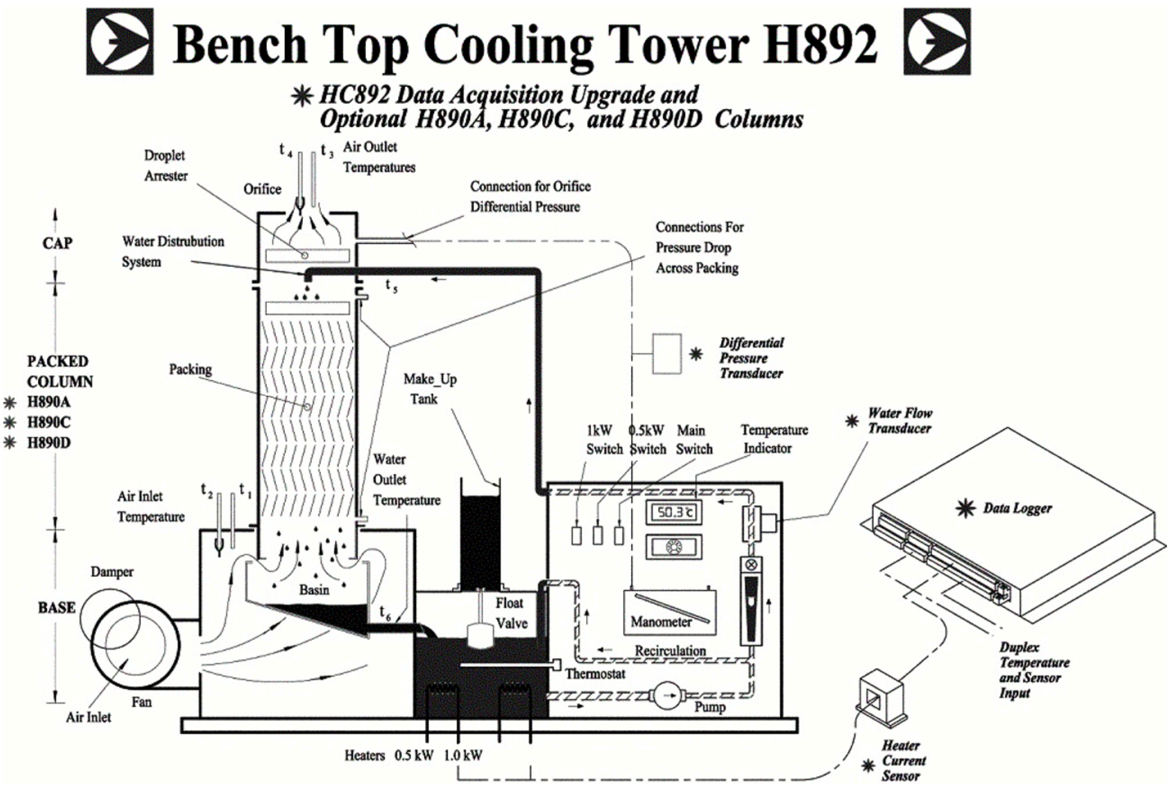
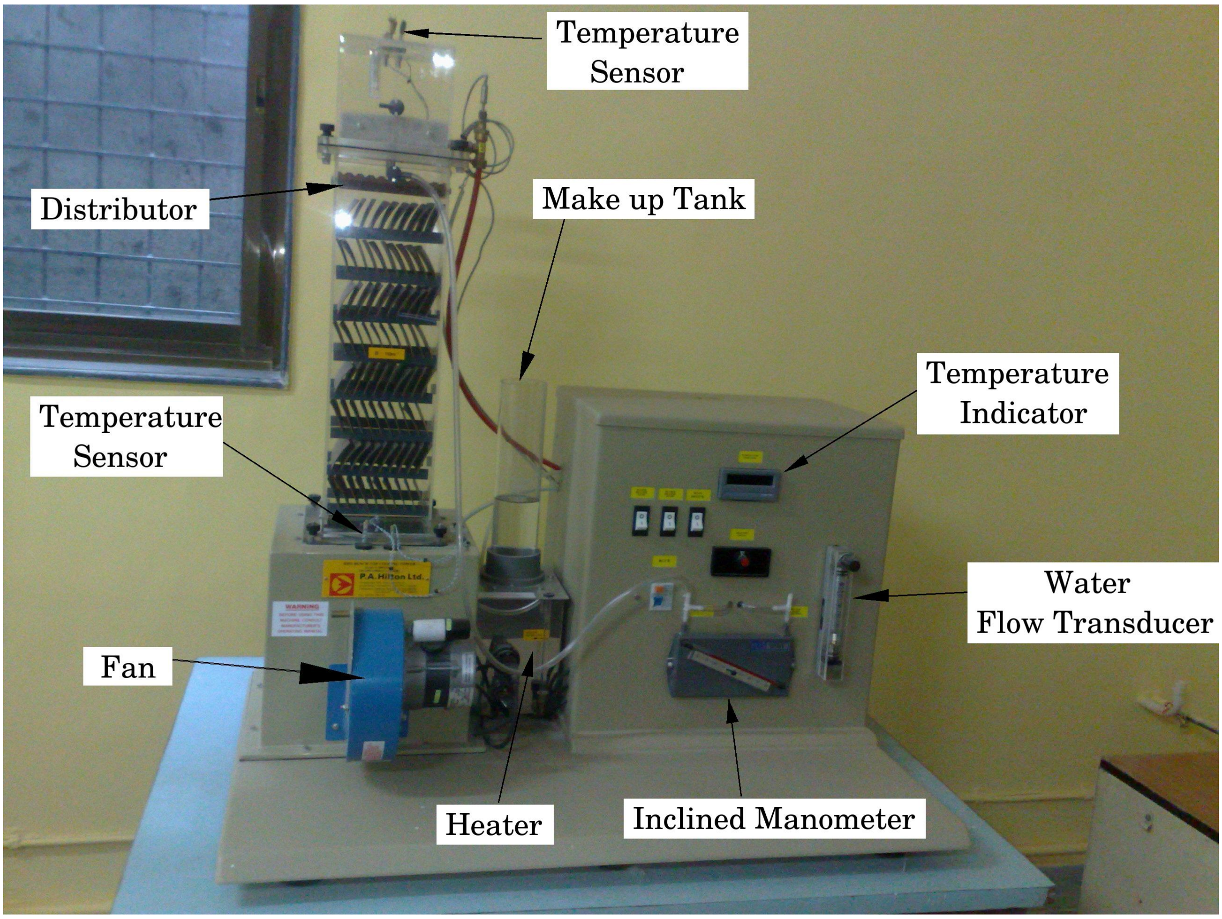
COOLING TOWER EXPERIMENT


