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DESIGN OF COOLING TOWER

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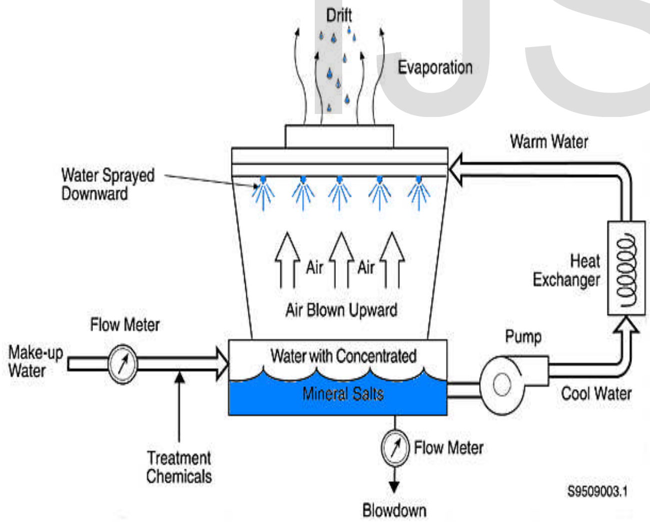
Abstract— This paper presents detailed methodology of a Induced draft cooling tower of counter flow type in which its efficiency, effectiveness, characteristics are calculated. The technical data has been taken from a mechanical draft cooling tower. Cooling towers are heat removal devices used to transfer process waste heat to the atmosphere. Cooling towers make use of evaporation whereby some of the water is evaporated into a moving air stream and subsequently discharged into the atmosphere. As a result, the remainder of the water is cooled down significantly.

Index Terms— Cooling tower, Types of cooling towers, Design of cooling tower, Different types of losses, characteristics of cooling tower, efficiency, effectiveness.

1 INTRODUCTION

A cooling tower is a semi-enclosed device for evaporative cooling of water by contact with air. It is a wooden, steel or concrete structure and corrugated surfaces or baffles or perforated trays are provided inside the tower for uniform distribution and better atomization of water in the tower. The hot water coming out from the condenser is fed to the tower on the top and allowed to tickle in form of thin drops [1] . The air flows from bottom of the tower or perpendicular to the direction of water flow and then exhausts to the atmosphere after effective cooling. To prevent the escape of water particles with air, draft eliminators are provided at the top of the tower.



SCHEMATIC DIAGRAM OF COOLING TOWER

Cooling tower reduces temperature of circulating water so that water may be used in heat exchange equipment and condensers [5]. Cooling towers are equipment devices commonly used to dissipate heat from power generation units, water-cooled refrigeration, air conditioning and industrial processes. Cooling towers offer an excellent alternative particularly in locations where sufficient cooling water cannot be easily obtained from natural sources or where concern for the environment imposes some limits on the temperature at which cooling water can be returned to the surrounding[1].

There are several important factors that govern the operation of cooling tower:

- The dry-bulb and wet-bulb temperatures of the air
- The temperature of warm water
- The efficiency of contact between air and water in terms of the volumetric mass transfer coefficient and the contact time between the air and the water
- The uniformity of distribution of the phases within the tower
- The air pressure drop
- The desired temperature of the cooled water.

Air might enter the tower driven by a density gradient (natural draft), might be pushed into the tower (forced draft) at the base or drawn into the tower (induced draft) assisted by a fan.

VARIOUS TYPES OF COOLING TOWERS:

The cooling tower might be classified into several types, but they are broadly

categorized by following considerations:

1. Whether there is direct or indirect contact
2. The mechanism used to provide the required airflow
3. The relative flow paths of air and water
4. The primary materials of construction
5. the type of heat transfer media applied
6. The tower's physical shape

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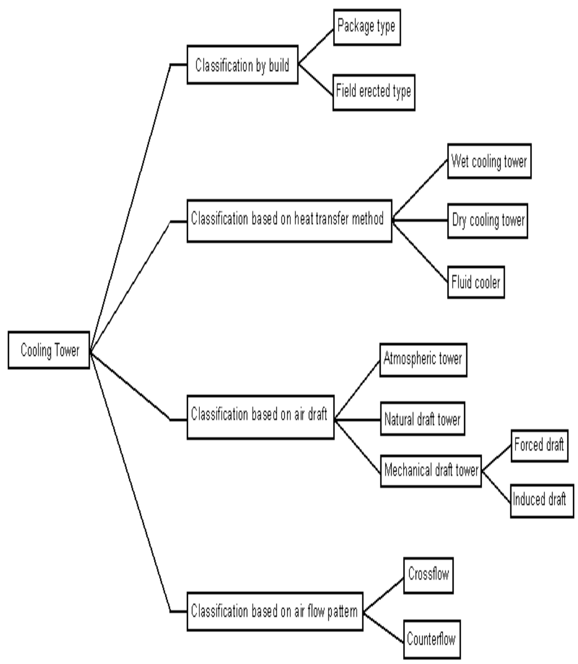


