DESIGN, CONSTRUCTION AND PERFORMANCE TEST OF INDUCED DRAFT WET COUNTER FLOW COOLING TOWER

This thesis paper is submitted to Department of Mechanical Engineering, Sonargaon University of partial fulfillment in requirements for the degree of Bachelor of Science in Mechanical Engineering.

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ABSTRACT

A cooling tower is a heat rejection device that rejects waste heat to the atmosphere through the cooling of a water stream to a lower temperature. Cooling towers are used in all heat producing industries. Cooled water is needed for air conditioners, manufacturing processes, power generation and many other heat transfer related operations. The purpose of this thesis is to design a counter flow induced draft wet cooling tower with a view to analyze the performance of the cooling tower. There are two shapes of cooling tower rectangular and circular cooling tower. In our thesis we are going to design rectangular cooling tower named as induced draft counter flow cooling tower. Induced draft towers are typically mounted with a fan at the top of the cooling tower, which allows hot air out and pulls air throughout. The high exiting air velocities reduces the chance of re-circulation. 2D CAD model design is created by AutoCAD 2016 . Construction of induced draft cooling tower is made, with necessary components such as GP sheet with necessary steel structure for bearing the load of the tower . The size of this cooling tower is 4.67ft (1.42m) height and 1.25ft(0.381m) wide rectangular shape cooling tower. After finished the project collecting technical parameter data and after calculation result shows that the efficiency 55% for the hot water mass flow rate of 480kg/hr.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

1.1 Introduction:

Cooling towers are a very important part of many chemical and power plants. The primary task of a cooling tower is to reject heat into the atmosphere. They represent a relatively inexpensive and dependable means of removing low-grade heat from cooling water. The make-up water source is used to replenish water lost to evaporation. Hot water from heat exchangers is sent to the cooling tower. The water exits the cooling tower and is sent back to the exchangers or to other units for further cooling. Typical closed loop cooling tower system is shown in Fig. 1.1

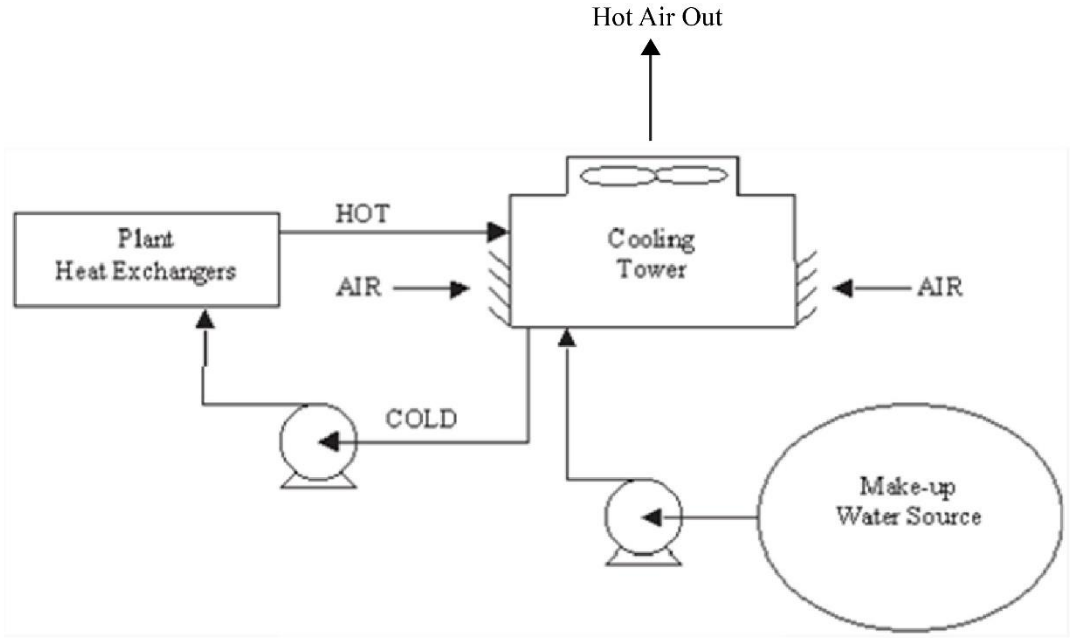

Fig. 1.1: Cooling water system

Cooling towers are widely used in oil refineries, petrochemical plants, thermal power plants, nuclear power plants, food processing plants, natural gas plants, etc. In Bangladesh large cooling towers are mainly used in Urea-fertilizer factories and some power plants. Small and medium size cooling towers are found in many small and medium industries and air conditioning of a large commercial building. Due to lack of technological capability in our country, even small size of cooling towers are imported from our neighboring counties. Although the technology of the cooling tower is well established. Ensuring its performance throughout the year with seasonal variation in the atmospheric condition is a challenging problem.

1.2 Cooling Tower Types: There are two main types of cooling towers.

a. Natural draft cooling tower(no fan)
b. Mechanical draft cooling tower(mechanical fan)

a. Natural Draft Cooling Tower:

There is no fan in natural draft tower. These towers use very large concrete chimneys to introduce air through the media. Due to the large size of these towers, they are generally used for water flow rates above 45,000 m3/hr. These types of towers are used only by utility power stations.