Bench Top Cooling Tower H892
HC892 Data Acquisition Upgrade and
Optional H890A, H890C, and H890D Columns
Droplet Arrester
Orifice
t4 t3 Air Outlet Temperatures
Connection for Orifice Differential Pressure
CAP
Water Distrubution System
t5
Connections For Pressure Drop Across Packing
PACKED COLUMN
H890A
H890C
H890D
Packing
Differential Pressure Transducer
Make_Up Tank
Water Outlet Temperature
Air Inlet Temperature
t2 t1
1kW Switch
0.5kW Switch
Main Switch
Temperature Indicator
Water Flow Transducer
Data Logger
50.3℃
Damper
Basin
BASE
t6
Float Valve
Manometer
Recirculation
Thermostat
Pump
Fan
Air Inlet
Heaters 0.5 kW 1.0 kW
Duplex Temperature and Sensor Input
Heater Current Sensor


Temperature Sensor
Distributor
Make up Tank
Temperature Indicator
Temperature Sensor
Water Flow Transducer
Fan
Heater
Inclined Manometer
P.A.Hilton Ltd.

AIM: To simulate an industrial cooling tower and study its performance based on

- The cooling load
- Approach to wet bulb

DESCRIPTION :

The Bench Top Cooling Tower behaves in a similar manner and has similar components to a full size cooling tower and may be used to introduce students to their characteristics and construction.

Water Circuit:

Warm water is pumped from the load tank through the control valve and water flow meter to the column cap. After its' temperature is measured (*t5)*, the water is uniformly distributed over the top packing deck and, as it spreads over the plates, a large thin film of water is exposed to the air stream. During its downward passage through the packing, the water is cooled, largely by the evaporation of a small portion of the total flow.
The cooled water falls from the lowest packing deck into the basin, where its temperature (*t*6) is again measured and then passes into the load tank where it is re-heated before re-circulation. Due to evaporation, the level of the water in the load tank tends to fall. This causes the float operated needle valve to open and transfer water from the make-up tank into the load tank. Under steady conditions, the rate at which the water leaves the make-up tank is equal to the rate of evaporation plus any small airborne droplets in the air discharge.

