International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 07 | July 2020 www.irjet.net p-ISSN: 2395-0072

Unique Approach to Validation of Mathematical Model of Counter Flow Cooling Tower

Manisha R. Ramtele[1], Dr. C. R. Patil[2]

[1]*Department of Mechanical Engineering, PRMIT&R, Badnera, Maharashtra, India*
[2]*Professor, Department of Mechanical Engineering, PRMIT&R, Badnera, Maharashtra, India*

---***---

Abstract - *Cooling towers generally found in industries which are used to extract the high temperature from the coolants and make it reusable in various plants. 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. In the present study, our approach is to design a thermally and economically optimum mechanical counter-flow cooling tower which allows the use of a variety of packing materials in the cooling tower toward optimizing heat transfer. In the present research a mathematical model of a cooling tower is developed however; validation of the mathematical model is done for checking the accuracy of the mathematical model. Simulation for the model is done with Visual Studio.net software. The model is tested against experimental data.*

Key Words: **Cooling Tower, Heat & Mass Transfer, Mathematical modelling, and validation.**

1. INTRODUCTION

The aim of any industry is to deliver the products maximally with the minimal consumption of resources and energy. These resources include electricity, labor etc. These resources were available in abundant during the last few decades. Due to the development of industrial sector, the resources that are available have decreased over the time.

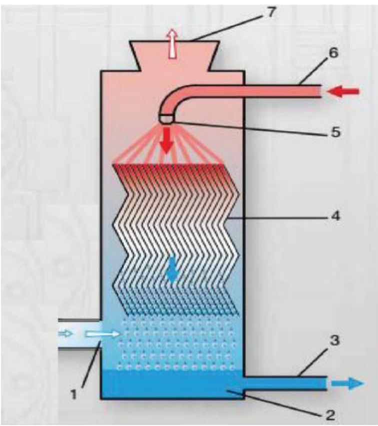


Fig. 1 Mechanical counter flow cooling tower

1)air in, 2)drip pan,3)outlet for cold water, 4)packing column, 4) hot water spay,6) inlet for hot water, 7)hot air out

The working principle of mechanical counter flow type cooling tower is shown in figure 1.first as per shown in fig. the hot water is sprayed from the spay nozzle on the packing material or packing column and the air also passed from the air inlet in upward direction. Due to which, temperature of hot water decreases and the cold water coming out from the cooling tower from water outlet and it will be reusable. In this way same water can be used again and again.

The system behavior can be studied by two different methods. First is by doing the practical or experiment with the actual system and another is by developing the system model. Practical with the actual system is all time very costly time consuming also. Hence the development of system model is easy and checking the physical behavior of the system is also possible. For model development, also there are three possible methods which are given below;

i) Mathematical modelling
ii) Scientific modelling
iii) Analytical modelling

In this work we are using mathematical modelling. A mathematical model is nothing but the derived equations for the heat and mass transfer through energy and mass balance equations. The thermal behaviour of the cooling tower in various operating and environmental conditions is also studied. The aim of this work is to better understanding of the performance of a cooling tower can be effective design of the cooling tower. This will be advantageous for the entire plant.

2. DEVELOPMENT OF MATHEMATICAL MODEL

Nomenclature

T Temperature (°C)

G flow rate per unit cross-sectional area (kg/ m^2-s)

z height of the tower (m)

h enthalpy (kJ/kg)

$\dot{m}$ flow rate (kg/s)

Cp specific heat at constant pressure (kJ/kg-K)

at specific surface area per unit volume (m^2/ m^3)

Subscripts

w water

e equilibrium

a air

v water vapor

i inlet

o outlet

T thermal

m moisture

Greek letters

λ evaporation loss (m^3/hr) or (kg/s)

ω air specific humidity ratio (kg_v /kg_{da})

αm mass transfer coefficient (kg/m^2-s)

αh heat transfer coefficient (W/m^2-K)

ξ effectiveness

δ latent heat of vaporization (kJ/k

Table 1 shows the operating conditions of the counter flow type cooling tower;

Table 1: Operating Conditions for Counter Flow Type Cooling Tower

Parameter	Operating range
Air flow rate (g/s)	20-42
Water flow rate (g/s)	17-24
Water temp. (^{0}c)	38-47
Ambient temp. (^{0}c)	23-29
Ambient relative humidity (%)	50-77
Packing density (m^2/m^3)	110
Specific area of packing column (m^2)	0.0225

All the measurements required for temperature measurement, measuring of water flow rate, ambient air and the relative humidity are taken physically.

