

## Performance Investigation of a Wet Counter flow Type cooling Tower with Corrugated Film Fill

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### ABSTRACT

Cooling towers are one of the biggest heat and mass transfer devices that are in widespread use. The paper comprises designing of counter flow type induced draft cooling tower applying Merkel's theory. Performance investigation was carried out of a wet counter flow induced draft type cooling tower with corrugated film fill. The fill packing was 0.93m high, made of 21 galvanized metal sheets having a sinusoidal form. Mass flow rate of water was changed to investigate other important parameters such as range, approach, effectiveness, capacity etc. Effectiveness decreases with increase of water flow rate as is also observed in other types of cooling tower. For the fulfillment of the thesis a relevant study has been accomplished, cooling tower heat load was estimated, design calculations of the water cooling tower showing different geometrical parameters and dimensions are performed, material selection, fabrication of the different components and assembly of the cooling tower was also completed.

Keywords: Counter flow, Range, Approach.

### 1. Introduction

Cooling towers are heat removal devices used to transfer process waste heat to the atmosphere. Now a day's large numbers of industrial applications are using cooling tower to remove the process heat especially in power generating, refrigeration and air conditioning, chemicals, petrochemicals and petroleum industries. Wherever water is used as a cooling medium or process fluid cooling towers are used extensively.

Cooling towers are able to lower the water temperatures more than devices that use only air to reject heat, like the radiator in a car, and are therefore more cost-effective and energy efficient. In most industrial locations, cooled fresh water is scanty therefore, continuous reuse and re cooling of the limited fresh water with the help of cooling tower is more common and economical. Another strong motivation for the increased use of cooling towers is the environmental protection provided through the reduction of water withdrawals and minimizing of thermal discharge.

Many types of cooling towers have been developed for use at such varied levels of technological sophistication and sizes. Although cooling towers can be classified several ways, the primary classification is into dry towers, wet towers and some hybrid wet-dry combinations exist. Classification also exists according to the air water flow characteristics.

### 2. Wet Counter Flow Type Cooling Tower

Wet cooling tower operates based on evaporation principle. The working fluid and the evaporated fluid (usually water) are one and the same. It cools water by contacting it with the air and evaporating some of the water 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. In a wet cooling tower, the warm water can be cooled to a temperature lower than the ambient air dry-bulb temperature, if the air is relatively dry. In counter flow design the air flow is directly opposite to the water flow. Air is being sucked from the lower part of the cooling tower and rises upwards in this induced draft type design, it gets warmer and when it reaches the top, it is hottest at that point. Since the water is flowing in the downward direction, it is the hottest at the top. Now as the hottest of air meets the hottest of water, evaporation is more, and thus, the cooling is more. The water is sprayed through pressurized nozzles and flows downward through the fill, opposite to the air flow. Cooling towers employ fills to facilitate heat transfer by maximizing water and air contact. Performance of a counter flow type tower is greatly influenced by film type fill. The principle of operation of cooling tower fill is to put as much water surface area in contact with as much air as possible, for the longest amount of time possible. Film fills allow the water to form thin flowing sheets to expose as much water surface area as possible to the interacting flow.

#### 2.1 Related parameters of cooling tower

Range: This is the difference between the cooling tower water inlet and outlet temperature. [3]

Approach: This is the difference between the cooling tower outlet cold water temperature and ambient wet bulb temperature.

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Liquid/Gas (L/G) ratio: The L/G ratio of a cooling tower is the ratio between the water and the air mass flow rates. Theoretically:

$$L/G = (h_2 - h_1) / (T_{w1} - T_{w2})$$

Effectiveness: 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).