Air Circuit :

Air from the atmosphere(with temperature *t*7), enters the fan at a rate which is controlled by the intake damper setting. The fan discharges into the distribution chamber and the air passes wet and dry bulb sensors (which measure the temperature *t*2 and *t*1 respectively) before entering the packed column. As the air flows through the packings, its' moisture content increases and the water is cooled. On leaving the top of the column the air passes through the droplet arrester, which traps most of the entrained droplets and returns them to the packings. The air is then discharged to the atmosphere via the air measuring orifice and further wet and dry bulb sensors (which measure the temperature *t*4 and *t*3 respectively).

Droplets of water (resulting from splashing, etc.) may become entrained in the air stream and then lost from the system. This loss does not contribute to the cooling, but must be made good by "make-up" water. To minimize this loss, a "droplet arrester", or "eliminator" is fitted at the tower outlet. This component causes droplets to coalesce, forming drops which are too large to be entrained and these fall back into the packings.

Under the action of the fan, air is driven upward through the wet packings. It will be seen that the change of dry bulb temperature is smaller than the change of wet bulb temperature, and that at air outlet there is little difference between wet and dry bulb temperatures. This indicates that the air leaving is almost saturated, i.e. Relative Humidity - 100%. This increase in the moisture content of the air is due to the conversion of water into steam and the "latent heat" for this accounts for most of the cooling effect. If the cooling load is now switched off and the unit allowed to stabilise, it will be found that the water will leave the basin close to the wet bulb temperature of the air entering. According to the local atmospheric conditions, this can be several degrees below the incoming air (dry bulb) temperature. With no load, the water would be cooled to the incoming wet bulb temperature, but this condition cannot be attained since the pump transfers about 100W to the water.

Flow through the column may be observed through the transparent casing.

Three sets of different packings, each in its own casing, are available. These may be interchanged quickly and without using tools.

Water is heated using a 1kW and/or 0.5kW electric heater.

USEFUL INFORMATION :

1. Orifice Constant:

$$\dot{m}_a = 0.0137\sqrt{\frac{x}{v_B}} = 0.0137\sqrt{\frac{x}{(1+\omega_B)v_{aB}}}$$

Where $\dot{m}_a$ = Dry air mass flow rate
x = Orifice differential (mm H_2O)
υ_B = Specific volume of steam and air mixture leaving top of column ($m^3\ kg^{-1}$)
υ_{aB} = Specific volume of dry air leaving top of column ($m^3\ kg^{-1}$)
ω_B = Specific humidity of air leaving top of the column ($kg\ kg^{-1}$)

2. Energy Transferred to Water by Pump: 0.1kW
3. Water Capacity of System: 3.0 litre (excluding make-up tank)
4. Dimensions of Column: 150mm x 150mm x 600mm high.
5. Packing Data

	A	B	C
Number of Decks	8	8	8
Number of Plates per Deck	7	10	18
Total Surface Area of Packing m^2	0.83	1.19	2.16
Height of Packing m	0.48	0.48	0.48
Packing "Density" Area/Vol m^{-1}	77	110	200

6. Temperatures

*t*1	Dry bulb temperature of air entering base of column
*t*2	Wet bulb temperature of air entering base of column
*t*3	Dry bulb temperature of air at exit from column
*t*4	Wet bulb temperature of air at exit from column
*t*5	Water temperature on entering column
*t*6	Water temperature on leaving column
*t*7	Water in make-up tank

SPECIFICATION :

Base Unit: All components are mounted on a robust G.R.P. base plate with integral instrument panel. Components include: (i) Air distribution chamber.

(ii) A tank with heaters to simulate cooling loads of 0.5, 1.0 and 1.5kW.

(iii) A make-up tank with gauge mark and float operated control valve.

(iv) A centrifugal fan with intake damper to give 0.06kg s^{-1} max. air flow.

(v) A bronze and stainless steel glandless pump. (230 V - 1 phase - 50Hz or 415 V - 3 phase - 50 Hz)

(vi) A water collecting basin.

(vii) An electrical control panel.

Packed Column : Four packed columns (A, B, C and D), each 150mm x 150mm x 600mm high, and fabricated from clear P.V.C., are available.Columns A, B and C have pressure tapping points and each contain eight decks of inclined, wettable, laminated plastic plates, retained by water distribution troughs.

