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Experimental Setup of a Mini Counterflow Cooling Tower

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***Abstract*: Cooling towers are heat removal devices used to transfer heat to the atmosphere. Cooling tower exits waste heat to the environment through the cooling of a water stream to a lower temperature. The objective of this work is to fabricate a mini cooling tower and evaluate its performance parameters such as efficiency, heat loss by water, heat gain by air, mass flow rate of air and water. The cooling tower produced in this study is an induced draft counter flow cooling tower. Aluminium plates are used for the cooling purpose and straw and wood dusts are used as filler materials. The mini cooling tower developed can be used reasonably in various small and medium scale industries and buildings for its cost effectiveness as locally available materials are used for fabrication and high thermal conductivity material along with additional fillers (made of cheaper materials) are employed leading to better efficiency.**

***Keywords*: Heat exchanger, Evaporative cooling, Rotameter, Pump, Efficiency.**

1. Introduction

A. Objective

Fabricating a mini induced draft counter flow cooling tower, through which it can be used effectively and efficiently at low cost.

B. Cooling towers

Cooling towers are equipment device that provides evaporative cooling of water by contact with air. It is a structure made of wood, steel or concrete. Corrugated surfaces or baffles or trays are provided inside the cooling tower for uniform distribution and better atomization of water in the tower. The hot water coming out of the condenser is fed to the tower on top and allowed to tickle in form of thin drop. The air flows from the bottom of the tower or perpendicular to the direction of water flow and then exhausts to the atmosphere after effective cooling.

C. Applications

Cooling towers are widely used in various industries. Some of them are as follows,

1. Heating, Ventilation & Air Conditioning
2. Oil refinery
3. Petrochemical & other chemical plants
4. Thermal power plants
5. Natural gas processing plants
6. Food processing plants
7. Semiconductor plants

D. Advantages

Since the air-water contact time is higher, the quantity of air required is lesser.

1. Less recirculation than forced draft towers because the speed of exit air is 3-4 times higher than entering air.
2. Maintenance for counter flow towers is much easier than cross flow towers. The simplicity of structure and comfortable sizing allow for quick and exhaustive maintenance.
3. The fan Power consumption is low as the required air quantities comparatively lower. The pumping head is also lower as the inlet header is located below the fan deck area.
4. Induced Draft Cooling Tower have the ability to handle large water flow rate than Forced Draft Cooling Tower.
5. Induced Draft Cooling Tower is suitable for large cell sizes and fan sizes as compared with Forced Draft. Larger fan size may result in greater efficiency and consequently lower power and sound level.

E. Disadvantage

1. Fans and the motor drive mechanism require Weather proofing against moisture and corrosion because they are in the path of humid exit air.
2. Typically, higher initial and long-term cost, primarily due to pump requirements.
3. Difficult to use variable water flow, as spray characteristics may be negatively affected.
4. Typically, noisier, due to the greater water fall height from the bottom of the fill into the cold water basin.

2. Literature survey

Sergey Anisimov, Aleksandr Kozlov, Paul Glanville, Mark Khinkis, Valeriy Maisotsenko and Jessica Shi, Advanced Cooling Tower Concept for Commercial and Industrial Applications states that for the majority of cooling towers installed, of which there are greater than half a million installed in the U.S., tower design uses direct evaporative cooler technology where an ideally enthalpy-neutral process cools the process water stream to a temperature above the ambient wet bulb. This ambient wet bulb temperature is the limiting factor for the process cooling. As such the energy-water connection is clear, these cooling towers are direct consumers of treated water and their cooling performance is intimately tied to the process efficiency.

J. D. Buys and D. G. Kroger Cost-Optimal Design of Dry Cooling Towers through Mathematical Programming Techniques by applies The Constrained Variable Metric Algorithm is chosen to minimize the objective function (cost) in the design of a natural draft dry cooling tower. An existing cooling system design that has specific performance characteristics under prescribed operating conditions is selected as a reference unit. By changing design variables, but not exceeding prescribed constraints, a more cost-effective design is achieved. The influences of various parameters, and the sensitivity of the objective function to these parameters, are evaluated.

J.W. Sutherland Analysis of Mechanical-Draught Counter flow Air/Water Cooling Towers compares an accurate analysis of mechanical draught counter flow cooling towers, including water loss by evaporation, with the approximate common method based on enthalpy driving force developed by Merkel in 1925. Computer programs were developed for both the accurate analysis (TOWER A) and the approximate analysis (TOWER B). Substantial underestimates of tower volume of from 5 to 15 percent are obtained when the approximate analysis is used; indicating the possibility of quite serious consequences as far as cooling tower design is concerned. Computer predictions of cooling tower integral are shown to compare well with published values.