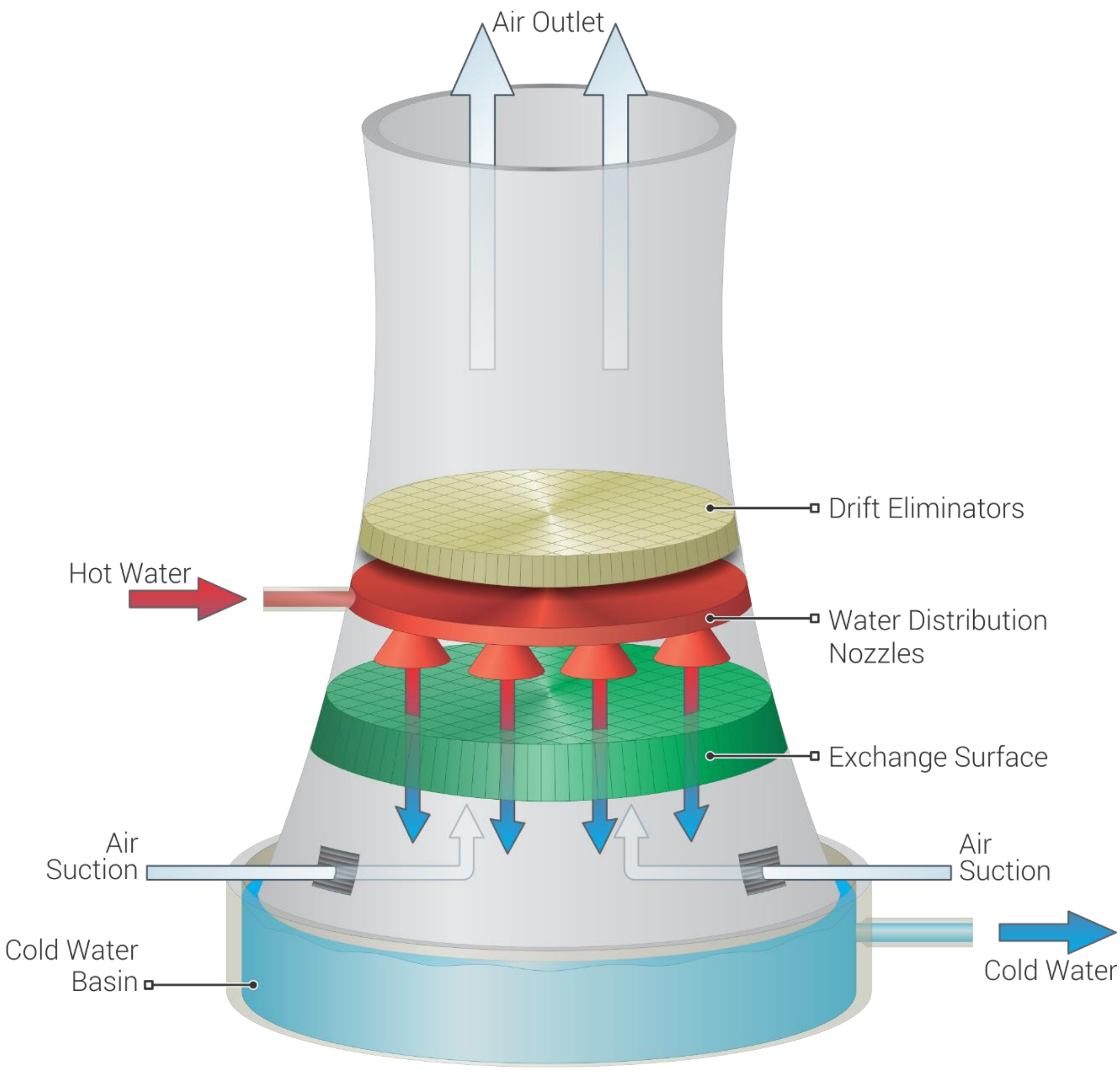

Fig. 1.2: Natural draft cooling tower

b. Mechanical Draft Tower:

Utilize large fans to force or suck air through circulated water. The water falls downward over fill surfaces, which help increase the contact time between the water and the air this helps maximize heat transfer between the two. Cooling rates of Mechanical draft towers depend upon their fan diameter and speed of operation. Since, the mechanical draft cooling towers are much more widely used, the focus is on them in this chapter.

1.3 Types of Mechanical Draft Tower:

I. According to air and water contact:

Mechanical draft towers are two types according to air and water contact:

a. Counter Flow Cooling towers: direction of air and water is reverse

b. Cross Flow Cooling towers: direction of air and water is approximately perpendicular

a. Counter Flow Cooling Towers:

In counter flow cooling towers the air is entered beneath the fills and moves upward opposite to the direction of the water flow. The air enters beneath the fill material and then rise upward through the fill material.

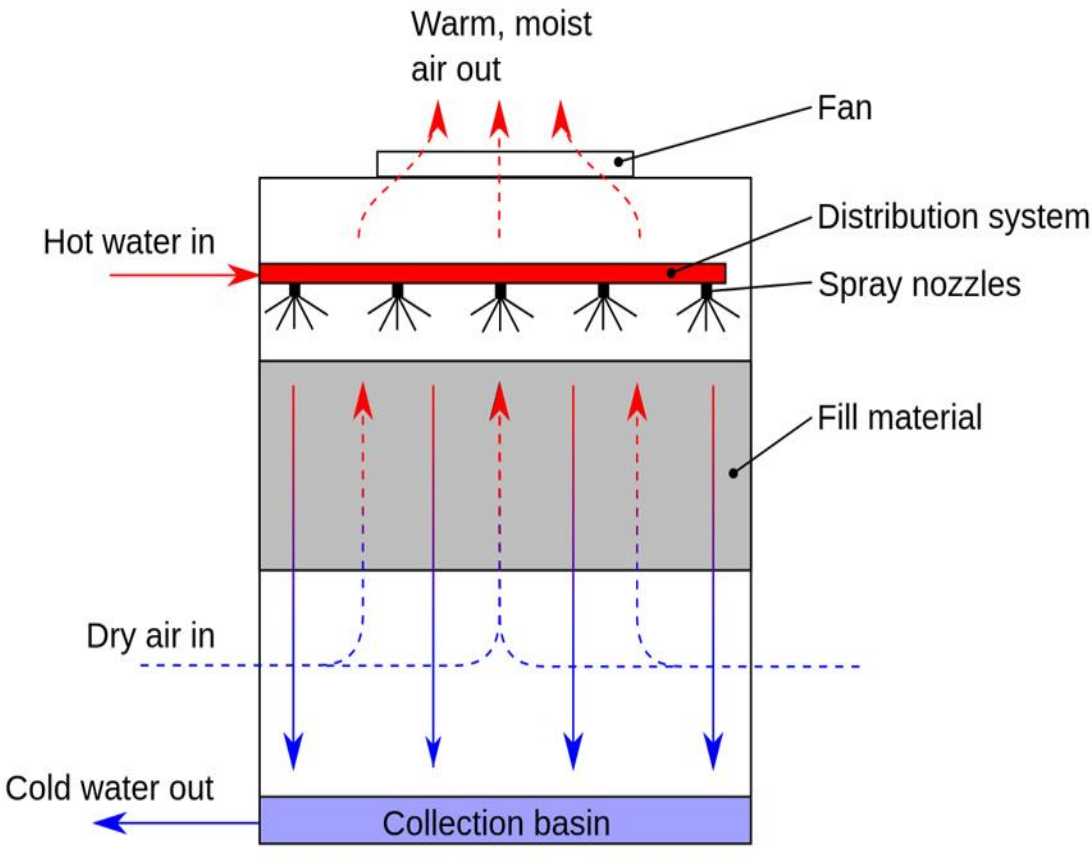

Fig. 1.3: Counter flow cooling tower

b. Cross Flow Cooling Towers:

In cross flow cooling tower water enters perpendicularly while air enters for the side walls of the tower horizontally and then rise upward from the center of the cooling tower. In crossflow cooling towers air enters at 90 degree to the direction of water.

