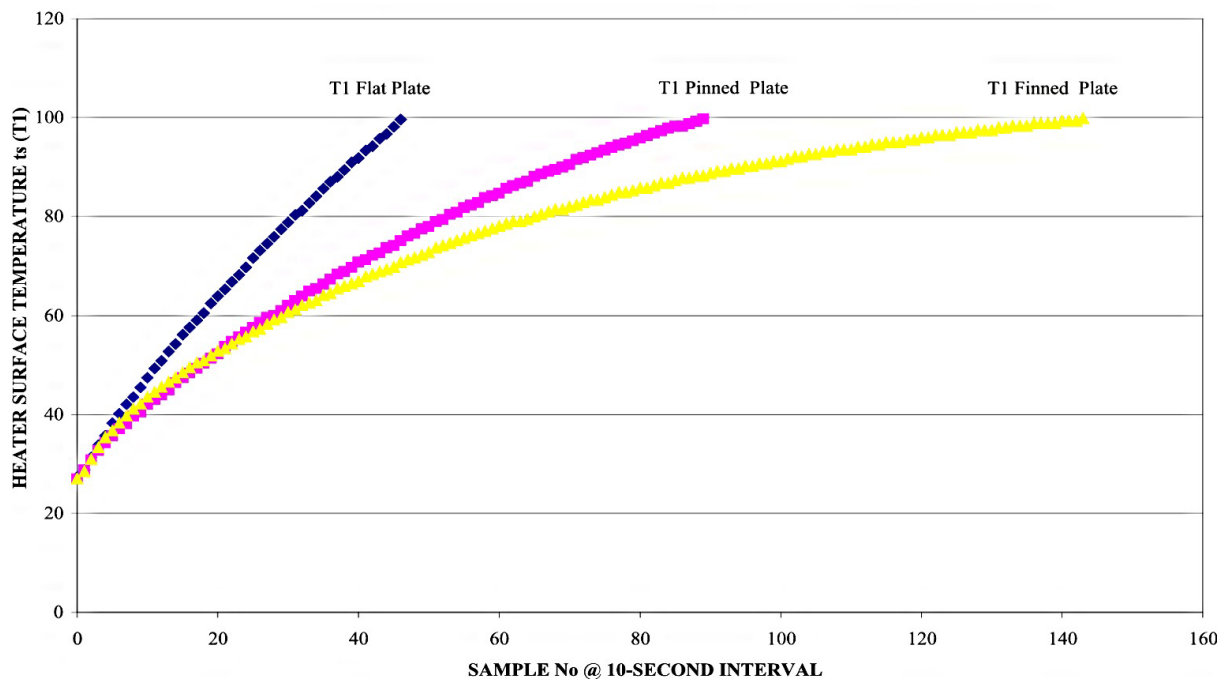
<u>Symbol</u>	<u>Quantity</u>	<u>Fundamental Unit</u>
A	Area	m <sup>2</sup>
h	Surface Heat Transfer Coefficient	W m <sup>-1</sup> K <sup>-1</sup>
I	Heater Current	Amps
k	Thermal Conductivity	W m <sup>-1</sup> K <sup>-1</sup>
P	Pressure	N m <sup>-2</sup>
$\dot{Q}$	Heat Transfer Rate	Watts
R	Heater Element Resistance	Ohms
t	Temperature (Customary)	<sup>0</sup> C
T	Temperature (Absolute)	K
U	Velocity	m s <sup>-1</sup>
V	Heater Voltage	Volts
<b>TEMPERATURE CHANNELS LOCATION</b>		
T1	Element surface t <sub>s</sub>	
T2	Pin 10mm from heater	
T3	Pin 30mm from heater	
T4	Pin 50mm from heater ON PINNED PLATE.	
	46mm from heater on FINNED PLATE	
T5	Air Temperature t <sub>a</sub>	
<b>Suffixes</b>		
a	Refers to the air or bulk fluid	
s	Refers to surface conditions	

## Appendix – II Some Useful Data

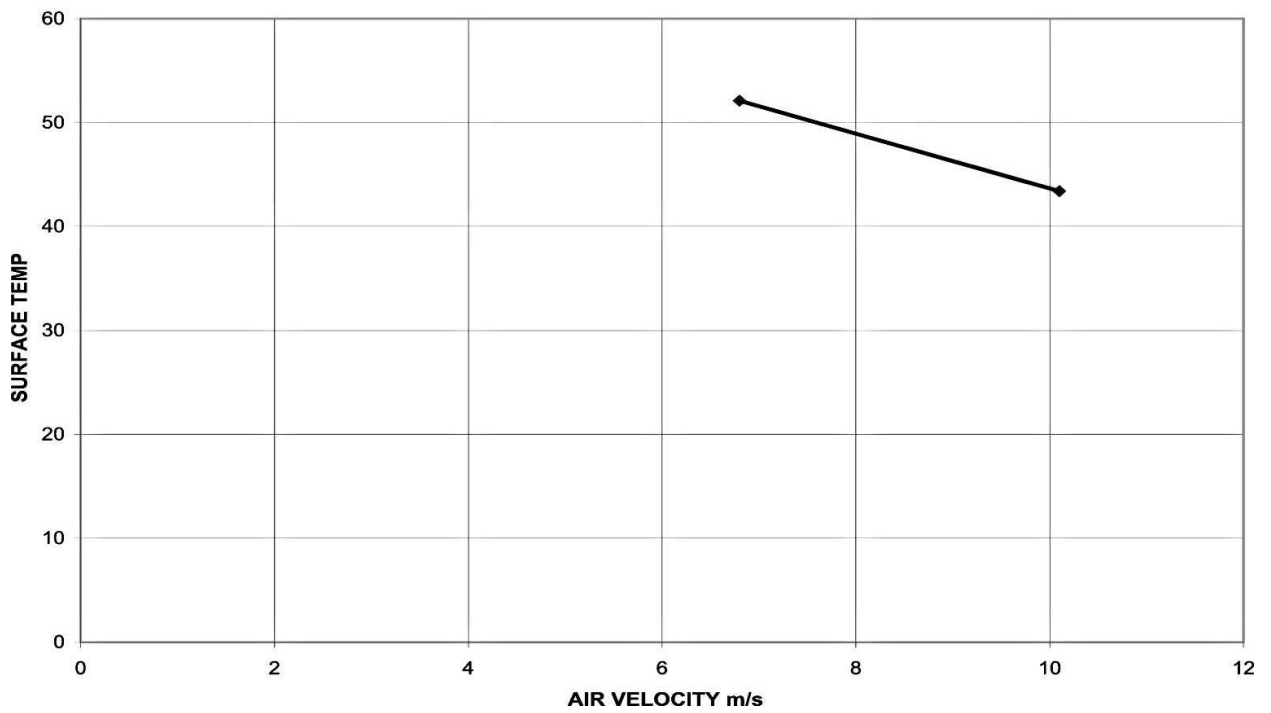
H111PP - HEATING IN FREE CONVECTIVE COOLING - MAX WATTS INPUT FOR  $t_s(T1) 100C$   
( $t_a(T2) = 23C$  DURING THIS TEST)