Figure 2 shows the heat and mass transfer occurring in between the air and water for counter flow.

Some assumptions are made here for simple or easy analysis, are given below;

- Adiabatic evaporative cooling (water cooling and air humidification) process.
- Change in mass flow rates of ambient air and water are negligible.
- Heat and mass transfer interaction at the air – water interface area is equal to the specific area of packing.
- Properties of water and ambient air are assumed to be constant with respect to the temperature.

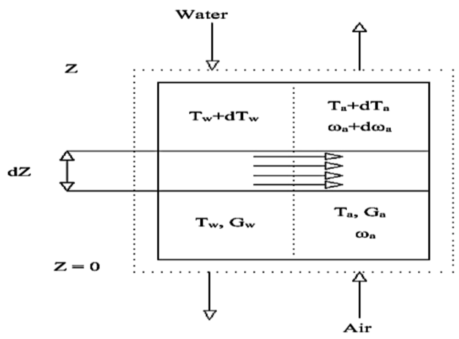


Fig. 2. Energy and mass balance across the Cooling tower

In the present study, for calculating the output values of evaporation loss, water temperature and air temperature etc. for the cooling tower there is a need of some constant parameters which are given in table 2 and all the input data collected from the plant are given in table 3.

Table 2: Constant Parameters Required for the Counter Flow Type Cooling Tower

Parameters	Values
Specific Heat of Vapor at Constant Pressure – Cp_v	1.996 KJ/Kg-k
Specific Heat of Air at Constant Pressure -	1.005 KJ/Kg-k
Specific Surface Area per Unit Volume - at	110 m^2/m^3
Cooling Tower Height - z	0.63 m
Relative Humidity - RH	55-77
Average Heat Transfer Coefficient - αh	W/m^2-k

Table 3: Inlet parameters used for the theoretical model

Tai (^{0}C)	Twi (^{0}C)	ωi (kg_v /kg_{da})	Mw (kg/s)	Ma (kg/s)
23.2	39.1	0.011	0.017	0.037
23.7	40.1	0.012	0.017	0.041
25.0	44.4	0.013	0.019	0.027
25.2	44.2	0.013	0.013	0.033
25.5	38.6	0.012	0.021	0.032

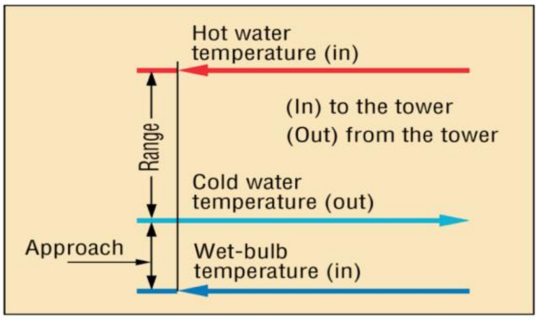


Figure 3: Range and Approach

The enthalpy on air side is given by;

$$ha = Cpa * Ta + \omega(Cpv * Ta + \delta) \quad (1)$$

On differentiation Eq. 1 can be obtained as

$$dha = (Cpa + \omega * Cpv)\, dTa + d\omega(Cpv * Ta + \delta) \quad (2)$$

Energy balance across the air side flow is written as

$$Ga(ha+dha) - Ga*ha =$$

$$\alpha h*at\,(Tw-Ta)dZ + Ga*d\omega\,(Cpv*Ta+\delta) \quad (3)$$

Combining Eq. (2) & (3), Temperature gradient of air is obtained as given below;

$$dTa/dz = (\alpha h*at(Tw-Ta))/(Ga(Cpa+\omega Cpv)) \quad (4)$$

By integrating equation 4, as shown below;

$$\int_{Tai}^{Tao} \frac{dTa}{(Ta-Tw)} = \int_{0}^{z} \frac{-\alpha h*at}{Ga\,(Cpa+\omega Cpv)} \quad (5)$$