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.

$$\text{Cooling capacity} = m_w \times C_{pw} \times (T_{wi} - T_{wo})$$

### 3. Markel's theory for cooling tower design

The analysis combines [2] the sensible and latent heat transfer into an over-all process based on enthalpy potential as the driving force. The two processes are combined, ingeniously, into a single equation:

$$dQ = Ka dV(h_w - h_a) = Gdh_a \quad (1)$$

which gives by integration

$$KaV/L = C_p \int_{T_{w2}}^{T_{w1}} \frac{dt}{(h_w - h_a)} \quad (2)$$

Where,

Q= Heat transfer rate, watt

L = mass water rate, kg/sec

G = air flow rate, kg dry air /sec

$T_{w1}$  = bulk water temperature at inlet (hot water), °C

$T_{w2}$  = bulk water temperature at outlet (cold water), °C

$h_w$  = enthalpy of air-water vapor mixture at the bulk water temperature, kJ/kg dry air

$h_a$  = enthalpy of air-water vapor mixture at the wet bulb temperature, kJ/kg dry air

$h_{a1}$ =enthalpy of entering air, kJ/kg

$h_{a2}$ =enthalpy of leaving air, kJ/kg

$KaV/L$  = Tower demand, kg air/ kg H<sub>2</sub>O

$Ka$  = Volumetric air mass transfer constant, kg H<sub>2</sub>O/(sec m<sup>3</sup>)

$C_p$  = Specific heat of water, J/kg °C

V = Fill volume, m<sup>3</sup>

For the evaluation of  $KaV/L$ ,

$$KaV/L = C_p \int_{T_{w1}}^{T_{w2}} \frac{dt}{(h_w - h_a)} = C_p x(t_{w2} - t_{w1}) x [1/Dh_1 + 1/Dh_2 + 1/Dh_3 + 1/Dh_4] / 4 \quad (3)$$

Where,  $Dh_1$ =value of  $(h_w - h_a)$  at a temperature of CWT + 0.1 x Range

$Dh_2$ =value of  $(h_w - h_a)$  at a temperature of CWT + 0.4 x Range

$Dh_3$ =value of  $(h_w - h_a)$  at a temperature of CWT + 0.6 x Range

$Dh_4$ =value of  $(h_w - h_a)$  at a temperature of CWT + 0.9 x Range

Equation for enthalpy of leaving air:

$$h_{a2} = h_{a1} + L/G * \text{Range}$$

Equation for determining Ka:

$$Ka = C \times [L]^m \times [G]^n$$

Where,

C, m and n are constants, which depend on the tower fill. These both factors are determined through fill test.

### 4. Design of the wet counter flow type cooling tower

#### 4.1 Assumptions:

Inlet temperature of hot water entering tower,  $T_1=50^\circ\text{C}$

Outlet temperature of cold water leaving tower,  $T_2=35.6^\circ\text{C}$

Dry bulb temperature of air entering tower,  $T_{dbt}=35^\circ\text{C}$

Wet bulb temperature of air entering tower,  $T_{wbt}=24^\circ\text{C}$

#### 4.2 Design data

Mass flow rate of hot water,  $m_w=0.0334$  kg/sec

Exhaust fan area,  $A_e=0.0929$  m<sup>2</sup>

Tower height,  $H=1.2192$  m

Exhaust fan discharge velocity,  $V_d=3.3$  m/sec

Exhaust fan suction velocity,  $V_s=0.99$  m/sec (3% of discharge velocity)

Humidity ratio for inlet air,  $\omega_{ai}=0.0141$

Enthalpy for inlet air,  $h_{ai}=72.4$  kJ/kg dry air

#### 4.3 Design

Design of cooling tower consists of calculation of basic parameters, determination of tower demand/tower characteristic  $KaV/L$ , tower dimension, capacity and makeup water requirement. Also calculation for dimensions and capacity of other related parts of the experimental setup such as collection basin and heater tank is carried out.

Basic parameters calculated are -

Mass flow rate of air,  $m_a = 0.1043$  kg/sec

Liquid Gas ratio,  $L/G = 0.32$

Range,  $R = 14.4^\circ\text{C}$

Approach,  $A = 11.6^\circ\text{C}$

Calculation for tower demand/ tower characteristic is presented in **Table 1**. Calculation for water side involve evaluation of bulk water temperature ( $t_w$ ) at  $\Delta$  intervals where  $\Delta = 0.1, 0.4, 0.6, 0.9$  within the cooling range using following expression –

$$t_w = T_2 + \Delta * R \quad (4)$$

where,  $T_2 = 35.5^\circ\text{C}$  = Outlet temperature of cold water leaving tower

And for air side enthalpy ( $h_a$ ) are found using following equations-

$$h_a = h_{a1} + L/G * \text{Range} \quad (5)$$

where,  $h_{a1}$  = enthalpy of entering air at wet bulb temperature  $T_{wbt}=24^\circ\text{C}$