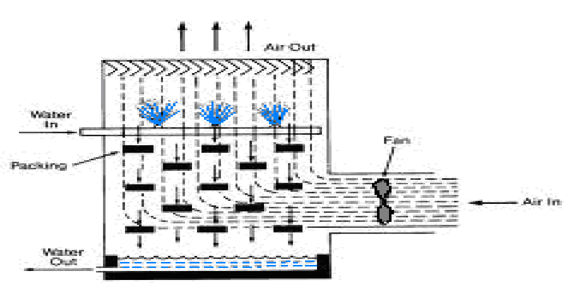
GENERAL CLASSIFICATION OF COOLING TOWERS

Classification based on air draft:

1) Atmospheric tower 2) Natural draft tower 3)Mechanical draft tower

Mechanical draft tower: Mechanical draft towers have large fans to force or draw air through circulated wate [2]. There are two different classes of mechanical draft cooling towers

a. **Forced draft**: It has one or more fans located at the tower bottom to push air into the tower [3]. During operation, the fan forces air at a low velocity horizontally through the packing and then vertically against the downward flow of the water that occurs on either side of the fan. The drift eliminators located at the top of the tower remove water entrained in the air



FORCED DRAFT COOLING TOWER

b.**Induced Draft**: A mechanical draft tower with a fan at the discharge which pulls air through tower [1] [6]. The fan induces hot moist air out the discharge. This produces low entering and high exiting air velocities, reducing the possibility of recirculation in which discharged air flows back into the air intake.

INDUCED DRAFT COOLING TOWER

DESIGN CONSIDERATION FOR COOLING TOWERS:

Once a tower characteristic has been established between the plant engineer and the manufacturer, the manufacturer must design a tower that matches the value [7].

The required tower size will be a function of:

1. Cooling range
2. Approach to wet bulb temperature
3. Mass flow rate of water
4. Wet bulb temperature
5. Air velocity through tower or individual tower cell
6. Tower height

Other design characteristics to consider are fan horse power, pump horse power make-up water source, fogging abatement, and drift eliminator [4].

CALCULATIONS FOR COOLING TOWER:

- Inlet temp of air (t_1)-27^{0}c
- Outlet temp of air (t_2)-36^{0}c
- Inlet temp of water (T_1)-40^{0}c
- Outlet temp of water (T_2)-32^{0}c
- Wet bulb temp-28^{0}c
- Mass Flow Rate (v) – 10 m^3/hr.

VALUES FROM PSYCHOMETRIC CHART:-

- Specific volume of air at inlet (V_{S1}) - 0.882 m^3/kg
- Specific volume of air at outlet (V_{S2}) - 0.931 m^3/kg
- Specific humidity of air at inlet (W_1) - 0.0227 kg/kg
- Specific humidity of air at outlet (W_2) – 0.0387 kg/kg
- Enthalpy of water at inlet temp (H_{W1}) – 167.57 kj/kg
- Enthalpy of water at outlet temp (H_{W2}) – 134.15 kj/kg
- Enthalpy of air at inlet temp (H_{a1}) – 73 kj/kg

- Enthalpy of air at outlet temp (H_{a2}) – 115 kj/kg

COOLING TOWER APPROACH:
CTA= outlet temp of water-wet bulb temp=32^0c-28^0c=4

COOLING TOWER RANGE:
CTR=inlet temp of water-outlet temp of water=40^0c-32^0c=8

MASS OF WATER:
M_W=Mass flow rate * density of water=10*10000 kg/hr.
HEAT LOSS BY WATER:
$H_L=M_W*C_{PW}*(T_1-T_2)$
=10000*4.186*(40-32)
=334880kj/hr.

VOLUME OF AIR REQUIRED (V):
$V= (H_L*V_{S1})/ [(H_{a2}-H_{a1})-\{(W_2-W_1)*C_{PW}*T_2\}]$
= (334880*0.882)/ [(115-73)-{(0.0387-0.0227)*4.186*32}]
= 18623.40099 m^3/kg.