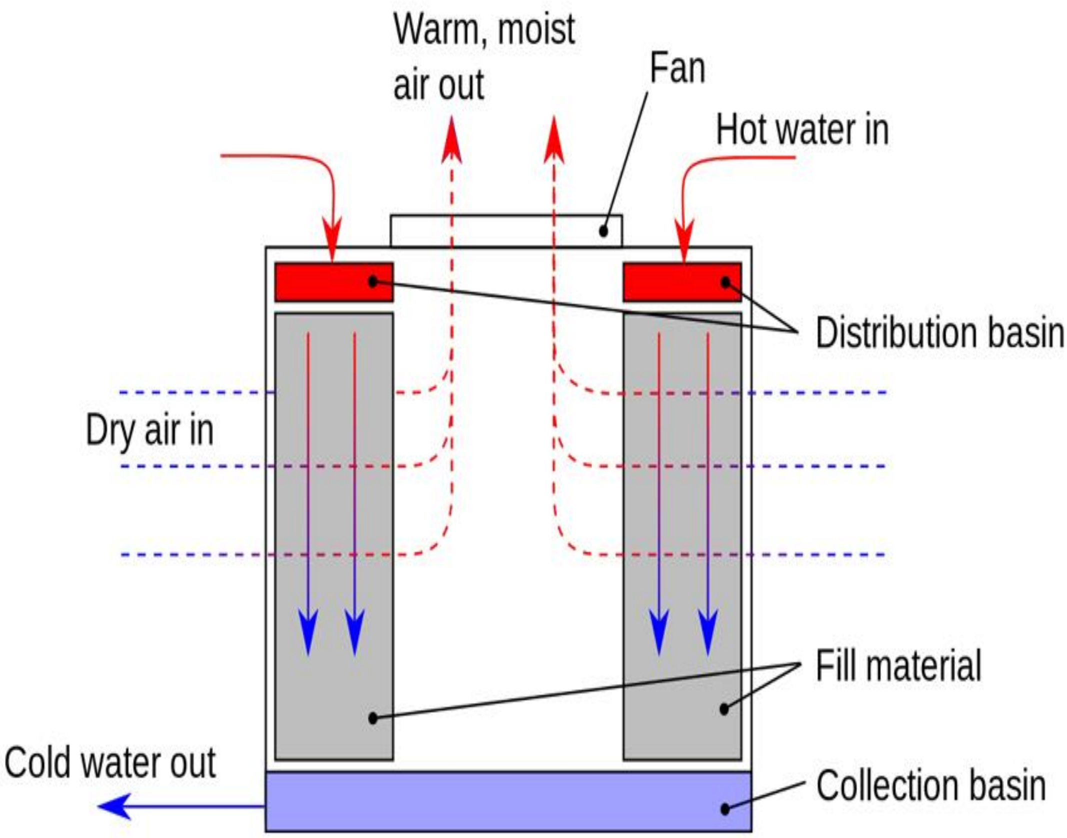

Fig. 1.4: Cross flow cooling tower

II. According to Fan Location:

a. Forced draft cooling tower:

Forced draft cooling tower is a mechanical draft cooling tower, which is less efficient than induced draft cooling tower. In a induced draft cooling tower exhaust fan placed at the air inlet of base of the cooling. Both axial and centrifugal fans can be used.

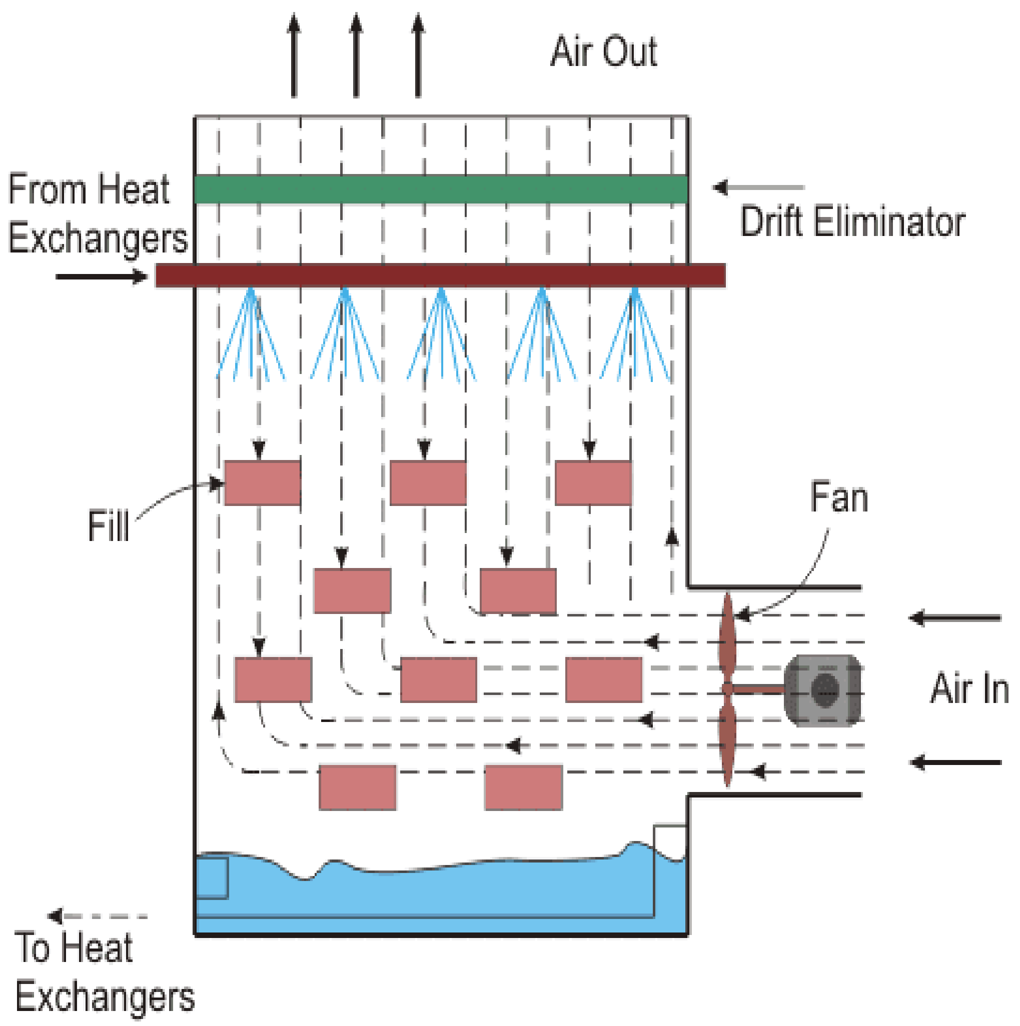

Fig. 1.5: Forced draft cooling tower

b. Induced Draft Cooling Tower:

Induced draft cooling tower is a mechanical draft cooling tower, which is more efficient than forced draft cooling tower. In induced draft cooling tower exhaust fan placed at air outlet top of the cooling tower. Axial fans are always used for this type of draft.