3. Theory and formulation

A. Principle of Operation

The principle of operation of a cooling tower is based on the principle of evaporative cooling, a cooling tower pulls heat from an area or a stream of water through use of evaporation or through using a continuous supply of air to cool the working fluid to the ambient air temperature. Ambient temperature is defined as the wet bulb temperature in case of evaporation and dry bulb temperature in case of air flow of a working fluid.

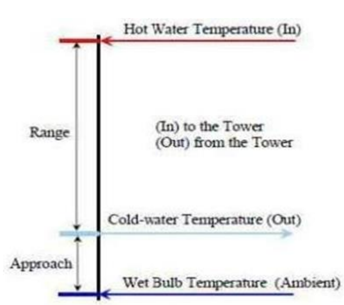

Fig. 1. Temperature Approach [3]

B. Induced Draft Counter Flow Cooling Tower

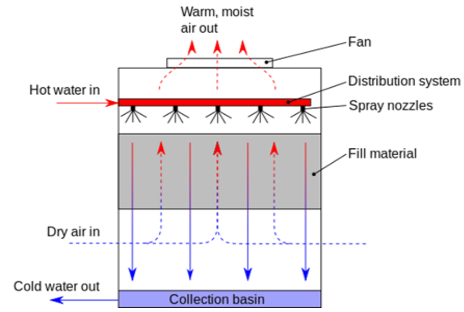

Fig. 2. Schematic of Induced Draft Counter

1) Flow Cooling Tower

Here the air flow is directly opposite to the water flow. Fresh air enters through an open area below the fill and through the holes on the side panels. A fan provided at the top of the tower draws the air vertically. The hot water is sprayed through pressurized nozzles near the top of the water. Heat from the hot water is transferred to fresh air and the fills by convection and conduction respectively. The hot air exits through the top of the cooling tower. And the cooled water flows to the tank below the fill or trays. This is as follows:

- Heat transfer in cooling tower occurs in two major mechanism
- Sensible heat from water to air (convection) and transfer of latent heat by the evaporation of water (diffuser).
- Both of this mechanism operates at air-water boundary layer.
- The total heat transfer can also be expressed in terms of the change in enthalpy of each bulk phase.

C. Calculation

1) Governing Equations

Cooling Tower Approach (CTA)
$CTA = T_2 – WBT$ ---- [1]

Cooling Tower Range(CTR)
$CTR = T_1 – T_2$ ---- [1]

Mass of water circulated in cooling tower(M_{w1})
Mw1 = Volume of circulating water x Mass density of water [1]

Heat Loss by Water (HL)
$HL = M_{w1} \times C_{pw} \times (T_1-T_2)$ ---- [1]

Volume of air required (V)
$V = (HL \times V_{s1}) \div [(H_{a2}-H_{a1})-(W_2-W_1) \times C_{pw} \times T_2]$ ---- [1]

Heat gained by air(HG)
$HG = (V \div V_{s1}) \times [(H_{a2}-H_{a1})-(W_2-W_1) \times C_{pw} \times T_2]$ ---- [1]

Mass of air required (M_a)
$M_a = V \div V_{s1}$ ---- [1]

Efficiency
E = (CTR- LOSSES)/(CTR+CTA)*100% ---- [2]

This equation is modified according to our project need.

2) Storage Design: Dimensions
Dimensions
Length, L=41 inch = (41×2.54)÷100 m=1.0414 m
Breadth, B=16inch= (16×2.54) ÷100m=0.4064 m
Height, H=14 inch= (14×2.54) ÷100 m=0.3556 m

Volume of Tank/Storage Capacity
Volume, V=L×B×H=0.15049 m^3=150.5 liter

Frame Design Dimensions
Length, L= 105 cm = 1.05 m
Breadth, B=102 cm=1.02 m
Height, H=240 cm =2.40 m

Frame Volume
Volume, V=L×B×H= 2.57 m^3

Cooling Tower Efficiency Calculations
Cooling Tower Approach

The difference between the cold water temperature (cooling tower outlet) and ambient wet bulb temperature is called as cooling tower approach

Approach = Cold Water Temperature – Wet Bulb Temperature= T_{CW} - T_{WB}

Cooling tower approach is the better indicator for the performance.