Column A has 7 plates per deck (giving 77m² per m³)
Column B has 10 plates per deck (giving 110m² per m³)
Column C has 18 plates per deck (giving 200m² per m³)
Column D has no packings.
Column Cap: This fits on top of the chosen column and includes:
(i) An 80mm dia. sharp edged orifice and pressure tapping.
(ii) A droplet arrester.
(iii) A water distributor.

INSTRUMENTATION:

Temperature indicator	6 point digital temperature indicator with Type K thermocouple sensors to measure terminal water temperatures, and wet and dry bulb air temperatures
Inclined Tube Manometer	0 to 40 mm H_2O, to measure orifice differential pressure, or packing resistance.
Variable Area Flow Meter	0 to 50gm s^{-1}, with control valve, for water flow rate to packings
DIMENSIONS:	Net Weight 24kg Height 725mm Width 710mm Depth 240mm
SAFETY:	(i) Thermostat in load tank. (ii) All heaters fitted with thermal cut-outs. (iii) Fan intake fitted with mesh guard. (iv) All electrical circuits protected by circuit breakers. (v) R.C.C.B. fitted.
SOFTWARE:	Detailed Instruction Manual Large plastic coated psychrometric chart.

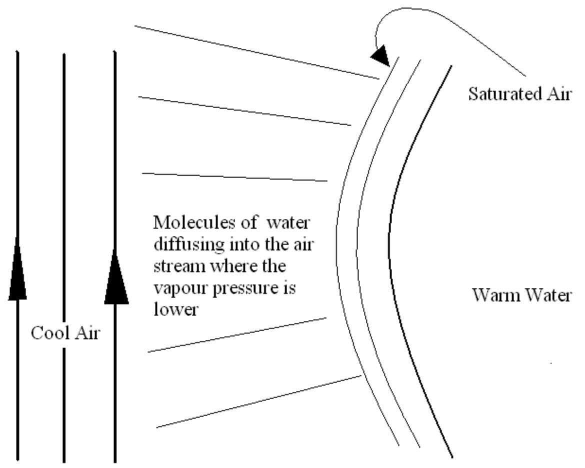
THEORY :

Cooling Tower Terms

Cooling Range	The difference between the water temperature at entry to and exit from the tower.
Cooling Load	The rate at which heat is removed from the water. This may be expressed in kW, Btu/h or k Cal/h.
Make-Up	The quantity of fresh water which must be supplied to the water circuit to make good the losses due to evaporation and other causes.
Drift or Carry Over	Droplets of water which are entrained by the air stream leaving the tower.
Packing or Fill	The material over which the water flows as it falls through the tower, so that a large surface area is presented to the air stream.
Approach to Wet Bulb	The difference between the temperature of the water leaving the tower and the wet bulb temperature of the air entering.

Basic Principles

Consider the surface of a warm water droplet or film in contact with an air stream.



Assuming that the water is hotter than the air, it will be cooled:

1. **By radiation**- This effect is likely to be very small at normal conditions and may be neglected.
2. **By conduction and convection -** This will depend on the temperature difference, the surface area, air velocity, etc.
3. **By evaporation**- This is by far the most important effect. Cooling takes place as molecules of H_2O diffuse from the surface into the surrounding air. These molecules are then replaced by others from the liquid (evaporation) and the energy required for this is taken from the remaining liquid.

Evaporation from a Wet Surface

The rate of evaporation from a wet surface into the surrounding air is determined by the difference between the vapour pressure at the liquid surface, i.e. the saturation pressure corresponding with the surface temperature, and the vapour pressure in the surrounding air. The latter is determined by the total pressure of the air and its absolute humidity.

In an enclosed space, evaporation can continue until the two vapour pressures are equal, i.e. until the air is saturated and at the same temperature as the surface. However, if unsaturated air is constantly circulated, the wet surface will reach an equilibrium temperature at which the cooling effect due to the evaporation is equal to the heat transfer to the liquid by conduction and convection from the air, which under these conditions, will be at a higher temperature.

The equilibrium temperature reached by the surface under adiabatic conditions, i.e. in the absence of external heat gains or losses, is the "wet bulb temperature", well known in connection with hygrometry.

In a cooling tower of infinite size and with an adequate air flow, the water leaving will be at the wet bulb temperature of the incoming air.
For this reason, the difference between the temperature of the water leaving a cooling tower and the local wet bulb temperature is an indication of the effectiveness of the cooling tower.
The "Approach to Wet Bulb" is one of the important parameters in the testing, specification, design and selection of cooling towers.
Conditions within a cooling tower packing are complex due to the changing air temperature, humidity and water temperature as the two fluids pass through the tower - usually in a counter flow fashion.