After integrating Eq. 5, final equation can be obtained as

$$(Tao-Tai)/(Twi-Tai) =$$

$$1-\exp((-\alpha h*at*z)/(Ga(Cpa + \omega ai*Cpv)) \quad (6)$$

But a temperature difference ratio in terms of outlet air temperature and inlet temperatures of the ambient air and the water is known as a thermal effectiveness (ξ), therefore

$$\xi = (Tao-Tai)/(Twi-Tai) \quad (7)$$

Put the value of a thermal effectiveness in Eq. 6 we get finalized equation at air side

$$\xi = 1-\exp((-\alpha h*at*z)/(Ga(Cpa+\omega ai*Cpv))) \quad (8)$$

Now,
Thermal effectiveness = (Tao-Tai)/(Twi-Tai) (9)

In this case where the outlet water temperature T_{wo} is not known, the empirical relation given below can be used to determine it (Jordan, R. C., Priester, G. B. Refrigeration and Air Conditioning Prentice-Hall of India (Pvt) Ltd, New Delhi (1966)).

Two = (Twi + 2* Twba +Tdba)/4

The Evaporation loss can be calculated from the heat balance across the cooling tower. The amount of heat to be removed from Circulating water according to Q = m Cp DT is Source: Perry's Chemical Engineers Handbook (Page: 12-17)

Q = C x Cp x R. (10)

The amount of heat removed by evaporative cooling is

Q = m x δ is

Q = λ x δ (11)

On equating Eq. 10 and 11, we get

λ = (C *R *Cp) /δ (12)

Where

λ = Evaporation Loss in m^3/hr

C = Cycle of Concentration (3.0. to 7.0)

C_p= Specific Heat = 4.184 kJ / kg / °C

δ = Latent heat of vaporization = 2260 kJ / kg

R = Range in °C

Cooling tower effectiveness is nothing but the cooling tower efficiency. Cooling tower effectiveness (in percentage) is the ratio of range, to the ideal range, i.e., difference between cooling water inlet temperature and ambient wet bulb temperature i.e. (Range + Approach).

Cooling tower effectiveness =

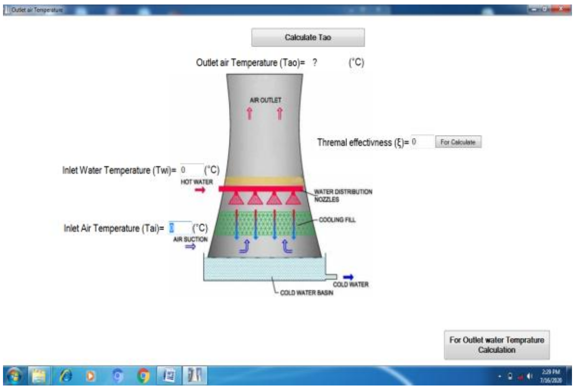
(Range/(Range + Approach))* 100 (13)

All above empirical relation and given data collected from Thermal Power Plant at Nandgaon peth Amravati

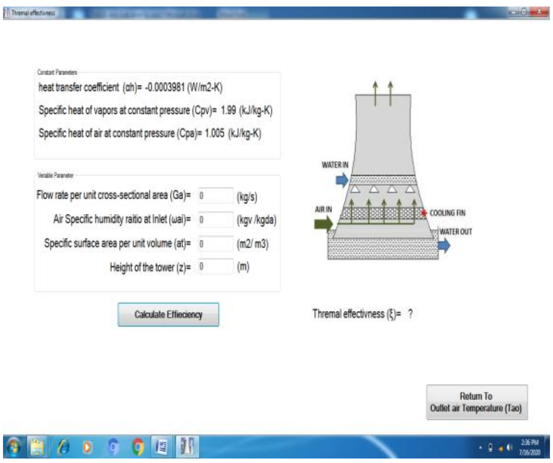
District, Maharashtra are used to determine the value of T_{ao}, T_{wo}, evaporation loss, and CTE for all five cases.