#### 4.4 Summary of design

$$KaV/L = 0.58$$

Tower dimension = 0.56m x 0.56 m x 1.2192m

Design effectiveness,  $\epsilon = 55.38\%$

Design cooling capacity,  $Q = 2 \text{ kW}$

Makeup water,  $V_{\text{makeup}} = 1.3 \text{ liters}$

Dimension of collection basin = 0.56m x 0.56m x 0.11 m

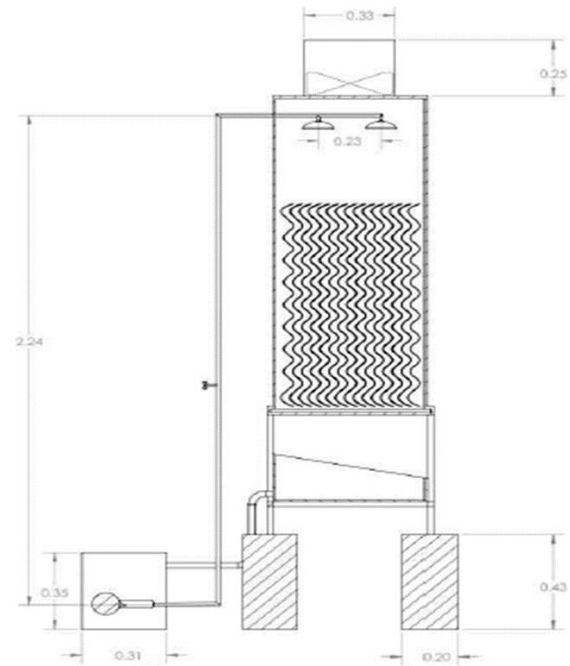
Design capacity of collection basin = 34 liters

Heater tank dimension = 0.33 m x 0.33 m x 0.33 m

Design capacity of heater tank = 35.9 liters

#### 5 Construction of the cooling tower

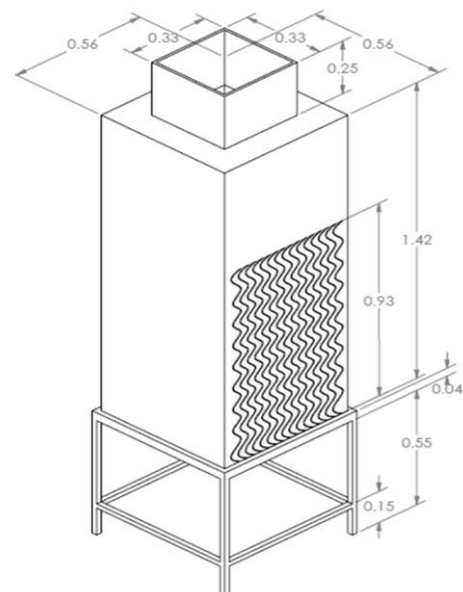
The constructed cooling tower unit consist of - hot water tank, hot water supply pump, cooling tower frame, exhaust fan, Ceiling shower, fill, sump, galvanized iron pipe, thermocouple. Water is heated up to  $50^\circ\text{C}$  in the hot water tank (capacity 35.9liters) with help of electric heater and supplied to the tower through pump. Made of G.I. sheet and well insulated. A centrifugal pump of 0.5 hp supplies the hot water to the tower at a velocity  $0.0659 \text{ m/sec}$  at a height of 2.24 m. A wooden frame (0.56m x 0.56m x 1.2192m) holds exhaust fan (1400rpm) to suck ambient air from bottom of tower, 2 Ceiling showers (dia-0.127m) to spray hot water and film fill. Dimension of fill: 0.5461m x 1.0287m. Gap between each sheet=0.0254m. The experimental set up is shown in Fig.1and Fig 2 which is an autocad drawing of the setup.