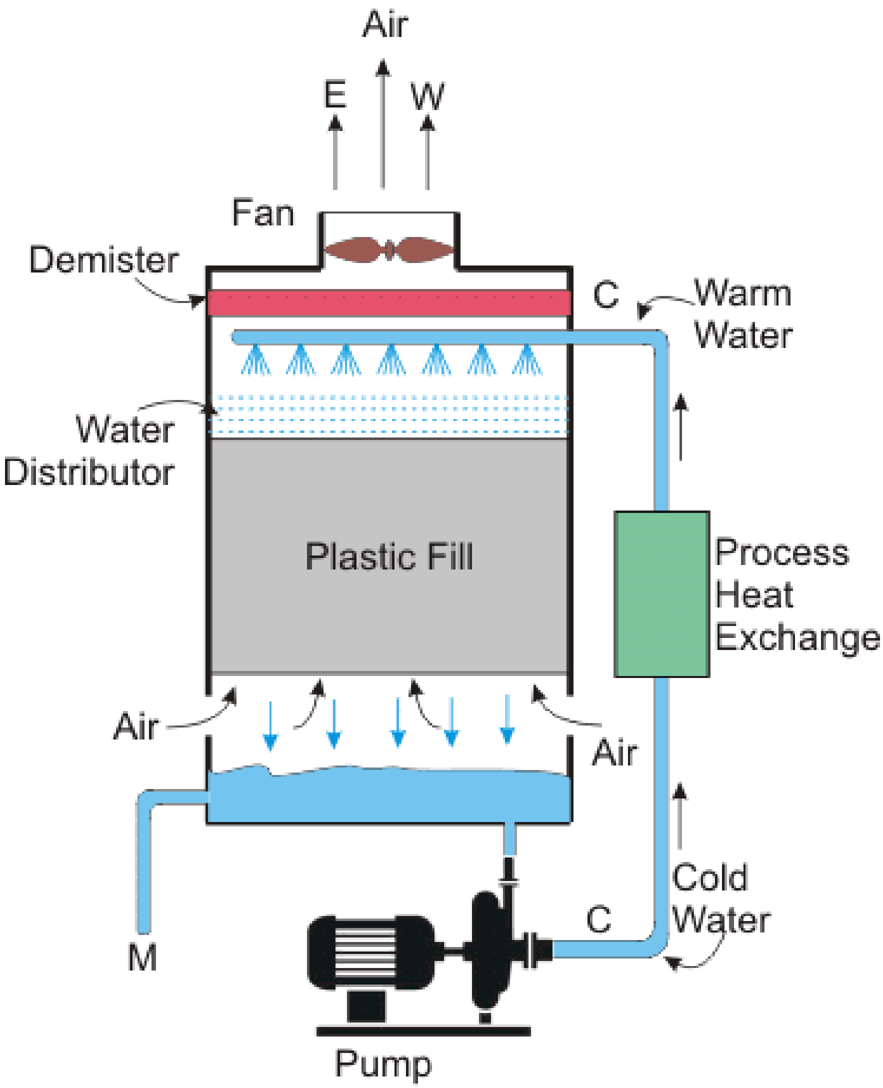

Fig. 1.6: Induced draft cooling tower

1.4: Various type of Mechanical Draft Cooling Tower in one Figure:

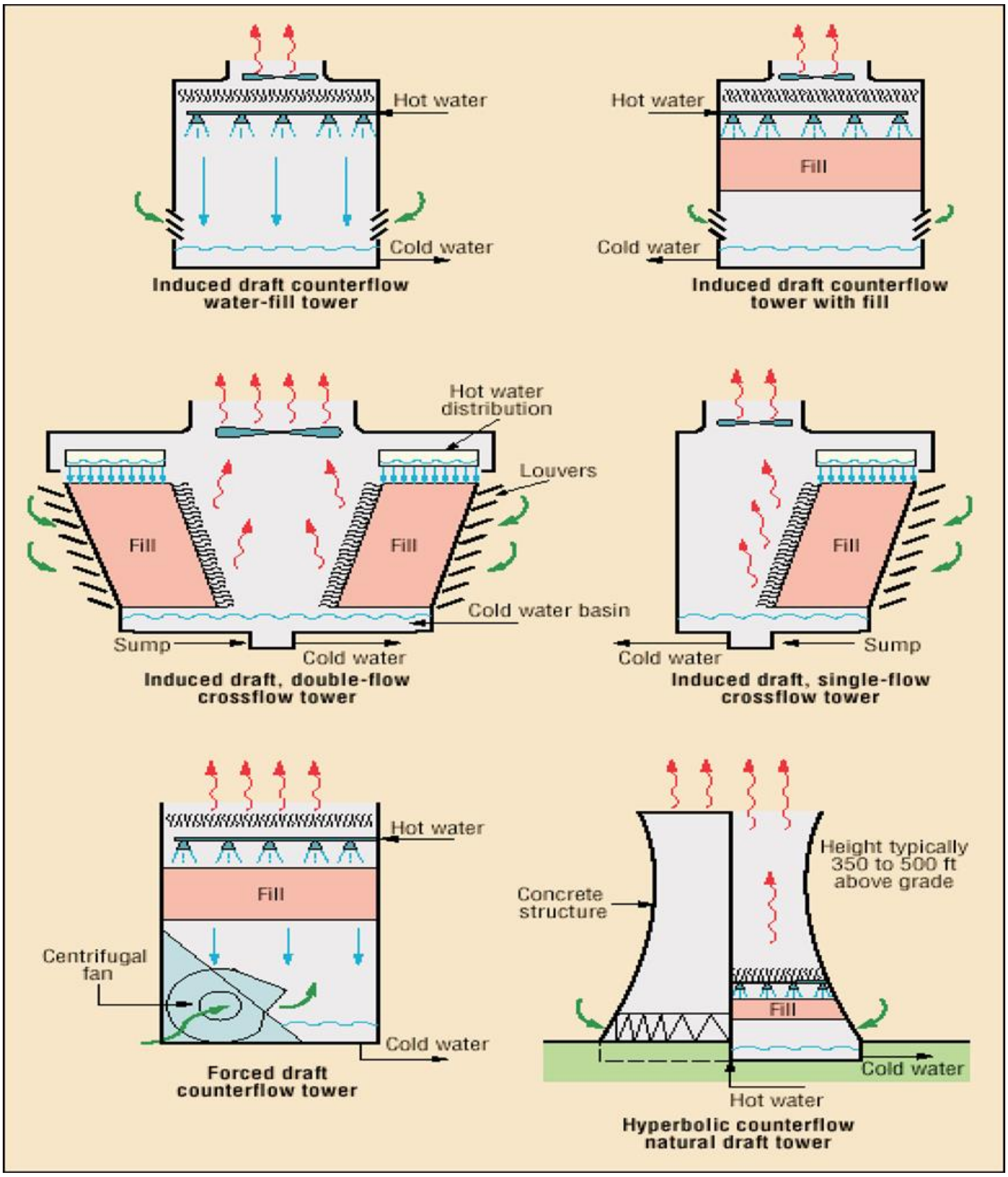

Fig. 1.7: Various type of mechanical draft cooling tower

1.5 Literature Review:

The cooling tower is of recent but obscure origin, first appearing in technical literature during the last few years of the 19th century. Beginning with the cooling pond, the cooling capability was increased by returning the water as a spray or by flowing the water over baffles or a series of platforms. These makeshift arrangements led to the platform tower that, when extended, became the atmospheric deck tower. The evaporative cooling allowed the water to approach the wet bulb rather than the dry bulb temperature as a limit, with the wind moving the air cross flow to the water. The additions of a chimney to induce a flow of air made the tower independent of wind velocity and counter flow possible. The draft induced by a chimney is a function of the ambient air temperature, making the natural draft tower independent of wind velocity. The development of cooling tower theory seems to begin with Fitzgerald.