3. VALIDATION OF MATHEMATICAL MODEL

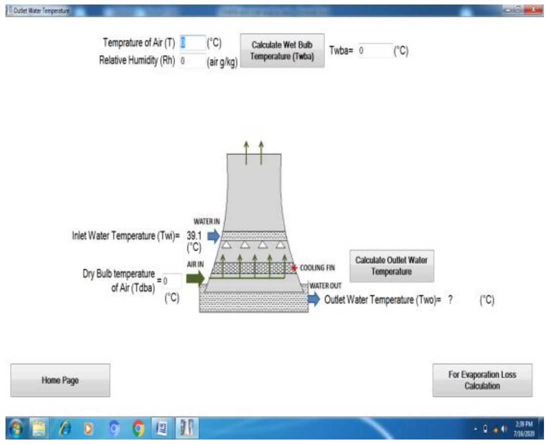
Simulation of a system is the operation of a model in terms of time or space, which helps analyze the performance of an existing or a proposed system. In other words, simulation is the process of using a model to study the performance of a system. It is an act of using a model for simulation. Simulation is one of the most widely used quantitative methods because it is so flexible and can yield so many useful results. Simulation algorithms of cooling tower are computed using Visual Studio.Net which is very user friendly software. Following figures shows the simulation model developed for the validation of mathematical model. From which easily output values can be find out as shown in fig. below,



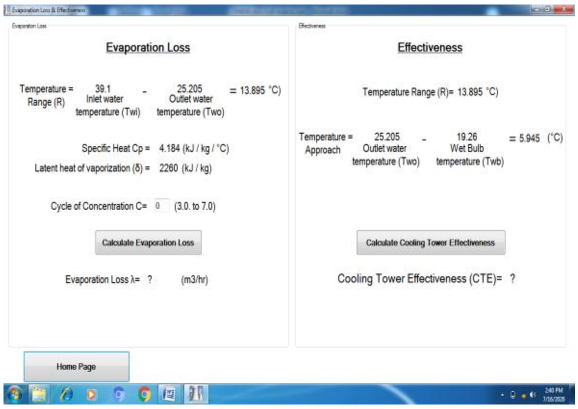
(a)



(b)



(c)



(d)

Fig.4 (a-d) Simulation model of cooling tower

4. RESULTS AND DISCUSSIONS

In order to use the theoretical model for estimating the evaporation loss and all output values of parameters of a counter flow cooling tower, a validation is essential. So, a comparison for the experimentally measured values with the results got from the mathematical and simulation model is made and is presented in Table 4 below;

The maximum difference between the calculated and experimentally measured outlet temperature of the ambient air is 0.74 ^{0}C and the mean difference is 0.80 ^{0}C. The water outlet temperature differ as much as1.32 ^{0}C, whereas the average difference is about -0.46 ^{0}C. The predicted evaporation loss has a maximum deviation of 2.88 % from the experimental values; the mean deviation is about 2.61 %.

