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Prediction of Cooling Tower Thermal Characteristics using Newly Developed Software for a Chemical Industry

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Abstract : This paper deals with development of a new software that will help to predict the Thermal Performance of a cross flow-cooling tower which is situated in a medium scale industry in Thoothukudi, Tamilnadu, INDIA. From this software, the industry persons can predict the outlet water temperature, effectiveness of the cooling tower, percentage of water loss from the input parameters like L/G ratio, Relative humidity; inlet water temperature and inlet air-dry bulb temperature. The methodology for developing software for cooling tower, which can be fit in any industry, is discussed here.
Keywords: Thermal Performance, Cross flow cooling tower, Software, Industrial application.

1 Introduction

Diesel Power plants engender huge amounts of waste thermal energy, which has to be liberated continuously to prevent the plant from deterioration; this can be done with the aid of cooling towers. Cooling towers (CT's) are devices accountable for dissipating waste thermal energy to the ambient environment. CT's function based on mass and thermal energy transfer from high temperature water to ambient air. Many research works are being carried out in thermal performance prediction of cooling towers. In this paper cross flow cooling tower present in a medium scale private industry in Thoothukudi, Tamil Nadu was taken to create software which is already simulated using stepwise integration method by Immanual et.al [1]. The data's used here are taken from this paper. Ebrahim Hajidavalloo et.al [2] applied a conventional mathematical model to existing cross flow tower under varying wet bulb temperature which shows that increasing the wet bulb temperature while keeping the dry bulb temperature at constant will decrease the approach, range and evaporation loss. Montri Pirunkaset [3] in his studies, applied the stepwise integration method to find the outlet water temperature by known Fill characteristic, flow rates of the inlet water and air, inlet dry and wet bulb temperature along with hot water temperature. According to Lemouari et al [4] the effectiveness of cooling tower is higher for low water flow rate. As per Xiantai wen [5] studies the stimulus of inlet air temperature and inlet liquid temperature is small. A.S. Pushnov [6] found that film type packing's are the most efficient design solution for realizing evaporation cooling. According to Sunil [7], inlet conditions of flow rate of water, air inlet temperature and water inlet temperature are important factors for cooling tower operations. M.Prasad [8] offered the method to substitute the fill in cooling tower economically. Mushtaq Esmael Hassan [9] tells that cross flow cooling tower is large size compared with the counter flow tower of same cooling load. Arash [10] as per his study, stated that, the water range can be increased at lower air temperature . Gharagheizi et al.[11] reported that the water to air mass flow ratio affect the performance of the cooling tower. Fisenko [12] predicts that the evaporation rate will be more for small droplets. R.Shakeri [13] predicts that the impact separator has no effect on outlet water temperature. Thirapong Muangnoi [14] obtained performance characteristics of a new type of water-jet cooling tower using experiments and numerical simulations. This characteristic forecasts that the energy and second law efficiency are normally sensitive to reasonable deviation in droplet diameter, Water to airflow rate ratio and tower spray zone heights. But it does not respond greatly to reasonable variation in droplet velocity and air velocity. This tower uses a high pressure water spray nozzle to induce a co-current air steam into the tower so that neither fill nor fan are mandatory. J.C. Kloppers [15] presented a methodology to solve the governing equations of the cross flow evaporative process which were derived from first principles according to the Poppe, Merkel and e-NTU methods. From the previous literatures it is very difficult to predict the outlet water temperature and the thermal performance of the cooling tower. If we want to know about the thermal performance of a cooling tower means one should measure the outlet water temperature or derive a mathematical model for the cooling tower. For industry peoples it is difficult to derive a mathematical model and find the thermal performance of a cooling tower. This paper deals with how to make a software for a cooling tower to find its thermal performance.

2 Methodology

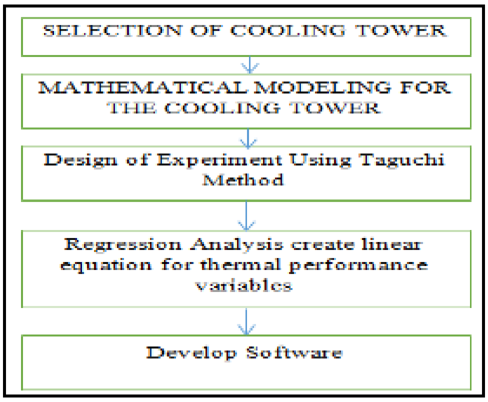

Fig. 1. Methodology

In figure 1. Flow chart shows how the Software development process is being carried out. Initially a cooling tower was selected for this study. And then mathematical model was formed and validated [01]. Here the stepwise integration mathematical model was used. Design of Experiments using Taguchi method is carried out on the input parameters as shown in the table 1.

Table 1. Parameters and levels for taguchi design.