PROCEDURE :

The Bench Top Cooling Tower should be prepared, started and allowed to stabilize under the following suggested conditions:

Orifice differential	16 mm H_2O
Water flow rate	40 gm s^{-1}
Cooling load	0 kW

(Note: Stability is reached when there is no further appreciable change in temperature, or flow rate).
At regular intervals over a measured period of say 10 minutes, all temperatures and flow rates should be noted and the mean values entered on the observation sheet.

At the commencement of this period, fill the make-up tank to the gauge mark with distilled water. At the end of this period, refill the tank from a known quantity of distilled water in a measuring cylinder. By difference, determine the quantity of make up which has been supplied in the time interval.

While keeping the water and air flows constant, the load should be increased to 0.5 kW, and when conditions have stabilised, the observations should be repeated.

Similar tests should be made with cooling loads of 1.0 and 1.5 kW.

OBSERVATION SHEET

Atmospheric Pressure :
Orifice Differential ‘x’ mm of H_2O :
Water Flow Rate $\dot{m}_w$ g/s :
Make-up Water Temperature $t7°C$:
Packing Installed :
Packing Density m^{-1}:

TEST NO.	1	2	3	4	5	6	7
Air Inlet Dry Bulb $t1°C$							
Air Inlet Wet Bulb $t2°C$							
Air Outlet Dry Bulb $t3°C$							
Air Outlet Wet Bulb $t4°C$							
Water Inlet Temperature $t5°C$							
Water Outlet Temperature $t6°C$							
Cooling Load $\dot{Q}$ kW	0	0	0	0.5	0.5	1	1.5
Make-up Quantity m_E kg							
Time Interval y s	0	10		10			

<u>Calculations For Cooling Load of 1 kW</u>

- <u>Calculations for SFFEE:</u>

Using the wet and dry bulb temperatures, points A and B may be plotted on the psychrometric chart, and the following values read off:

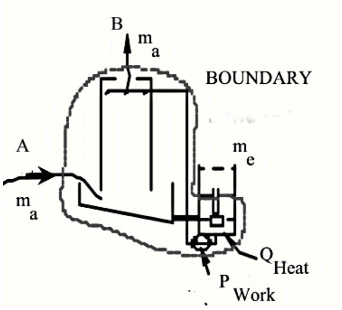
h_A= /kg
h_B= /kg
$\omega_{B=}$ /kg
$\upsilon_{aB=}$ m^3/kg of dry air

$$\dot{m}_a = 0.0137\sqrt{\frac{x}{(1+\omega_B)v_{aB}}}$$

$$\dot{m}_E = m_E / y$$

Specific Enthalpy of make-up, (h_f at room temp °C)

$$h_E =$$



Applying the Steady Flow Equation to the system indicated by the Boundary

$$\dot{Q} - P = \Delta H + \Delta KE$$

$$\dot{Q} - P = 1.0 - (-0.01) \text{ kW}$$
$$= 1.1 \text{ kW}$$

(Pump power is approximately 100W, negative)

$$\Delta \dot{H} = \dot{H}_{Exit} - \dot{H}_{Entry}$$
$$= \dot{m}_a h_B - \dot{m}_a h_A - \dot{m}_E h_E$$
$$= \dot{m}_a (h_B - h_A) - \dot{m}_E h_E$$

- Mass Balance

$$\dot{m}_E = \dot{m}_{steamB} - \dot{m}_{steamA}$$
$$= \dot{m}_a (\omega_B - \omega_A)$$

- <u>Calculations for ‘Approach to Wet Bulb’ and ‘Cooling Range’:</u>

The pump transfers approximately 100W to the water, and this should be added to the load imposed in the load tank.

Total cooling load = Applied load + Pump input
= 1.0 + 0.1 kW
= 1.1 kW

Approach to Wet Bulb = $t_6 - t_2$

Cooling Range = $t_5 - t_6$

<u>Graph</u>:

Plot a graph with ordinate as 1.‘water entry temperature $t5$’ K
and 2. ‘Water exit temperature $t6$’ K
and absicca as ‘Cooling load’ kW

Plot another graph with ordinate as ‘Approach to Wet Bulb temperature’ K
and absicca as ‘Cooling Load’

[redacted]

Conclusions