Table 4: Comparison of the Cooling Tower Model Results

Experimental Data	**1**	**2**	**3**	**4**	**5**
Water Inlet Temperature (ºC)	39.1	40.1	44.4	44.2	38.6

Water Outlet Temperature (ºC)	28.30	27.00	27.40	30.15	29.10
Air Inlet Temperature (ºC)	23.2	23.7	25.0	25.2	25.5
Air Outlet Temperature (ºC)	28.30	29.90	29.60	30.00	29.05
Mass Flow Rate of Water (Kg/s)	0.017	0.017	0.019	0.013	0.021
Mass Flow Rate of Air (Kg/s)	0.037	0.041	0.027	0.033	0.032
Evaporation Loss (%)	0.1340	0.1611	0.1125	0.1910	0.1813
Model Output Result					
Water Outlet Temperature (ºC)	27.19	25.69	26.50	28.89	27.87
Air Outlet Temperature (ºC)	27.56	29.28	29.46	28.56	27.69
Evaporation Loss (%)	0.1287	0.1335	0.0021	0.1622	0.1530
Result Error					
Water Outlet Temperature Diff. (ºC)	1.11	1.32	0.90	1.27	1.23
Air Outlet Temperature Diff. (ºC)	0.74	0.62	0.14	1.44	1.36
Evaporation Loss Diff. (%)	0.0053	0.0276	0.0004	0.0288	0.0283
Cooling Tower Effectiveness	70.035	70.721	76.321	66.356	61.105

Figs.5 shows the experimental results with the theoretical modeling. These results show the effect of various inlet parameters on the cooling tower effectiveness.

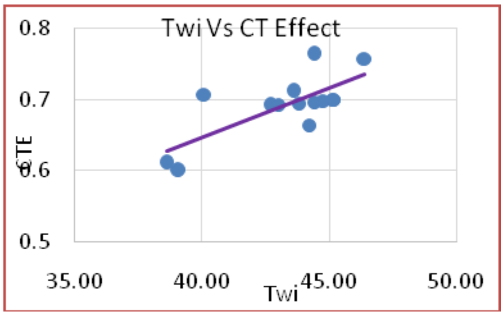
Fig.5 (a) shows the effect of water inlet temperature on cooling tower effectiveness. From the fig. 5(a) we can say that the cooling tower effectiveness increases with increase in water inlet temperature. This shows that higher temperature results in higher the partial pressure.

In Fig 5 (b) it is observed that the cooling tower effectiveness slightly decreases with increase in air flow rate. As cooling tower effectiveness slightly decreases from 70% to 68% so, it doesn't have phenomenal effect on the cooling tower efficiency.

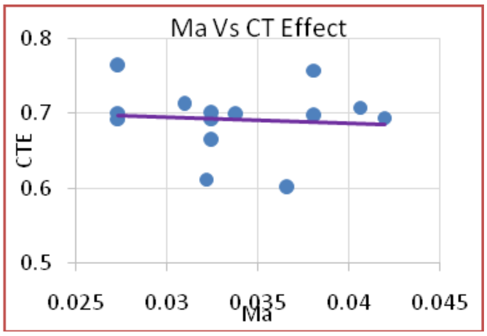
Fig. 5(c) shows the effect of air specific humidity ratio on cooling tower effectiveness. The cooling tower effectiveness increases with increase in air specific humidity ratio. This is because; the higher humidity ratio gives higher vapour pressure of air and hence lower potential for mass transfer.

From Fig. 5(d), it is proved that the cooling tower effectiveness increase slightly with increase in water flow rate. At high water flow rate there will be less reduction in water temperature.

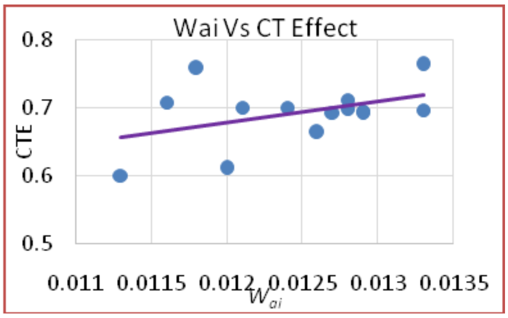
Finally fig. 5(e) shows the effect of ambient air temperature on cooling tower effectiveness. The ambient air temperature increases the cooling tower effectiveness is also increase.