Cooling Tower Range

The difference between the hot water temperature (Cooling tower inlet)

And cold water (Cooling tower outlet) temperature is called cooling tower range.

Range =Hot water temperature– cold water temperature= T_{HW} - T_{CW}

Cooling Tower Efficiency

Cooling tower efficiency is limited by the ambient wet bulb temperature. In ideal case the cold water temperature will be equal to the wet bulb temperature. This is practically not possible to achieve. This requires very large tower and results in huge evaporation and windage or drift loss resulting in a practically not viable solution.

E = (CTR- LOSSES) /(CTR+CTA)*100%

Losses in Cooling Tower
Evaporation Loss

Evaporation loss (EL) is the water quantity evaporated for cooling duty.

EL(m^3/hr) =0.00085×circulation rate of water× CTR

Windage Loss(WL)
For Induced Draft Cooling Tower
WL(m^3/hr) = 0.005× Circulation rate of water

Drift Loss(DL)
DL(m^3/hr) = (0.2×Circulation rate of water)÷100

D. Components of a Cooling Tower

1. Frame
2. Casing
3. Plates/Fills
4. Cold Water Basin
5. Rotameter
6. Pump
7. Spray Nozzles
8. Exhaust fan

1) Frame

The tower structure (frame) encloses the cooling components (eg. fans, pipes) and supports the exterior devices (pumps, motors). A structural framing system is required to support the fan(s), fill, intake, drift eliminators etc. Casing is required to enclose to the fill and to create the tower air and water flow path.

2) Casing

A cooling tower's casing performs two roles.

- First, it forms an enclosure around the fill to create a contained air path or plenum, forcing the air flow through the fill.
- Secondly, it simply helps to keep the water inside the water.

3) Plates

Plates are used in a cooling tower for the heat exchange between the water, air and plates. The plate can be said as heat exchanger or a plate type of heat exchanger. The function of the tower plates or fill is to provide a large ―contact area between the water flow and airflow to promote evaporation and heat transfer.

Table 1
Materials

S. No.	Materials	Thermal Conductivity (w/m^2)
1	Diamond	1000
2	Silver	406
3	Copper	385
4	Gold	314
5	Aluminum	235

4) Cold water basin

The cold-water basin is located at or near the bottom of the tower, and it receives the cooled water that flows down through the tower and fill. The basin usually has a sump or low point for the cold-water discharge connection. In many tower designs, the cold-water basin is beneath the entire fill. In some forced draft counter flow design, however, the water at the bottom of the fill is channeled to a perimeter through that functions as the cold-water basin. Propeller fans are mounted beneath the fill to blow the air up through the tower. With this design, the tower is mounted on legs, providing easy access to the fans and their motors.

5) Rotameter

A rotameter is a device that measures the flow rate of fluid in a closed tube. The rotameter consists of a tube and float. The float response to flow rate changes in linear. The rotameter is popular because it has a linear scale, a relatively long measurement range, and low pressure drop. It is simple to install and maintain. Flow meter is chosen according to the minimum and maximum flow rate for the flow meter. Our Rotameter range is from 100- 1000 L/hr.

Fig. 3. Rotameter.

6) Water Pump

A pump is used to circulate the hot water from the plants to the spray nozzles of the cooling tower. Hot waters are circulated through the pipe lines to the spray nozzle at a definite flow rate measured with the rotameter.

7) Spray Nozzles

These spray water to wet the fill. Uniform water distribution at the top of the fill is essential to achieve proper wetting of the entire fill surface. Nozzles can either be fixed and spray in a round or square patterns, or they can be part of a rotating assembly as found in some circular cross-section towers.

8) Exhaust Fan

Both axial (propeller type) and centrifugal fans are used in towers. Generally, propeller fans are used in induced draft towers and both propeller and centrifugal fans are found in forced draft towers. Depending upon their size, the type of propeller fans used is either fixed or variable pitch. A fan with non-automatic adjustable pitch blades can be used over a wide kW range because the fan can be adjustable to deliver the desired air flow at the lowest power consumption. Automatic variables pitch blades can vary air flow in response to changing load conditions.

