**REFRIGERATION AND AIR CONDITIONING LABORATORY**

****

**LAB SESSION 6**

**BENCH TOP COOLING TOWER**

1. Observation of the process within forced draught cooling tower.
2. Determination of all end state properties of air and water from tables or charts and the application of the steady flow equation to selected systems to draw up energy and mass balances.
3. Investigation of the effect of cooling on “approach to wet bulb” and Relationship between Cooling Load and Cooling Range.
4. Investigation of relation between air velocity and i) Wet bulb approach ii) Pressure drop through the packing.
5. Investigation of the effect of packing density on the performance of the cooling tower.

DEPARTMENT OF MECHANICAL ENGINEERING &TECHNOLOGY

UNIVERSITY OF ENGINEERING AND TECHNOLOGY LAHORE (KSK CAMPUS)

**SCHEMATIC:**

****

**THEORY:**

**Cooling Tower Terms**

**Cooling range**: The difference between the water temperature at entry to and exit from the tower.

**Cooling rate**: The rate at which heat is removed from the water. This may be expressed in KW, Btu/h or Kcal/h.

**Make-up**: The quantity of fresh water which must be supplied to the water circuit to make up for the losses due to evaporation and other causes.

**Drift or Carry out:** 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 as to expose a large surface area to the air stream)

**Approach to wet bulb:** The difference between the temperature of the water leaving the tower and the bulb temperature of the air entering. Drain down: Water deliberately removed from the water system to prevent the excessive concentration of dissolved solids (due to evaporation) and sludge (due to impurities from the atmosphere).

**BASIC UNIT**

**Water Circuit:**

Warm water is pumped from the load tank through the control valve and water flow meter to the column cap where its temperature is measured. 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, from where it flows past a thermocouple and into the load tank where it is re-heated for re-circulation. Due to the evaporation, the level of the water in the load tank slowly falls. This causes the float-operated needle valve to open and transfer water from the make-up tank to equal the rate of evaporation, plus any small airborne droplets in the air that may have discharged.

**Air Circuit:**

Air from the atmosphere, pre-heated by external means if desired, 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 upwards through the packing

**OBJECTIVE 1:**

**Observation of the process within forced draught cooling tower**

**Working Procedure**

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.

The Bench Top Cooling Tower should be set to operate with moderate air and water flows and with either 1.0 or 1.5kW cooling load.

After conditions have stabilized the following may be observed:

**Water System**

1. The warm water enters the top of the tower and is fed into troughs from which it flows via notches onto the packing. The troughs are designed to distribute the water uniformly over the packing within minimum splashing.
2. The packing have an easily wetted surface and the water spreads over this to expose a large surface to the air stream.
3. The cooled water falls from the lowest packing into the basin and may then be pumped to a process requiring cooling (or in the Bench Top Cooling Tower, to the simulated load in the load tank).
4. Due to evaporation from the water, “make-up” must be supplied to maintain the quantity of water in the cooling system. The falling level in the load tank may be observed over a period of time.
5. 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”. 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 packing.

**Air System**

1. Under the action of the fan, air is driven upward through the wet packing. 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 account for most of the cooling effect.
2. If the cooling load is now switched off and the unit allowed stabilising, 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 transfer about 100W to the water.

Note that under conditions of high ambient humidity the effectiveness of the cooling tower reduces due to the incoming air already being close to the saturated condition.

This is an interesting and instructive demonstration for students and explains the importance of “Approach to wet bulb” as a cooling tower parameter.

**OBJECTIVE 2:**

**Determination of all end state properties of air and water from tables or charts and the application of the steady flow equation to selected systems to draw up energy and mass balances**

**Working Procedure**

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

 Orifice differential 16mm $H\_{2}O$

Water flow rate 40gm $s^{-1}$

Cooling load 1.0kW

**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 temperature 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 makeup which has been supplied in the time interval.

The observation may be repeated at other water or air flow rates and with another load.

**HILTON BENCH TOP COOLING TOWER OBSERVATION SHEET**

Date: investigation: Atmospheric Pressure: 1010 mbar

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  TEST NO. | 1 | 2 | 3 | 4 | 5 | 6 |
| Packing installed  | B |  |  |  |  |  |
| Packing Density $m^{-1}$ | 110 |  |  |  |  |  |
| Air Inlet Dry Bulb$$\frac{t1}{℃}$$ | 20.8 |  |  |  |  |  |
| Air Inlet Wet Bulb$$\frac{t2}{℃}$$ | 17 |  |  |  |  |  |
| Air Outlet Dry Bulb$$\frac{t3}{℃}$$ | 22.9 |  |  |  |  |  |
| Air Outlet Wet Bulb$$\frac{t4}{℃}$$ | 22.7 |  |  |  |  |  |
| Water Inlet Temperature$$\frac{t5}{℃}$$ | 29.5 |  |  |  |  |  |
| Water Outlet Temperature$$\frac{t6}{℃}$$ | 23.1 |  |  |  |  |  |
| Water Make-up Temperature$ \frac{t7}{℃}$(Assumed same as ambient dry bulb temperature | 20.8 |  |  |  |  |  |
| Orifice Differentia $\frac{x}{mmH\_{2}O}$ | 16 |  |  |  |  |  |
| Water Flow Rate$$m\_{w/gs^{-1}}$$ | 42 |  |  |  |  |  |
| Cooling Load$$\frac{Q}{kW}$$ | 1.0 |  |  |  |  |  |
| Make-up Quantity$$\frac{mE}{kG}$$ | 0.26 |  |  |  |  |  |
| Time Interval$$\frac{y}{s}$$ | 600 |  |  |  |  |  |
| Pressure Drop Across Packing $\frac{∆p}{mm H\_{2}O}$ |  |  |  |  |  |  |