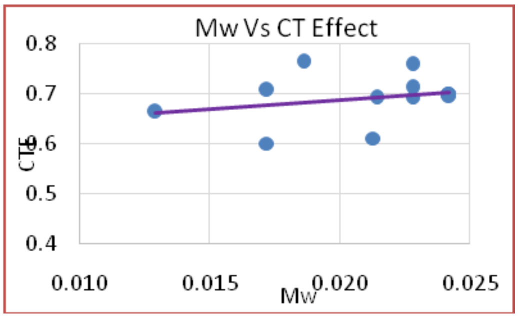
(a)



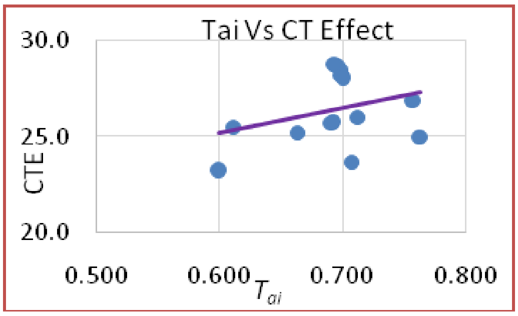
(b)



(c)



(d)



(e)

Fig.4 (a-e). Comparison of present model with the experimental findings: The influence of a) Water inlet temperature; b) Mass flow rate of air; c) Specific humidity; d) Mass flow rate of water and e) Air inlet temperature on cooling tower effectiveness.

5. CONCLUSIONS

The focus of the present research is on the study of the effect of Visual Study ASP.net on computer aided study of cooling tower. The experiment has been performed considering range, approach, in and out water temperature etc. of cooling tower. The mathematical model has been prepared for improving overall performance of cooling tower.

In this study, the thermal performance of the cooling tower is simulated in terms of varying air and water temperatures, and of the ambient conditions a unique finite difference model using dimensionless parameters such as thermal effectiveness in terms of heat transfer coefficient has been proposed. Influences of various inlet parameters on the water evaporation loss are found to be linear. The model predictions show a good agreement with the experimental data.

REFERENCES

[1] Aloksingh, S P S Rajput "Application of CFD in Natural Draft Wet Cooling Tower Flow" International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 2, Issue 1,Jan-Feb 2012, pp.1050-1056

[2] cooling tower- part i, exit cold water temperature" International Journal of Applied Engineering and Technology ISSN: 2277-212X 2012 Vol. 2 (3) July-September, pp.5-9

[3] T.Jagadeesh, Dr.K.Subba Reddy "Performance Analysis of the Natural Draft Cooling Tower in Different Seasons" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 7, Issue5(Jul.-Aug.2013),PP19-23www.iosrjournals.org

[4] Tanweer S. Deshmukh& V.K Gahlot "Simulation of flow through a pump sump and its validation" International Journal of Civil Engineering Department, M.A.N.I.T,Bhopal,IJRRAS4(1)●July2010

[5] Mohd Amir, Fithry1, Yusoff, MohdZamri2 "Numerical Investigation of a Single Phase Air Flow inside Porous Media of a Cross Flow Cooling Tower"International Journal of Science and Research (IJSR), India Online ISSN: 2319-7064

[6] Arvind kumar patel, Dr. Aloksingh "Simulation of natural draft wet cooling tower with variation of air inlet height through computational fluid dynamics" International journal of innovative research & studies(IJIRS), ISSN 2319-9725

[7] Veena N, SayeedSulaiman, Aswath M U "Comparative Study Of The Effect Of Seismic And Wind Loads On Cooling Tower With A-Frame And H-Frame Column Supports." The International Journal Of Science &Technoledge (ISSN 2321–919X)

[8] B. Kiran Naika, V. Choudharya, P. Muthukumara* C. Somayajia "Performance Assessment of a Counter Flow Cooling Tower –Unique Approach" International Conference on Recent Advancement in Air Conditioning and Refrigeration, RAAR 2016, 10-12 November 2016, Bhubaneswar, India-134