Table 2
Equipment and its specification

S. No.	Equipment's	Specifications
1	Rotameter	Range = 100 – 1000 l/hr
2	Water Pump	0.75kW/0.5HP, speed=2700rpm, dim= 27cm x17cm x22cm,weight = 7 kg
3	Exhaust Fan	Speed = 2600 rpm, Dim=120mm x120mm x38 mm, weight = 7kg
4	Temperature and Humidity	Weight = 132g, L =10.7cm, B=2.5cm H =10cm

E. Factors affecting performance of cooling tower

1) Temperature of air

The temperature of air as read in the thermometer is called dry bulb temperature. Lower value of dry bulb temperature will result in better release of sensible heat of the hot water. Thus performance of cooling tower will increase with reduction in dry bulb temperature. In practice, if the temperature of air flowing through the cooling tower is less, it will release more latent heat of vaporization and thereby dropping the temperature of water. It should be performed in areas where the flaming air temperature should be low.

2) Size and height of cooling tower

A larger cooling tower will produce a colder water for a given heat load, flow rate and entering air condition. Since it will allow more air to flow and thus more heat transfer occurs between the water and air and also more plates can be placed.

3) Relative humidity

It is the ratio of the quantity of water vapour parallel in a cubic feet of air to the greatest amount of vapour which the air could hold at a given temperature. When the relative humidity is 100%, the air cannot hold any more water and therefore, water will not evaporate in 100% humid air. When the Relative humidity is 100%, the wet bulb temperature is the same as the dry bulb temperature, because the water cannot evaporate any more. But when the relative humidity is less than 100%, the wet bulb temperature will be less than the dry bulb temperature and water will evaporate. In actual practice, the final cold water temperature will always be at least a few degrees above wet bulb temperature, depending on design condition.

4) Accessibility of air to every part of the cooling tower:

The design should be such that, air can be accessed to almost every part of the tower. Since it will allow more contact between air and water and more sensible heat from water can be evaporated.

5) Design and arrangement of plates:

Plates or fills are introduced so that the water comes in contact with more surface area and small holes are provided in the plates so that water falls in fine droplets.

6) Design specifications of the cooling tower (prototype)

Height= 7 ft 11 inch
Length= 3 ft 6 inch
Breadth= 3 ft 4 inch

4. Methodology and approach

A. Experimental Setup

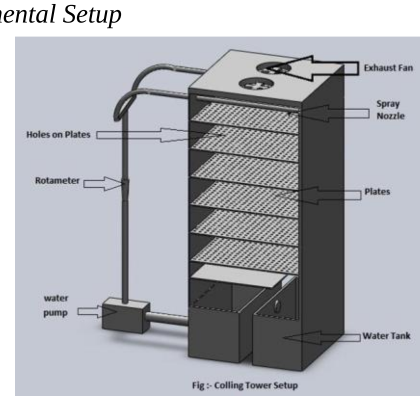

Fig. 4. 3D diagram of the Cooling Tower setup

Fig. 5. Front View of Cooling Tower

B. Fabrication

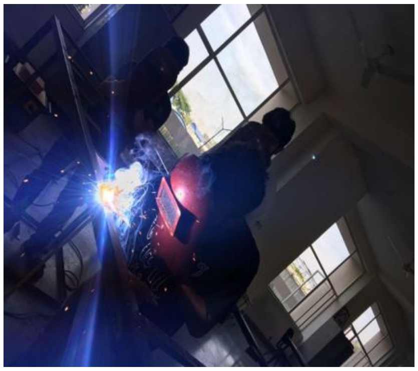

Fig. 6. Frame Formation

Step 1: Frame Formation:

The raw materials are collected, piece by piece according to the design requirement. The material of frame is mild steel (MS). Then by welding, the solid structure as the main frame of the cooling tower is formed.

Fig. 7. Frame Formation

Step 2: Installation of Slots

Supportive angles (MS materials) are provided on the coulomb of the frame as to insert plates (Aluminum) in the main frame.

Fig. 8. Formation of slots

Step 3: Forming of plates

Aluminum plain sheets (4ft*24ft) are bought and by cutting it, the desired size is formed for the cooling tower.

Step 4: Creating Holes

Holes are created on the plates for the drop by drop flow of water.