		Process Parameters			
		L/G Ratio (A)	**Relative Humidity % (B)**	**Inlet Water Temperature°C (C)**	**Dry Bulb Temperature °C (D)**
Levels	**1**	0.8	45	46	30
	2	1	55	48	32
	3	1.25	65	50	34
	4	1.5	75	52	36

2.1 Design Of Experiments

Design of experiments using Taguchi method was used to reduce the more number of experiments. This study is associated with four factors with each at four levels. An orthogonal array is used to find the effects of the four parameters namely the L/G Ratio, Relative Humidity, Inlet Water Temperature and Dry bulb Temperature based on the prediction of cooling tower. The four selected parameters at four levels i.e., L-16, Orthogonal array along with its mathematical simulation considered are shown in table I. Stepwise integration method Procedure for this cooling tower was given by Immanual.R [1].

These levels and parameter value ranges are set by the available data's and working ranges in the cooling tower of medium scale private industry. In this study, Minitab 15, which is a software for automatic design, was used to analyze the results for setting the control variables. Orthogonal array is being used to design the experiments with four parameters at four levels, L-16(44). According to this array values, the effectiveness, outlet water temperature and % of water loss are found by using the stepwise integration method . The values are then Substituted with actual values in the L-16 array matrix. Then SN ratio graph is generated from the software. Now using these sixteen data of four parameters along with their outputs such as effectiveness, outlet water temperature and % of water loss, the regression analysis is done using Minitab 15 software.

From the Taguchi analysis it is conclusive that the effectiveness of the cooling tower and the outlet water temperature mainly depends on liquid to gas flow ratio. The percentage mainly depends upon the relative humidity of the inlet air. Stepwise integration simulation runs for the orthogonal array input conditions and their outputs were taken.

The outputs derived are outlet water temperature, percentage of water loss and efficiency. These input and output process parameters are used to form Linear function using regression analysis. Simulation has been carried out and their results have been tabulated in Table 2.

Table 2. Simulated output for stepwise Integration mathematical model.

Run No	**Input Process Parameters**				**Output Process Parameters**		
	L/G	**DRYT (°c)**	**RH (%)**	**IWT (°c)**	**TWO (°c)**	**LOSSP (%)**	**EFF (%)**
1	0.8	30	45	46	24.83	3.24	84.66
2	0.8	32	55	48	27.17	3.19	86.78
3	0.8	34	65	50	29.75	3.10	88.02
4	0.8	36	75	52	32.59	2.97	94.68
5	1	34	45	48	28.64	2.96	80.68
6	1	36	55	46	30.79	2.33	82.23
7	1	30	65	52	29.11	3.50	81.75
8	1	32	75	50	31.15	2.88	85.70
9	1.25	36	45	50	31.61	2.81	76.62
10	1.25	34	55	52	32.06	3.05	78.19
11	1.25	32	65	46	31.42	2.23	72.92
12	1.25	30	75	48	31.62	2.51	74.47
13	1.5	32	45	52	32.15	3.04	68.44
14	1.5	30	55	50	31.94	2.76	66.88
15	1.5	36	65	48	34.86	2.01	71.00
16	1.5	34	75	46	34.50	1.76	69.68

2.2 Creating Function Using Regression Analysis

Statistical method for analyzing multi variable data is a Regression analysis. It is used to provide the functional relationships to correlate data with known variables. From the Multiple linear regression analysis, create the function for the following

Function 1: to increase the Effectiveness of the cooling tower
Function 2: to reduce the percentage of water loss
Function 3: to reduce the outlet water temperature

Function 1

Regression Analysis: TWO versus L/G, DRYT, RH, IWT

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.330182	98.77%	98.32%	96.97%

Regression Equation

TWO = -8.97 + 6.849 L/G + 0.5015 DRYT + 0.10258 RH + 0.1911 IWT (01)

Function 2

Regression Analysis: EFF versus L/G, DRYT, RH, IWT

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.12	98.55%	98.03%	96.62%

Regression Equation

EFF = 54.92 - 27.90 L/G + 0.663 DRYT + 0.1051 RH + 0.562 IWT (02)

Function 3

Regression Analysis: LOSSP versus L/G, DRYT, RH, IWT

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.051	99.18%	98.88%	97.99%

Regression Equation

LOSSP = 1.373 - 1.0478 L/G - 0.07672 DRYT - 0.01570 RH + 0.12376 IWT (03)

2.3 Software

By using Microsoft Visual studio 2010 develop the software. In this software, it uses the linear function to predict the thermal performance of the cooling tower. To reduce the human effort at the DCW here develops software. From this software, one can find the outlet condition of the water without measuring it. This software works on the regression equation so the error of this software within 5% that is acceptable one. This software developed from C# coding in . Net Platform. This software can be downloaded from the website [16].