**Fig.1** Schematic diagram of the experimental setup

**Table.1** Calculation of tower demand in tabular form

Water side			Air side		Enthalpy diff.	
Descriptions	$t_w$ ( $^\circ\text{C}$ )	$h_w$ (kJ/kg)	Descriptions	$h_a$ (kJ/kg)	$h_w - h_a$	$1 / (h_w - h_a)$
35.6+ 14.4* 0.1	37	154.86	72.5+0.32 *14.4*0.1	72.96	81.9	0.0122
35.6+ 14.4* 0.4	41.4	173.0	72.5+0.32 *14.4*0.4	74.34	98.66	0.0101
35.6+ 14.4* 0.6	44.2	185.12	72.5+0.32 *14.4*0.6	75.26	109.89	0.0091
35.6+ 14.4* 0.9	48.6	203.18	72.5+0.32 *14.4*0.9	76.65	126.53	0.0079
Sum of $1 / h_w - h_a = 0.0393$						



**Fig.2** Isometric view of the experimental set up

## 6 Performance Test

The performance of cooling towers is evaluated to assess present levels of approach and range against their design values. During the performance evaluation, portable monitoring instruments are used to measure the following parameters: wet bulb temperature of air, dry bulb temperature of air, cooling tower inlet water temperature, cooling tower outlet water temperature, Exhaust air humidity, water flow rate. These measured parameters are then used to determine the cooling tower performance in several ways such as:

- Range
- Approach
- Effectiveness
- Cooling capacity
- L/G ratio

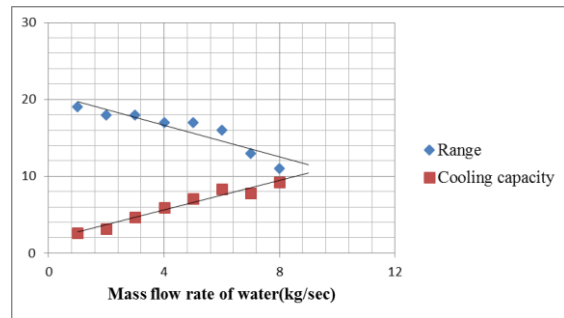
## 7 Result and Discussion

Results are presented in tabular form in **Table 2**.

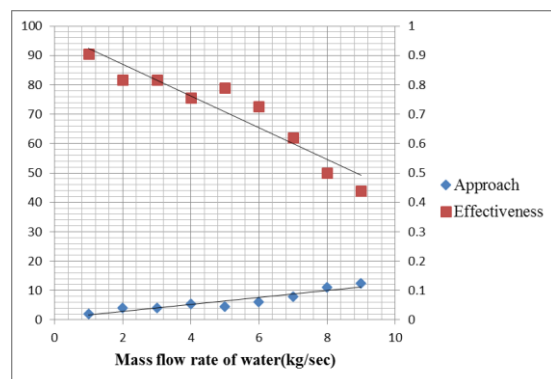
Experiments were conducted to investigate the effects of mass flow rate of water on range, cooling capacity, approach, and effectiveness. The water inlet temperature and air flow rate were maintained constants to 50°C and 0.1043kg/sec respectively for all the experiments. Mass flow rate was varied from 0.0333kg/sec to 0.333kg/sec. It was observed that with the increase of water mass flow rate, range was decreased and cooling capacity was increased which is shown in **Fig 3**. An increased amount of water mass flow rate was responsible for decreasing heat transfer as it reduce the heat transfer time and disturbs the proper film formation. The wet bulb temperature of ambient air was found to vary between 27.5 °C and 29°C. The decrease of inlet humidity ratio and increase of water flow rate results in an increase of the percentage of water mass vaporized inside the cooling tower. While calculating the evaporation rate the highest evaporation rate 1.12x10<sup>-3</sup>kg/sec was found in the 9th observation, where water flow rate was the highest which is 0.333kg/sec and wet bulb temperature was found lowest of all the observations which was 27.5°C. Evaporation rates did not change uniformly due to variation of atmospheric conditions. From Fig 17 it is observed that the approach increases with increase of mass flow rate of water which is due to the increase of outlet water temperature. Effectiveness decreases with water mass flow rate to 44%. Though effectiveness was found highest at the lowest value of mass flow rate, we can't appreciate the lowest mass flow as it decreases the cooling capacity greatly. So it is recommended it to run the cooling tower at a medium water mass flow rate such as 0.125kg/sec so that one can achieve a good range and effectiveness with corresponding cooling capacity and approach.