Fig. 9. Formation of Plates

Fig. 10. Creating Holes

Step 5: Installation of Tanks/ storage / sump

Two separate sumps for hot and cold water are created. From hot sump the water will be pumped with the help of 0.5 HP

Table 3
Experimental observation

Setup No.	Inlet Temperature (ºC) (T_1)	Outlet Temperature (ºC) (T_2)	Fan Condition	No. of Plates	Addition of Straw	Addition of Wood Dust	Range
1	68	42	OFF	12	NO	NO	26
2	68	34	ON	12	NO	NO	34
3	68	41	OFF	8	YES	NO	27
4	68	36.5	ON	8	YES	NO	31.5
5	68	39	OFF	12	YES	NO	29
6	68	31	ON	12	YES	NO	37
7	68	32	ON	12	NO	YES	36
8	68	35	OFF	12	NO	YES	33
9	68	35	ON	6	NO	YES	33
10	68	37	OFF	6	NO	YES	31

pump to the top of the cooling tower.

Fig. 11. Installation of sump

Step 6: installation of exhaust fans

Two exhaust fans at the top of the cooling tower are installed to suck out the hot and moist air inside the cooling tower.

Step 7: Addition of Casing

The casings are installed on all the four sides of the frame. Plywood casings are installed on three sides of the frame and fiber glass is installed on one side.

Fig. 12. Installation of casings

Step 8: Installation of Rotameter and motor

The motor and rotameter are installed to deliver the hot water to the spray nozzles and to measure the mass flow of water in the cooling tower respectively.

Fig. 13. Installation of rotameter and motor

C. Calculations

Mass of Water circulation(Mw1):

M_{w1}=Volume of circulating water ×mass density of water= 225 kg/hr

Volume of Air required (V):

$V=(HL\times V_{S1})/[(H_{a2}-H_{a1})-((W_2-W_1)\times C_{pw}\times T_2)]=12511.75\ m^3/hr$

Heat loss by Water (HL):

HL = Mw1×Cpw×(T1-T2)

Setup 1: No. of plates=12; Fan Condition=OFF HL = 24488.1KJ/hr

Setup 2: No. of plates=12; Fan Condition=ON HL = 32022.9KJ/hr

Setup 3: No. of plates=8; Fan Condition=OFF; Using Straw HL = 25429.95 KJ/hr

Setup 4: No. of plates=8; Fan Condition=ON; Using Straw HL= 29668.27KJ/hr

Setup 5: No. of plates=12; Fan Condition=OFF; Using Straw HL= 27313.65KJ/hr

Setup 6: No. of plates=12; Fan Condition=ON; Using Straw HL= 34848.45KJ/hr

Setup 7: No. of plates=12; Fan Condition=ON; Using Wood Dust HL=33906.6 KJ/hr

Setup 8: No. of plates=12; Fan Condition=OFF; Using Wood Dust HL= 31081.05KJ/hr

Setup 9: No of plates=6; Fan Condition=ON; Using Wood Dust HL= 31081.05KJ/hr

Setup 10: No. of plates=6; Fan Condition=OFF; Using Wood Dust HL= 29197.35KJ/hr

Mass of Air required(Mair):
Mair= V/Vs1= 14719.7 kg/hr

Heat Gain by Air (HG):
HG= $(V/V_{s1})\times[(H_{a2}-H_{a1})-\{(W_2-W_1)\times C_{pw}\times T_2\}]$
Setup 1: No. of plates=12; Fan Condition=OFF HG = 334725.978KJ/hr
Setup 2: No. of plates=12; Fan Condition=ON HG=338258.706KJ/hr
Setup 3: No. of plates=8; Fan Condition=OFF; Using Straw HG = 335167.569 KJ/hr
Setup 4: No. of plates=8; Fan Condition=ON; Using Straw HG=337154.728KJ/hr
Setup 5: No. of plates=12; Fan Condition=OFF; Using Straw HG= 336050.751KJ/hr
Setup 6: No. of plates=12; Fan Condition=ON; Using Straw HG= 339583.479KJ/hr
Setup 7: No. of plates=12; Fan Condition=ON; Using Wood Dust HG= 339141.888KJ/hr
Setup 8: No. of plates=12; Fan Condition=OFF; Using Wood Dust HG= 337817.115KJ/hr
Setup 9: No of plates=6; Fan Condition=ON; Using Wood Dust HG= 337817.115KJ/hr
Setup 10: No. of plates=6; Fan Condition=OFF; Using Wood Dust HG= 336933.933KJ/hr