**SPECIMEN CALCULATIONS:**

**COMMENTS:**

**OBJECTIVE 3:**

**Investigation of the effect of cooling load on“wet bulb approach” and Relationship between Cooling Load and Cooling Range.**

**Working Procedure**

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

Water flow rate 40gm $s^{-1}$

Air flow manometer differential 16mm$H\_{2}O$

Cooling load 0kW

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

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

The four tests may then be repeated at another constant air flow.

The test can be repeated:

1. At other water flow rates
2. At other air flow rates
3. With other packing

**HILTON BENCH TOP COOLING TOWER OBSERVATION SHEET**

 Date: investigation: Atmospheric Pressure: 1010 mbar

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  TEST NO. | 1 | 2 | 3 | 4 | 5 | 6 |
| Packing installed  | B | B | B | B |  | B |
| Packing Density $m^{-1}$ | 110 | 110 | 110 | 110 |  | 110 |
| Air Inlet Dry Bulb$$\frac{t1}{℃}$$ | 20.0 | 20.2 | 21.2 | 21.4 |  | 20.0 |
| Air Inlet Wet Bulb$$\frac{t2}{℃}$$ | 15.7 | 15.7 | 16.4 | 16.4 |  | 15.7 |
| Air Outlet Dry Bulb$$\frac{t3}{℃}$$ |  |  |  |  |  |  |
| Air Outlet Wet Bulb$$\frac{t4}{℃}$$ |  |  |  |  |  |  |
| Water Inlet Temperature$$\frac{t5}{℃}$$ |  |  |  |  |  |  |
| Water Outlet Temperature$$\frac{t6}{℃}$$ | 16.7 | 19.9 | 23.2 | 25.2 |  | 16.7 |
| Water Make-up Temperature$ \frac{t7}{℃}$(Assumed same as ambient dry bulb temperature |  |  |  |  |  |  |
| Orifice Differentia $\frac{x}{mmH\_{2}O}$ | 16 | 16 | 16 | 16 |  | 16 |
| Water Flow Rate$$m\_{w/gs^{-1}}$$ | 40 | 40 | 40 | 40 |  | 40 |
| Cooling Load$$\frac{Q}{kW}$$ | 0 | 0.5 | 1.0 | 1.5 |  | 0 |
| Make-up Quantity$$\frac{mE}{kG}$$ |  |  |  |  |  |  |
| Time Interval$$\frac{y}{s}$$ |  |  |  |  |  |  |
| Pressure Drop Across Packing $\frac{∆p}{mm H\_{2}O}$ |  |  |  |  |  |  |

**SPECIMEN CALCULATIONS:**

**GRAPH:**

1. Draw Graph B/W Cooling Load and Approach to wet Bulb Temperature.
2. Draw Graph B/W Cooling Load & temperature.

**COMMENTS:**

**OBJECTIVE 4:**

**Investigation of relation between air velocity and i) Wet bulb approach ii) Pressure drop through the packing**

**Working Procedure:**

The Bench Top Cooling Tower should be prepared with the selected packed column and set to stabilise at a cooling load of 1.0kW and, at maximum air flow and with a water flow of40gm$s^{-1}$.

Note: To measure the pressure drop across the packing it is necessary to temporarily disconnect the plastic tube from the orifice tapping point. The tube should be reconnected to the pressure tapping point just below the packing, and another tube between the right-hand tapping on the manometer and the pressure tapping at the point of the pickings.

The test should be repeated with orifice pressure drop of 10, 4 and 1.0 mm$H\_{2}O$, but with unchanged water flow rate and cooling loads.

The test may then be repeated:

1. At another constant load.
2. At another constant water flow rate.
3. Using another packing.

**HILTON BENCH TOP COOLING TOWER OBSERVATION SHEET**

Date: investigation: Atmospheric Pressure: 1010 mbar

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  TEST NO. | 1 | 2 | 3 | 4 | 5 | 6 |
| Packing installed  | C | C | C | C |  | C |
| Packing Density $m^{-1}$ | 200 | 200 | 200 | 200 |  | 200 |
| Air Inlet Dry Bulb$$\frac{t1}{℃}$$ | 21.7 | 22.0 | 21.9 | 24.2 |  | 21.7 |
| Air Inlet Wet Bulb$$\frac{t2}{℃}$$ | 18.3 | 18.5 | 17.6 | 18.2 |  | 18.3 |
| Air Outlet Dry Bulb$$\frac{t3}{℃}$$ | 22.0 | 23.9 | 25.5 | 32.0 |  | 22.0 |
| Air Outlet Wet Bulb$$\frac{t4}{℃}$$ | 21.9 | 23.9 | 25.5 | 31.8 |  | 21.9 |
| Water Inlet Temperature$$\frac{t5}{℃}$$ | 28.5 | 30.6 | 31.9 | 37.8 |  | 28.5 |
| Water Outlet Temperature$$\frac{t6}{℃}$$ | 22.9 | 24.7 | 26.3 | 31.9 |  | 22.9 |
| Water Make-up Temperature$ \frac{t7}{℃}$(Assumed same as ambient dry bulb temperature |  |  |  |  |  |  |
| Orifice Differential $\frac{x}{mmH\_{2}O}$ | 18.5 | 10 | 4.5 | 1.0 |  | 18.5 |
| Water Flow Rate$$m\_{w/gs^{-1}}$$ | 40 | 40 | 40 | 40 |  | 40 |
| Cooling Load$$\frac{Q}{kW}$$ | 1.0 | 1.0 | 1.0 | 1.0 |  | 1.0 |
| Make-up Quantity$$\frac{mE}{kG}$$ |  |  |  |  |  |  |
| Time Interval$$\frac{y}{s}$$ |  |  |  |  |  |  |
| Pressure Drop Across Packing $\frac{∆p}{mm H\_{2}O}$ | 6 | 2.9 | 1.4 | 0.3 |  | 6 |

**SPECIMEN CALCULATIONS:**

**GRAPH:**

1. Draw Graph B/W Nominal Air Velocity & approach to Wet bulb.

**COMMENTS:**

**OBJECTIVE 5:**

**Investigation of the effect of packing density on the performance of the cooling tower**

**Working Procedure:**

Note that this experiment will only be possible if additional optional columns are available. The Bench Top Cooling Tower should be prepared, started and allowed to stabilise under the following suggested conditions:

Orifice differential 16mm$H\_{2}O$

Load 1.5 kW

Water flow rate 30gm $s^{-1}$

Column installed A

Column A should then be removed and Column B substituted. After preparation and stabilisation at the same conditions the observations should be repeated.

Finally, Column C should be installed and the observations repeated.

Note: Before removing and replacing a column, it may be desirable to carry out a series of tests at other loads, water flow rates and/or air flow rates.

**Derived Results**

|  |  |  |  |
| --- | --- | --- | --- |
| Packing Density $m^{-1}$   |  |  |  |
| Wet Bulb Approach K |  |  |  |

**HILTON BENCH TOP COOLING TOWER OBSERVATION SHEET**

Date: investigation: Atmospheric Pressure: 1010 mbar

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  TEST NO. | 1 | 2 | 3 | 4 | 5 | 6 |
| Packing installed  | C | C | C | C |  | C |
| Packing Density $m^{-1}$ | 200 | 200 | 200 | 200 |  | 200 |
| Air Inlet Dry Bulb$$\frac{t1}{℃}$$ | 21.7 | 22.0 | 21.9 | 24.2 |  | 21.7 |
| Air Inlet Wet Bulb$$\frac{t2}{℃}$$ | 18.3 | 18.5 | 17.6 | 18.2 |  | 18.3 |
| Air Outlet Dry Bulb$$\frac{t3}{℃}$$ | 22.0 | 23.9 | 25.5 | 32.0 |  | 22.0 |
| Air Outlet Wet Bulb$$\frac{t4}{℃}$$ | 21.9 | 23.9 | 25.5 | 31.8 |  | 21.9 |
| Water Inlet Temperature$$\frac{t5}{℃}$$ | 28.5 | 30.6 | 31.9 | 37.8 |  | 28.5 |
| Water Outlet Temperature$$\frac{t6}{℃}$$ | 22.9 | 24.7 | 26.3 | 31.9 |  | 22.9 |
| Water Make-up Temperature$ \frac{t7}{℃}$(Assumed same as ambient dry bulb temperature |  |  |  |  |  |  |
| Orifice Differentia $\frac{x}{mmH\_{2}O}$ | 18.5 | 10 | 4.5 | 1.0 |  | 18.5 |
| Water Flow Rate$$m\_{w/gs^{-1}}$$ | 40 | 40 | 40 | 40 |  | 40 |
| Cooling Load$$\frac{Q}{kW}$$ | 1.0 | 1.0 | 1.0 | 1.0 |  | 1.0 |
| Make-up Quantity$$\frac{mE}{kG}$$ |  |  |  |  |  |  |
| Time Interval$$\frac{y}{s}$$ |  |  |  |  |  |  |
| Pressure Drop Across Packing $\frac{∆p}{mm H\_{2}O}$ | 6 | 2.9 | 1.4 | 0.3 |  | 6 |

**SPECIMEN CALCULATIONS:**

**GRAPH:**

1. Draw Graph B/W Packing Area/Unit Volume & Approach to Wet Bulb.

**COMMENTS:**