**Table.2** Presentation of result in tabular form

No of obs	Mass flow rate of hot water $m_w$ (kg/sec)	L/G	Range R (°C)	Approach A (°C)	Effectiveness $\epsilon$	Cooling capacity Q (kW)
1.	0.0333	0.319	19	2	0.905	2.64
2.	0.0417	0.399	18	4	0.818	3.13
3.	0.0625	0.599	18	4	0.818	4.70
4.	0.0833	0.798	17	5.5	0.756	5.92
5.	0.100	0.958	17	4.5	0.790	7.10
6.	0.125	1.19	16	6	0.727	8.35
7.	0.143	1.37	13	8	0.619	7.76
8.	0.200	1.92	11	11	0.500	9.19
9.	0.333	3.19	10	12.5	0.440	13.9



**Fig.3** Effect of mass flow rate of water on range and cooling capacity



**Fig.4** Effect of mass flow rate of water on effectiveness and approach

## 8 Conclusion

Performance of cooling tower found satisfactory throughout the test. The design wet bulb temperature was taken approximately average of year round wet bulb temperature of Bangladesh. In this study rectangular shaped cooling tower is designed with corrugated film fill. Which is different than conventional cooling towers with cylindrical tower body and PVC film fill. One of the major advantage of this design with rectangular shape and corrugated fill is cost effectiveness and ease of construction. As both the construction of cylindrical tower and fabrication of PVC fill is comparatively difficult.

Within the range of experiments following observations were found,

- a) The cooling capacity was found to increase from 2.64 kW to 13.9 kW with the increase of water flow rate from 0.0333kg/sec to 0.333kg/sec.
- b) With the increase of mass flow of water from 0.0333kg/sec to 0.333kg/sec the approach was found to increase from 2 °C to 12.5 °C respectively.
- c) The effectiveness was found to decrease from 90% to 44% with the increase of mass flow rate of water from 0.0333kg/sec to 0.333kg/sec.
- d) The range was found to be decreased from 19 °C to 10°C with the increase of mass flow rate of water from 0.0333kg/sec to 0.333kg/sec respectively.
- e) During comparison between two arrangements a fair deviation of range and effectiveness after a water flow rate of 0.0625kg/sec was observed.
- f) The overall performance of the cooling tower designed, constructed and tested was found satisfactory.

## NOMENCLATURE

$T_1$	: Inlet hot water temperature, °C
$T_2$	: Outlet cold water temperature, °C
$m_{\text{evap}}$	: Rate of evaporation, kg/sec
$m_{\text{da}}$	: Mass flow rate of dry air, kg/sec
$\omega_{\text{ao}}$	: Humidity ratio of cooling tower outlet air
$\omega_{\text{ai}}$	: Humidity ratio of cooling tower inlet air
$m_w$	: Cooling water mass flow rate, kg/sec
$C_p$	: Specific heat of water, J/kg °C
$h_2$	: Enthalpy of air-water vapor mixture at exhaust wet-bulb temperature, kJ/kg
$h_1$	: Enthalpy of air-water vapor mixture at inlet wet-bulb temperature, kJ/kg
$L/G$	: Water air flow rate ratio
$KaV/L$	: Tower characteristic, kg air/kg H <sub>2</sub> O
$Ka$	: Volumetric air mass transfer constant
$V$	: Fill volume, m <sup>3</sup>
$D$	: Diameter of pipe, m
$H$	: Tower height, m
$R$	: Range, °C
$T_{\text{wbt}}$	: Ambient air wet bulb temperature, °C
$Q$	: Cooling capacity, kW

## REFERENCES

- [1] S. V. Bedekar, P. Nithiarasu and K. N. Seerharanu, Experimental investigation of the performance of a counter-flow, packed-bed mechanical cooling tower, *Energy*, Vol. 23, pp 943-947 (1998)
- [2] Don W. Green, Robert H. Perry, Evaporative cooling, *Perry's Chemical Engineers' Handbook*, Eighth Edition, Vol 12, pp 1214-1223(1999)
- [3] Goshayshi HR, Missenden JF, Tozer R, Cooling tower an energy conservation resource, *Applied Thermal Engineering*, Vol 19, pp 1223-1235 (1999)