Many people like Mosscrop, Coffey & Horne, Robinson, and Walker, etc. tried to develop the theory. The early investigators of cooling tower theory grappled with the problem presented by the dual transfer of heat and mass. The Merkel theory overcomes this by combining the two into a single process based on enthalpy potential. In 1925 Dr. Frederick Merkel from faculty of the Technical College of Dresden in Germany developed the theory. Liechtenstein introduced the "Cooling Tower" equation in 1943 and he used Merkel theory in conjunction with differential and fundamental equations to define cooling tower boundary conditions. As stated by Liechtenstein the use of his method required a laborious trial and error graphical integration solution for tower design. During his employment with the Foster-Wheeler Corporation, he published a limited edition of "Cooling Tower Black Book" in 1943.The tower demand calculations were incorporated into a volume of curves eliminating the need for tedious busy work. A similar publication entitled "Counter Flow Cooling Tower Performance" was released during 1957 by J. F. Pritchard and Co. of California. The so-called "Brown Book" allows the cooling tower characteristic curves to be plotted as straight lines.

The publication includes cooling tower design data for various types of counter flow fill. With the advent of the computer age the Cooling Tower Institute published the "Blue Book" entitled "Cooling Tower Performance Curves" in 1967. The curves contain a set of 821 curves, giving the values of KaV/L for 40 wet bulb temperatures, 21 cooling ranges and 35 approaches. Baker and Shryock (1961) used the Markel theory to analyze the cooling tower performance, they suggested an equation for performance characteristics when air velocity variation is considered. Crozier (1980) suggested that increasing the temperature of water to the cooling tower cuts down the quantity of water circulated through the tower, thus increasing the performance of the cooling tower. It also suggested that cooling tower investment and operating cost are reduced by returning the water to the tower as hot as possible. The models developed by Bernier (1994) and Fisenko et al. (2004) are for spray type cooling towers, which assumes that water droplet fall freely at a constant velocity. This is not a true reflection as in most cooling towers splash or film type packing is used to increase heat transfer surface and time. The model shows that cooling is increased by increasing air flow rate. However, there must be a compromise between high air flow rates and fan energy consumption. This model has been neglected the presence of tower filling material.

1.6 Objective:

The main objectives of this thesis are as follows:

- To study about induced draft counter flow cooling tower.
- To design a locally made of induced draft counter flow cooling tower.
- To construct a locally made of induced draft counter flow cooling tower.
- To test the performance of a locally made of induced draft wet counter flow cooling tower.

CHAPTER II

THEORY

2.1 Theory:

Cooling tower cool the warm water discharged from the condenser and feed the cooled water back to the condenser. They, thus, reduce the cooling water demand in the power plant. They can be either wet or dry type

2.2 Wet Cooling Tower:

Wet cooling tower have a hot water distribution system that shower or sprays water evenly over a lattice of horizontal slats or bras called fill or packing. The fill thoroughly mixes the falling water with air moving through the fill as the water splashes down from one fill level to another by gravity. Outside air enters the tower through louvers on the side of the tower. Intimate mixing of water and air enhance heat and mass transfer (evaporative cooling). Cold water is collected in a concrete basin at the bottom of the tower, from where it is pumped back to the condenser. Hot and moist air leaves the tower from the top.

Air entering the tower is unsaturated and as it comes in contact with the water spray, water continues to evaporate till the air becomes saturated. So, the minimum temperature to which water can be cooled is the adiabatic saturated or wet bulb temperature of the ambient air. At this temperature (WTB), air is 100% saturated and cannot absorb any more water vapor. Hence, there will be contact with warm water spray and so the air temperature rises.

A cooling tower is specified by

(a) Approach,
(b) Range, and
(c) Cooling efficiency.

2.3 Cooling Tower Performance:

The important parameters, from the point of determining the performance of cooling towers, are:

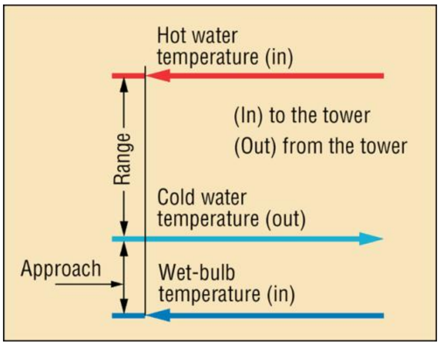

Fig 2.1: Range and approach

2.3.1 Approach:

This is the difference between the cooling tower outlet cold water temperature and ambient wet bulb temperature. The lower the approach the better the cooling tower performance. Although, both range and approach should be monitored, the ' Approach' is a better indicator of cooling tower performance.

Approach (°C) = [CT outlet water temp (°C) - Wet bulb temp (°C)]

2.3.2 Range:

This is the difference between the cooling tower water inlet and outlet temperature. A high CT Range means that the cooling tower has been able to reduce the water temperature effectively, and is thus performing well. The formula is:

Range (°C) = [CT inlet water temp (°C) - CT outlet water temp (°C)]

2.3.3 Efficiency:

This is the ratio between the range and the ideal range (in percentage), i.e. difference between cooling water inlet temperature and ambient wet bulb temperature, or in other words it is = Range / (Range + Approach). The higher this ratio, the higher the cooling tower efficiency.

Efficiency(%) = Range / (Range+ Approach) × 100

2.3.4 Cooling Capacity:

Cooling capacity. This is the heat rejected in kCal/hr or TR, given as product of mass flow rate of water, specific heat and temperature difference.

2.3.5 Evaporation Loss:

This is the water quantity evaporated for cooling duty. Theoretically the evaporation quantity works out to 1.8 m3 for every 1,000,000 kCal heat rejected. The following formula can be used [5]

$$\text{Evaporation Loss } (m^3/hr) = 0.00085 \times 1.8 \text{ x circulation rate } (m^3/hr) \times (T_1\text{-}T_2)$$

Where, T_1-T_2 = Temp. difference between inlet and outlet water.

2.3.6 Cycles of Concentration (C.O.C):

This is the ratio of dissolved solids in circulating water to the dissolved solids in makeup water.

2.3.7 Blow Down Losses:

Blow down losses depend upon cycles of concentration and the evaporation losses and is given by formula:

$$\text{Blow down} = \text{Evaporation loss} / (\text{C.O.C.} - 1)$$

2.3.8 Liquid/Gas (L/G) ratio:

Liquid/Gas (L/G) ratio, of a cooling tower is the ratio between the water and the air mass flow rates. Against design values, seasonal variations require adjustment and tuning of water and air flow rates to get the best cooling tower effectiveness through measures like water box loading changes, blade angle adjustments.

Thermodynamics also dictate that the heat removed from the water must be equal to the heat absorbed by the surrounding air:

$$L(T_1 – T_2) = G(h_2 – h_1)$$

$$L/G = (h_2 – h_1)/(T_1 – T_2)$$

Where:

L/G = liquid to gas mass flow ratio (kg/kg)

T_1 = CT inlet water temp (°C)

T_2 = CT outlet water temp (°C)

h_2 = enthalpy of air-water vapor mixture at exhaust wet- bulb temperature (same units as above)

h_1 = enthalpy of air-water vapor mixture at inlet wet-bulb temperature.