HEAT GAINED BY AIR (H_G):
$H_G=\{V*[(H_{a2}-H_{a1})-\{(W_2-W_1)*C_{PW}*T_2\}]\}/ V_{S1}$
={1863.4009*[(115-73)-{(0.0387-0.0227)*4.186*32}]]}/0.882
=334879.9983 kj/hr.

MASS OF AIR (M_a):
$M_a=V/V_{S1}$
=18623.4009/0.882 = 21,114.96711 kj/hr.

MAKE UP WATER:
$M_{Make}= \{V*(W_2-W_1)\}/V_{S2}$
= {18623.40099*(0.0387-0.0227)}/0.875
= 234.1227 kg/hr.

CONSIDERING EVAPORATIVE LOSS
M_{Make}=234.1227*[1+(1.44/100)]
=237.494 kg/hr.

VELOCITY OF WATER IN PIPE (V_W):
$V_W=10*\{[\pi/4]*(0.1)^2\}$
V_W=1273.239 m/hr.

COOLING TOWER CHARACTERSTICS:
$(KaV/M_{W1})= [(T_1-T_2)/4]*[(1/\Delta_{h1})*(1/\Delta_{h2})*(1/\Delta_{h3})*(1/\Delta_{h4})]$
Δ_{h1}=value of H_w-H_a at $T_2+0.1(T_1-T_2)$
=value of H_w-H_a at {32+0.1(40-32)}
= value of H_w-H_a at 32.8
=44.15 (since H_w at 32.8 is 134.15 and H_a at 32.8 is 90)
Δ_{h2}=value of H_w-H_a at $T_2+0.4(T_1-T_2)$
=value of H_w-H_a at 32+0.4(40-3)
=46.68 (since H_w at 35.2 is 146.68 and H_a at 35.2 is 100)
Δ_{h3}=value of H_w-H_a at $T_1-0.4(T_1-T_2)$
=value of H_w-H_a at 40-0.4(40-32)
= value of H_w-H_a at 36.8 =35.86 (H_w at 36.8 is150.86 and H_a at 36.8 is 115)
Δ_{h4}=value of H_w-H_a at $T_1-0.1(T_1-T_2)$
=value of H_w-H_a at 40-0.1(40-32)
= value of H_w-H_a at 39.2
=37.57 (since H_w at 39.2 is 167.57 and H_a at 39.2 is 130)
$(KaV/M_{W1})= [(T_1-T_2)/4]*[(1/\Delta_{h1})*(1/\Delta_{h2})*(1/\Delta_{h3})*(1/\Delta_{h4})]$
=[(40-32)/4]*[(1/44.15)*(1/46.68)*(1/35.86)*(1/37.57)]
= 0.1971

EFFICIENCY OF COOLING TOWER:
$\eta= [(T_1-T_2)/(T_1-WBT)]$
= [(40-32)/(40-28)]
= 0.666

EFFECTIVENESS OF COOLING TOWER:
$\varepsilon = [(T_1-T_2)/(T_1-T_{a1})]$
= [(40-32)/(40-7)]
=0.61

DIFFERENT TYPES OF LOSSES:
- DRIFT LOSS (DL)
  DL= $(0.20*M_W)/100$
  = (0.20*10000)/100
  = 20 kg/hr.
- WINDAGE LOSS (WL):
  WL= 0.005* M_{W1}
  = 0.005*10000
  = 50kg/hr.
- EVAPORATIVE LOSS:
  EL=0.00085* M_W*(T_1-T_2)
  = 0.00085*10000*(40-32)
  = 68kg/hr.
- BLOW DOWN LOSS:
  BL= [EL/(CYCLES-1)]
  No of cycles= (XC/XM)
  Where XC is concentration of solids in circulating water
  Where XM is concentration of solids in make-up water

WATER BALANCE EQUATION:
M=WL+EL+OL
=20+68+50
=138
(XC/XM)= [(M/(M-EL)]
= [138/(138-68)]
=1.971
BL= [EL/(CYCLES-1)]
= 70.03kg/hr.
≈ 70kg/hr.

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NOMENCLATURE

HG	heat gained
HL	heat loss
Hw	enthalpy of water
Ha	enthalpy of air
Ma	mass of air
MMake	make up water
VW	volume of water
VS	specific volume

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