Inputs to the software are

1. Inlet water temperature
2. Relative humidity
3. Dry bulb temperature
4. L/G ratio

Output from Software

1. Effectiveness
2. Water Loss

3. Outlet Water Temperature
4. Cooling Range

2.4 Program Code

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Windows.Forms;

namespace DCWCOOLINGTOWER

{public partial class Form1 : Form

float result1;
float result2;
float c1 = (float)54.92;
float c2 = (float)0.562;
float c3 = (float)0.1051;
float c4 = (float)0.663;
float c5 = (float)27.90;
float c6 = (float)1.373;
float c7 = (float)0.12376;
float c8 = (float)0.01570;
float c9 = (float)0.0767206;
float c10 = (float)1.0478;

public Form1()

{ InitializeComponent(); }

private void button1_Click(object sender, EventArgs e)
{ float s1 = (float)Convert.ToDouble (textBox1.Text);
float s2 = (float)Convert.ToDouble(textBox2.Text);
float s3 = (float)Convert.ToDouble(textBox3.Text);
float s4 = (float)Convert.ToDouble(textBox4.Text);
result1 = c1 + c2 * s1 + c3 * s2 + c4 * s3 - c5 * s4;
result2 = c6 + c7 * s1 - c8 * s2 - c9 * s3 - c10 * s4;
textBox5.Text = result1.ToString();
textBox6.Text = result2.ToString();}

private void button2_Click(object sender, EventArgs e)

{ textBox1.Clear();
textBox2.Clear();
textBox3.Clear();
textBox4.Clear();
textBox5.Clear();}

private void Form1_Load(object sender, EventArgs e)
{        }
private void textBox2_TextChanged(object sender, EventArgs e)
{       }
private void label2_Click(object sender, EventArgs e)
{       }
```

```
private void textBox3_TextChanged(object sender, EventArgs e)
{       }   }}
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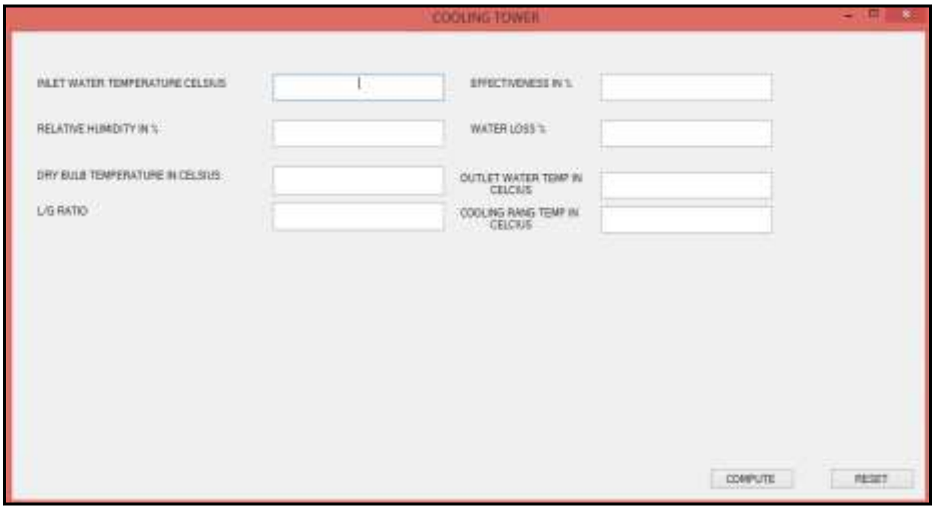

Fig. 2. Screen shot of software

3 Results and Discussion

The outputs get from the site data compare with the software output data which error is less than 5% shown in Table 3. This shows that this software is reliable for the ranges within the limits of taguchi design of experiment. From the previous three years site data shows that the cooling tower worked in this range only.

Table 3. Software Reliability.

Sr. No.	DATE	TIME	(Twi) (°C)	(Tdi) (°c)	RH (%)	(Two) (°C) (experimental results)	(Two)(°C) (Software Predicted results)	Error (%)
1	10/09/2015	02.00 pm	48	36	53	33	32.59	1.24
2	10/09/2015	08.00 pm	46	34	60	32	31.93	0.21
3	15/09/2015	10.00 am	54	36	49	34	33.33	1.97
4	16/09/2015	11.00 am	53	37	49	34	33.64	1.05
5	16/09/2015	03.00 pm	53	38	43	34	33.74	0.76

4 Conclusions

1. The procedures for how to develop software for prediction of thermal performance of cross flow-cooling tower discussed.
2. New software was developed to predicts the thermal performance of a cross flow cooling tower without measuring the outlet water temperature.
3. The Thermal performance get from the software compared with the site-measured data, which shows that the software prediction is within 5% of error.

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