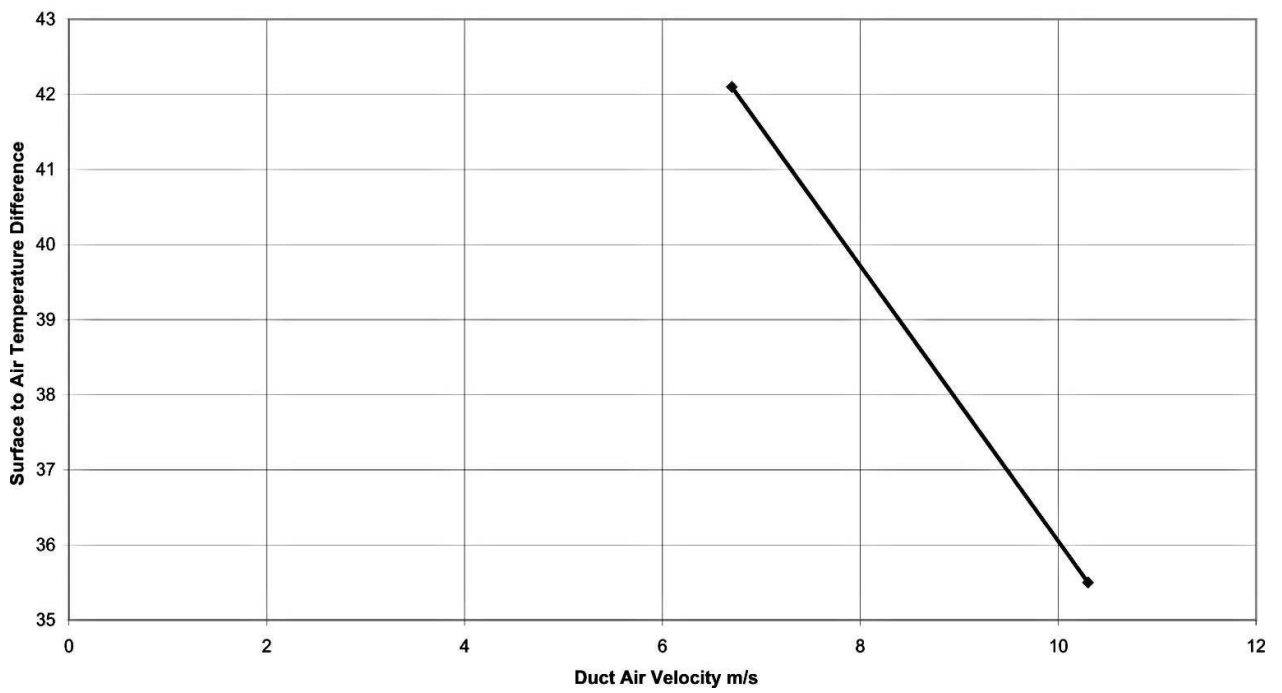
H351D PLATE HEAT EXCHANGERS  
NATURAL CONVECTION HEATING CURVE AT 100W HEAT INPUT



**PINNED PLATE 88W HEAT INPUT , SURFACE TEMPERATURE v AIR VELOCITY m/s**



**FINNED PLATE, 89W HEAT INPUT. SURFACE to AIR TEMPERATURE DIFFERENCE (ts-ta) v AIR VELOCITY**





Heater Used :-

Atmospheric Pressure =

Sample No.	1	2	3	4	5	6
Time $t/s$						
Heater Volts $V$						
Heater Current $I$ Amps						
Heater Power $V \times I$ Watts						
Ambiant $t_a$ ( $T_5$ )/ $^{\circ}C$						
Flat Plate $t_s$ ( $T_1$ )/ $^{\circ}C$						
Pinned Plate $t_s$ ( $T_1$ )/ $^{\circ}C$						
Pinned Plate $T_2$ / $^{\circ}C$						
Pinned Plate $T_3$ / $^{\circ}C$						
Pinned Plate $T_4$ / $^{\circ}C$						
Finned Plate $t_s$ $T_1$ / $^{\circ}C$						
Finned Plate $T_2$ / $^{\circ}C$						
Finned Plate $T_3$ / $^{\circ}C$						
Finned Plate $T_4$ / $^{\circ}C$						
Surface-Air Temperature Difference $(t_s - t_a) / K$						
Duct Air Velocity $U$ m/s						