CHAPTER III

PROPOSED DESIGN

3.1 2D CAD Drawing:

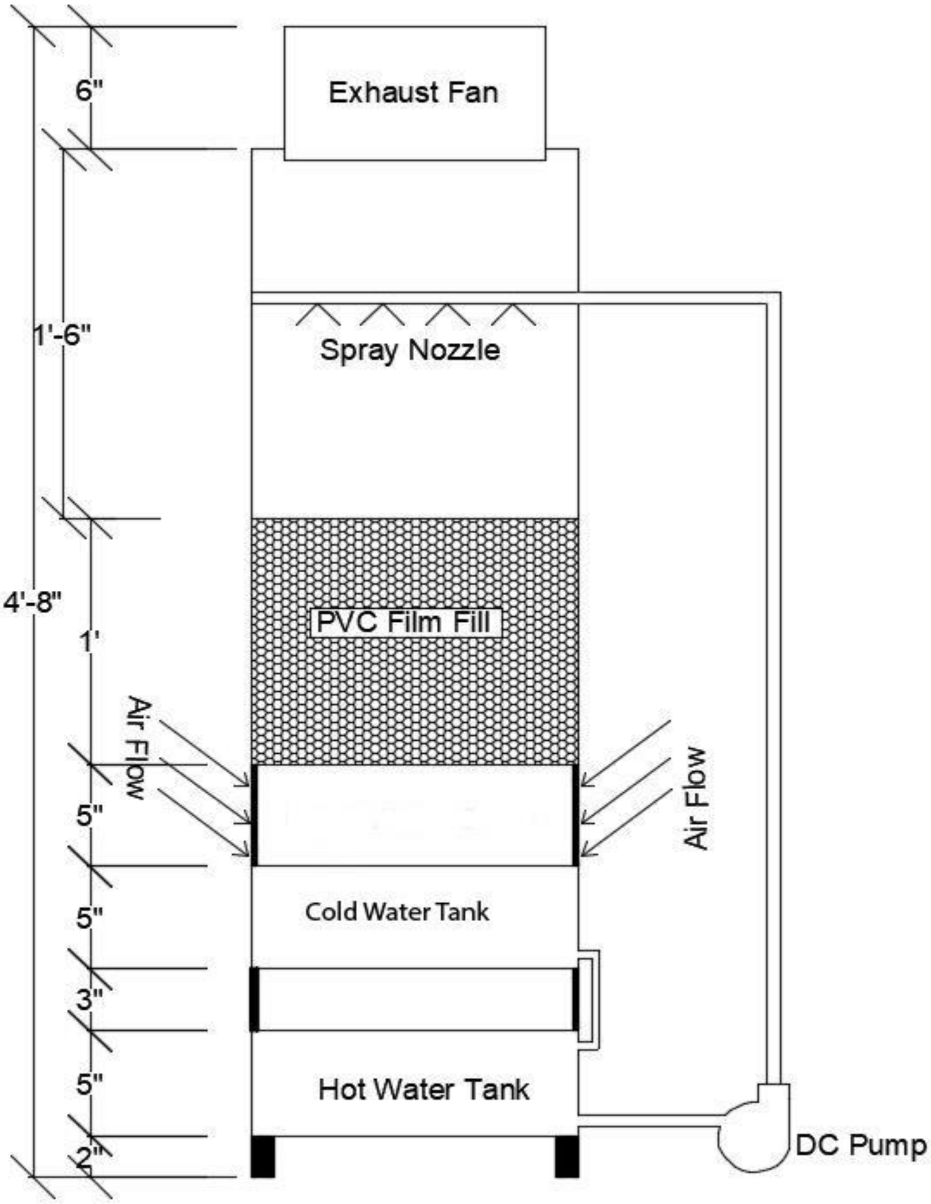

Fig. 3.1: 2D CAD Drawing of model of induced draft counter flow wet cooling tower

3.2 3D CAD Model:

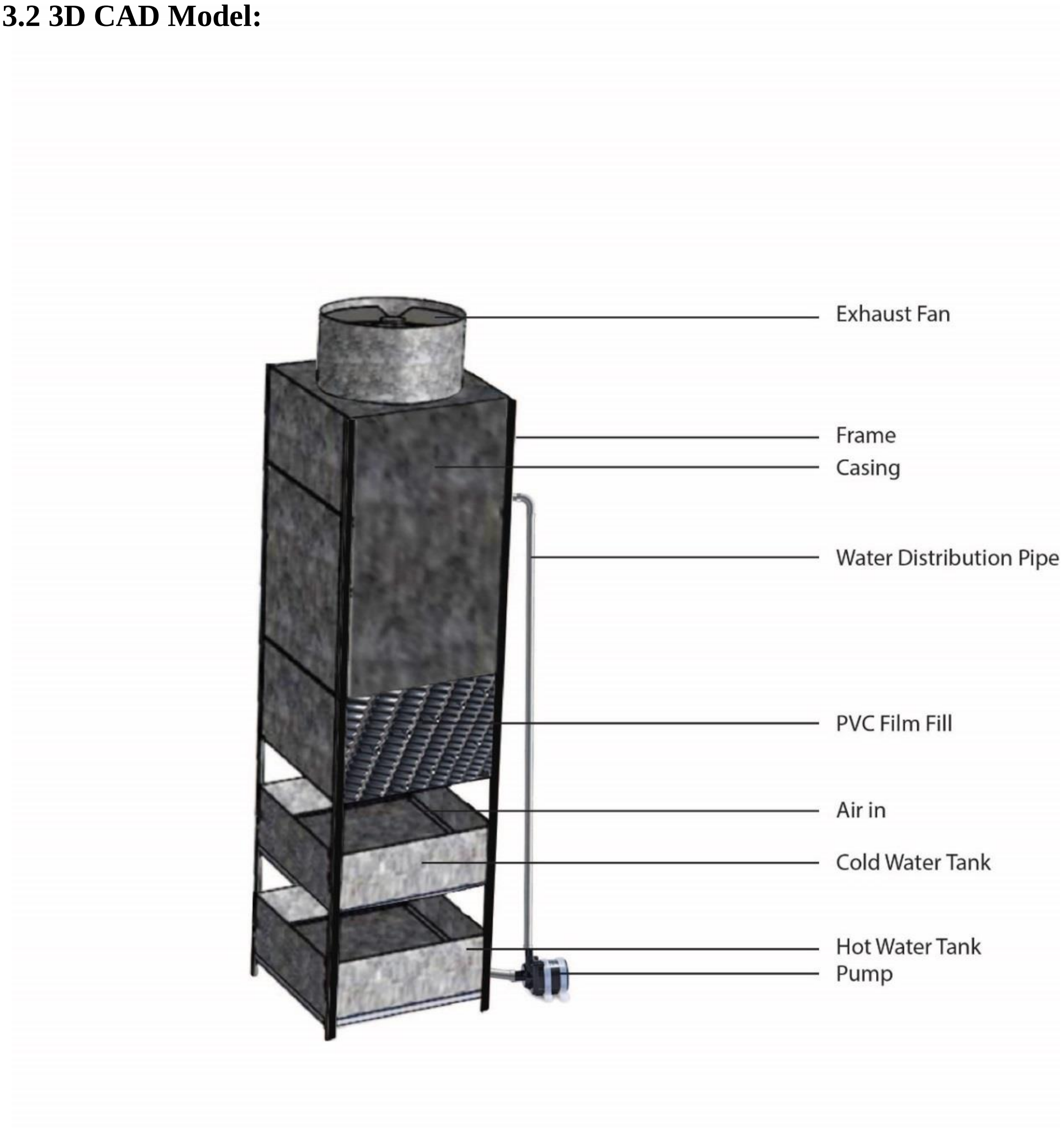

Fig. 3.2: 3D CAD Model of Induced Draft Counter Flow Wet Cooling Tower

3.3 Description of the Model:

- Frame: It supports the entire frame with all its components, and the both water tanks also.
- Casing: Casing is used to cover the water spray and the fill.
- Hot water Tank: It is placed at the bottom of the frame of the tower. In this tank water will get warm by an electric heater.
- DC Pump: It is used to pumped up the water from hot water tank through the water distribution pipe to discharged through the spray nozzle.
- PVC Film Fill: PVC Film Fill is used to slow down the water speed which water is spray down over the fill media. Which helps increase the contact time between the water and the air.
- Exhaust Fan: It is used to suck the hot air from bottom to the top of the tower.
- Cold water tank: It is placed at the upper of the hot water tank to collect the cold water.

3.4 Required Component:

There are major several components required for implementation of “Induced Draft Counter flow wet cooling tower” are as follows:

1) Frame
2) Casing
3) Film Fill
4) Hot Water Tank
5) Eclectic Heater
6) Cold water Tank
7) Exhaust Fan
8) DC pump
9) Water spray system
10) Water supply system
11) Temperature measurement system
12) Flow measurement system.

3.4.1 Frame and Casing:

Wooden towers are still available, but many components are made of different materials, such as the casing around the wooden framework of glass fiber, the inlet air louvers of glass fiber, the fill of plastic and the cold-water basin of steel. Many towers (casings and basins) are constructed of galvanized steel or, where a corrosive atmosphere is a problem, the tower and/or the basis are made of stainless steel. Larger towers sometimes are made of concrete. Glass fiber is also widely used for cooling tower casings and basins, because they extend the life of the cooling tower and provide protection against harmful chemicals.
M.S angle bar and GP sheet have been used for this thesis.

Figure 3.3: Frame of the tower

3.4.2 PVC Film Fill:

The water falls downward over the fills surface, which helps increase the contact time between the water and the air. Plastics are widely used for fill, including PVC, polypropylene, and other polymers.

PVC film fill has been used for this thesis.

Figure 3.4: PVC film fill

3.4.3 Hot Water Tank:

It is placed at the bottom of the frame. It is a reservoir in it the water is heated to the desired temperature by electric heater and then it is pumped to the tower head by centrifugal pump.

Material of the tank is G.I sheet (20 gauges).

Total volume of the tank: $V = (0.381 \times 0.381 \times 0.127) m^3$

$$V = 0.01843545 m^3$$

Corresponding capacity of water = (0.01843545×1000) L

= 18.4 L

3.4.4 Cold Water Tank:

It is placed at the upper of the hot water tank to collect the cold water. Material of the tank is also G.I sheet (20 gauges).

Total volume of the tank: $V = (0.381\times0.381\times0.127)\ m^3$

$$V = 0.01843545\ m^3$$

Corresponding capacity of water = (0.01843545×1000) L

$$= 18.4L$$

3.4.5 Electric Heater:

It is used to heating the cold water. In our project we use regulatory type electric heater. So that we could set up our desired temperature, in which we want to experiment.

For the hot water tank, 1000 watt electric heater has been used.

Fig. 3.5: Electric Heater.

3.4.6 Exhaust Fan:

Propeller type exhaust fans are used in induced draft cooling tower. To suck the ambient air from bottom to the top of the tower.

Fan size: 11in (Round Shape).
Watt: 130
Volt: AC 220

Figure 3.6: Exhaust Fan

3.4.7 Pump:

To pump the hot water into the tower head from the hot water tank. DC pump is used here.

Pump specification:

a) Max delivery Head: 5m.
b) Maximum flow: 10Lit/minute.
c) Power supply: DC 12Volt

Figure 3.7 Pump

3.4.8 Water Spray System:

Water sprays to wet the fill. Uniform water distribution at the top of the fill is essential to achieve proper wetting of the entire fill surface. PVC flexible boring pipe has been used to spray the hot water evenly over the entire PVC film fill. The pipe has been bored manually using a needle.

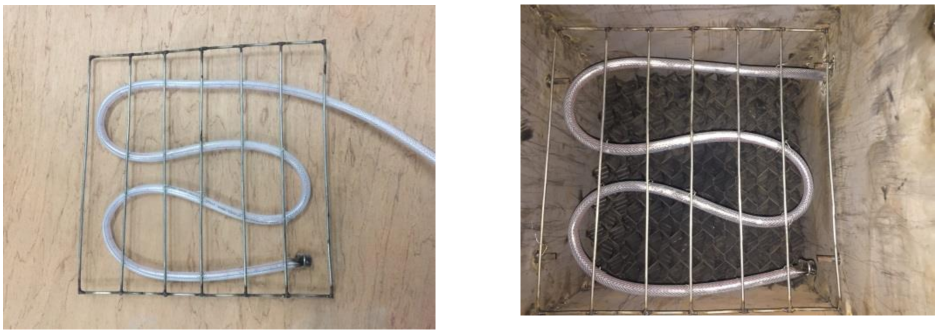

Fig. 3.8: Water spray pipe

3.4.9 Temperature Measurement System:

We have used Hygrometer to measure Wet Bulb Temperature & Dry Bulb Temperature and digital thermometer to measure temperature of hot and cold water

Figure 3.9: Hygrometer

3.4.10 Flow Measurement System:

a) Water flow was measured by manual system.
b) Exhaust fan air flow was measured by anemometer.

CHAPTER IV

CONSTRUCTED PROJECT

4.1 Constructed Model:

Fig. 4.1: Induced draft counter flow cooling tower

4.2 Stepwise construction:

- At first the supporting frame was prepared with M.S angle bar in a workshop.
- Then the casing was prepared that was provided with a square hole to set up the exhaust fan and hole for piping. It was also provided with supporting objects to support the fill.
- Then the hot water tank and cold-water tank also prepared in the workshop.
- The cold tank was welded and the required fittings for water distribution were provided in it.
- The hot water tank was first welded while there are holes prepared for piping. It was not fully welded for further tasks. Then the heater was added with the connection line. After that it was made water tight with m-seal. Then the final part of the tank was being welded.
- G.P sheet was cut with desired dimension and then attached in the flat bar by welding.
- A circular frame was prepared for the exhaust fan and then exhaust fan was attached in it and set on the casing.
- Entire piping system connection was given. Pump related to the system where suction line is in the hot water tank and discharge line ends through spray nozzle.
- Electrical connection for the exhaust fan, electric heater and the pump was made.
- Flow rate has been gotten from the pump by manual system
- Figure 4.1 shows the complete setup after finishing construction.