Losses:
Evaporation loss(E_{LOSS}):
$E_{LOSS}= 0.00085\times M_{w1}\times(T_1-T_2)$
Setup 1: No. of plates=12; Fan Condition=OFF E_{LOSS}= 4.94 kg/hr
Setup 2: No. of plates=12; Fan Condition=ON E_{LOSS}= 6.46 kg/hr
Setup 3: No. of plates=8; Fan Condition=OFF; Using Straw E_{LOSS}= 5.13 kg/hr
Setup 4: No. of plates=8; Fan Condition=ON; Using Straw E_{LOSS}= 5.98 kg/hr
Setup 5: No. of plates=12; Fan Condition=OFF; Using Straw E_{LOSS}= 5.13 kg/hr
Setup 6: No. of plates=12; Fan Condition=ON; Using Straw E_{LOSS}= 4.94 kg/hr
Setup 7: No. of plates=12; Fan Condition=ON; Using Wood Dust E_{LOSS}= 6.84 kg/hr
Setup 8: No. of plates=12; Fan Condition=OFF; Using Wood Dust E_{LOSS}= 6.27 kg/hr
Setup 9: No of plates=6; Fan Condition=ON; Using Wood Dust E_{LOSS}= 6.27 kg/hr
Setup 10: No. of plates=6; Fan Condition=OFF; Using Wood Dust E_{LOSS}= 5.89 kg/hr

Windage Loss(W_{LOSS}):
$W_{LOSS}= 0.005\times M_{w1}$= 1.125 kg/hr

Drift Loss(D_{LOSS}):
$D_{LOSS}= (0.20\times M_{w1})/100$= 0.45 kg/hr

Efficiency:
Efficiency = [(CTR-Losses)/(CTR+CTA)]×100%
Setup 1: No. of plates=12; Fan Condition=OFF Efficiency=44.28%
Setup 2: No. of plates=12; Fan Condition=ON Efficiency=59.01%
Setup 3: No. of plates=8; Fan Condition=OFF; Using Straw Efficiency=46.13%
Setup 4: No. of plates=8; Fan Condition=ON; Using Straw Efficiency= 54.4%
Setup 5: No. of plates=12; Fan Condition=OFF; Using Straw Efficiency=50.67%
Setup 6: No. of plates=12; Fan Condition=ON; Using Straw Efficiency=69.28%
Setup 7: No. of plates=12; Fan Condition=ON; Using Wood Dust Efficiency=62.69%
Setup 8: No. of plates=12; Fan Condition=OFF; Using Wood Dust Efficiency=57.17%
Setup 9: No of plates=6; Fan Condition=ON; Using Wood Dust Efficiency=57.17%
Setup 10: No. of plates=6; Fan Condition=OFF; Using Wood Dust Efficiency=53.49%

5. Results and discussions

In this study, we performed the experiment for ten different conditions or set ups. From these experiments, it is observed that the cooling tower efficiency is mainly dependent on three factors. These are as follows-

- Number of plates
- Exhaust fan ON/OFF
- Addition of filler material

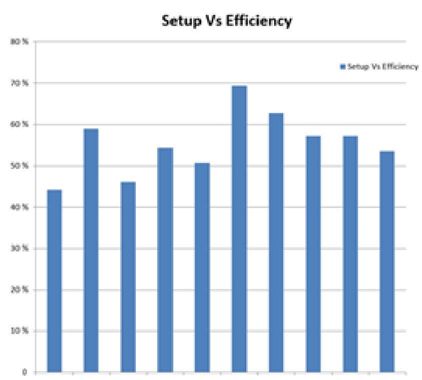

Fig. 14. Setup vs. Efficiency

It is observed that the cooling tower efficiency is directly proportional to the number of plates inside the cooling tower. If the number of plates are increased, efficiency also increases and vice versa. More number of plates means more contact surface and more time for the heat transfer to occur. thus increase in efficiency. Also efficiency increases if the exhaust fans are switched ON. This is because exhaust fans suck out the hot air from the cooling tower and helps in a better heat transfer between the hot water and fresh air. Efficiency increases if a filler material is added to the plates. Depending upon the filler material used, efficiency may vary again. In this experiment, we used two filler materials – Straw and Wood dust. Between these two materials, efficiency is higher for straw than that of wood dust. The efficiencies for the various conditions are represented on the graph shown in fig. 14.

6. Conclusion

The performance of cooling tower is closely related to tower Characteristic and different types of losses generated in cooling tower. Even though losses are generated in the cooling tower, the cooling is achieved due to heat transfer between air and water. Cooling towers represent a relatively inexpensive and dependable means of removing low grade heat from cooling water so that the water can be reused in the industrial process. The fabricated cooling tower setup can be used in places where there is scarcity of fresh water. It is suitable for small scale industries or buildings that requires relatively lesser mass flow rate of cooling water.

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