4.3 Working Procedure:

Cooling towers are a special type of heat exchanger that allows water and air to come in contact with each other to lower the temperature of the hot water.

During this process, the hot water tank that is placed lower of the tower have to be filled up by fresh normal water. This water has been heated up in the heater tank for 50 minutes to reach above temperature at 40°C. At this time only the heater was turned on but the exhaust fan and pump were turned off. When the thermometer was reading shows a desired temperature, the heater was turned off and both the exhaust fan and pump was turned on. At this time the hot water was pumped from the hot water tank through the water distribution pipe and discharged through spray nozzles inside the tower. Spray nozzles have sprayed the hot water evenly over the entire PVC film fill. The water has passed downwards through the PVC film fill (heat exchanger) whilst air has passed upwards. As the water have traveled through the fill which has been slow the water flow down and exposed the maximum amount of water surface area possible for the best air-water contact. The water has been exposed to air as it flows throughout the cooling tower. The air has been pulled out from the tower by an exhaust fan "cooling tower fan". So that heat could be rejected out through the exhaust fan from hot water.

When the air and water has come together, a small volume of water has evaporated, creating an action of cooling. The colder water has fallen down in the cold water tank and it has gotten pumped back to the hot water tank that has absorbed heat or the condenser. It repeats the loop over and over again to constantly cool down the heated hot water in hot water tank or condensers.

4.4 Data and Calculation:

4.5 Data Collection:

Table 4.1: Technical parameter

Technical Parameter	**Values**
CT outlet water temperature °C	34°C
CT inlet water temperature °C	45°C
Wet bulb temperature °C	25°C
Water flow kg/hr	480 kg/hr
Water flow m^3/hr	0.48 m^3/hr
Fan air flow m^3/hr	763.33 m^3
Density of air kg/m^3	1.08 kg/m^3
Fan air flow kg/hr	824.3964 kg/hr

4.6 Calculation:

1) Cooling tower efficiency:

Approach = CT outlet water temperature - Wet bulb temperature
= 34^oC - 25^oC
= 9^oC

Range = CT inlet water temperature – CT outlet water temperature
= 45^oC - 34^oC
= 11^oC

Cooling tower efficiency= range/(range+ approach)
= 11^oC/ (11^oC+9^oC)
= 0.55
= 55%

2) Evaporation Losses:

Evaporation Losses in m^3/hr = 0.00085 ×1.8 × water circulation rate (m^3/hr)× (T_1-T_2)

= 0.00085 × 1.8 × 0.48 × (45-34)

= 0.0080784 m^3/hr

Percentage Evaporation Loss= (0.0080784/0.48)×100

= 1.683%

CHAPTER V

RESULTS & DISCUSSION

5.1 Result of Cooling Tower Performance:

Table 5.1: Result of cooling tower performance

Parameter	**Values**
Wet bulb temperature	25°C
CT outlet water temperature	34°C
CT inlet water temperature	45°C
Range	11°C
Approach	9°C
CT efficiency	55.%
Evaporation Losses	0.0080784 m^3/hr
Percentage Evaporation Loss	1.683%

5.2 Discussion:

In present study cooling tower is of close approach, small range, low height compare with literature data for industrial towers. A comparison for the lowest approach recommended by Perry [5] is given below:

Table 5.2: A comparison for the lowest approach recommended by Perry [5]

Study	Approach	Range	Height
Literature	2.2 to 4 ºC	14 to 19ºC	11 to 12m
Present study	9ºC	11 ºC	1.42m

Usually it is not recommended to design a cooling tower with an approach lower than 2.8 ºC, because it is no economical. In this present study the height of cooling tower was only 4 feet and 8inch shown in figure:3.1. Since the range was much lower than literature data, corresponding tower total height also decreased proportionally. Tower height is a significant factor for cooling range because the contact time between air flow and the steam of water depend on the height.

It is very difficult to achieve higher efficiency with small size.

CHAPTER VI

FUTURE RECOMMENDATION

6.1 Future Work:

- We were currently working on small size of model but in future it can be used for heavy duty usages by making small changes.
- Future recommendation of the thesis can be done by attaching drift eliminators at the top of the tower but under the exhaust fan to reduce water loss.
- Boring pipe was used for water spray system in this thesis. Spray nozzles can be used instead of boring pipe to get better performance.
- It can be replaced with higher power pump and higher power exhaust fan for high water flow and air flow rate to get higher efficiency.

CHAPTER VII

CONCLUSION

First we concerned the meaning of cooling tower and knew each one how to use it, how it is installed, and from which materials it is prepared.

Then identified the main two types of cooling tower and recognized the series of work of each one and its uses.

By an effective list we knew how to check the work of cooling tower.

In this study the design and performance analysis of induced draft counter flow cooling tower is done using mathematical methods. During the design and analysis process different parameter were consider for improving the productivity and performance of induced draft counter flow cooling tower. In this paper the results of the experimental investigation on local intensities of heat and mass transfer in fill of wet cooling tower, have been presented. The experimental cooling tower has been constructed and installed in our university's lab. Cooling efficiency was found 55% at mass flow rate of water 480kg/hr. The range was found 11°C and the approach was found 9°C. Over all the resulted data was like what have found in previous studies. This innovative method was also cost effective, and provided an opportunity to manufacture medium size cooling tower in our country.

REFERENCE

[1] Holman, J. P, "Heat Transfer", 10th edition, McGraw-Hill, New York, 2009.

[2] A test book of Refrigeration & air Conditioning, R.S Khurmi & J.K Gupta.

[3] Nicholas P. Cheremisinoff & Paul N. Cheremisinoff, "Cooling Towers: Selection Design and Practice", Anin Arbor Science Publishers, Inc, 1984.

[4] Cussler, E.L, "Design of cooling towers in diffusion: mass Transfer in fluid system", 2nd edition. Cambridge University Press pp.512-518(1997).

[5] Robert H. Perry & Don W. Green, "Perry's Chemical Engineers' Handbook", 8th edition, McGraw-Hill, New York, 2008.

[6] Delta Cooling Towers Privet Limited, Delhi, India; website; www.deltactowers.com.

[7] Chemical Engineering Progress Technical Manual, Vol.2, "Cooling Towers", AIchE, p.27 (1975). Begum, F. Parvez, A.M Performance analysis of cooling tower used in sulfuric acid plant in WATA chemical Ltd. B.Sc. engineering thesis chemical engineering department, BUET,2004.

[8] Power Plant Engineering, 3rd edition, P. K. Nag.

[9] Ameen Ahmadul, "Refrigeration & Air Conditioning", PHI Learning Pvt. Ltd, New Delhi, 2012.