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Analysis of Counter Flow Induced Draft Cooling Tower using Taguchi Method

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***Abstract*— Cooling tower is a very important unit of most of plants. The capital and operating cost is often very high so we require optimizing the performance parameters of cooling tower. This work proposes the application of Taguchi method to achieve maximum cooling of outlet water of counter flow induced draft cooling tower. The experiments were planned based on Taguchi's L9 orthogonal array. The trail was performed under different inlet conditions of flow rate of water, heat load, inlet water temperature and air flow rate. Signal-to-noise ratio (S/N) analysis, analysis of variance (ANOVA) and regression were carried out in order to determine the effects of process parameters on cooling tower outlet water temperature and to identify optimal factor settings of counter flow induced draft cooling tower performance with sufficient accuracy.**

Keywords*— optimization, Cooling tower, performance, Taguchi Method

1. INTRODUCTION

Cooling towers are heat exchangers which are used to dissipate large heat loads to the atmosphere. It is equipment used to reduce the temperature of a water stream by extracting heat from water and emitting it to the atmosphere. In mechanical draft towers, air is moved by one or more mechanically driven fans to provide a constant air flow. The function of the fill is to increase the available surface in the tower, either by spreading the liquid over a greater surface or by retarding the rate of fall of the droplet surface through the apparatus. The fill should be strong, light and deterioration resistant. In this study, expanded wire mesh was used as the filling material. Its hardness, strength and composition guard against common cooling tower problems resulting from fire, chemical water treatment and deterioration. The operating theory of cooling tower was first suggested by Walker [1]. Simpson and Sherwood studied the performances of forced draft cooling towers with a 1.05 m packing height consisted of wood slats [3]. Kelly and Swenson studied the heat transfer and pressure drop characteristics of splash grid type cooling tower packing [4]. Barile et al studied the performances of a turbulent bed cooling tower. They correlated the tower characteristic with the water/air mass flow ratio [5].

There are several types of cooling towers. Wet cooling towers can work as natural or mechanical draft. Mechanical draft towers can be either forced or induced draft. Air and water flow can be countercurrent, crosscurrent or both. Therefore, some types of cooling towers are presented in details.

Mechanical draft cooling towers are predominant types of cooling towers and built in many places in the world. Therefore, the performance characteristic of a induced draft cooling tower is the subject of this paper.

The packing is the most crucial part of the cooling tower. The purpose of the packing material is to provide a large surface area for contact between air and water by distributing the water flow uniformly to enhance evaporation and heat transfer. As the water flows down the packing, it contacts air that is forced across the packing by a fan. A small percentage of the water evaporates by cooling the water. The relatively small portion of the water droplets in the air stream is called as "drift". The warm, moist air then passes through the drift eliminator and exits at the top of the tower, by carrying out some of the drifts out of the tower.

2. EXPERIMENTAL LAYOUT

The experimental study is carried out in M/s. Neelam College of Engineering & Technology, Agra (Uttar Pradesh). In this experiment counter flow induced draft cooling tower is used. As the literature and study of cooling tower in Neelam College of Engineering & Technology, Agra (Uttar Pradesh) suggested, the experimental setup is constructed for the cooling tower and the various factors and their levels are chosen, which are dependent on the following properties of the cooling tower: Heat Load, Range, Dry bulb temperature, Wet bulb temperature, Height of tower, No. of cell, Type of fill material, Air flow Rate, Inlet water temperature, Water flow rate.

Figure 2.1 Water Cooling Tower

Courtesy: Heat & Mass Transfer Lab of Neelam College of Engg. & Technology, Agra (Uttar Pradesh)

3. TAGUCHI METHODOLOGY

In early 1950's, Dr. Genichi Taguchi, "The Father of Quality Engineering," introduced the concept of off-line quality control techniques known as Taguchi parameter design. Offline quality control are those activities which were performed during the Product (or Process) Design and Development phase. The Taguchi method is statistical tool, adopted experimentally to investigate influence of cooling effectiveness by cooling parameters such as Water Flow, Air Flow and Inlet Water Temperature. The Taguchi process helps to select or to determine the optimum cooling conditions for various processes. Many researchers developed many mathematical models to optimize the cooling parameters to get highest cooling effectiveness by various processes. The variation in the water flow, air flow and other factors affecting cooling effectiveness.
Here the Taguchi design of experiments is used to optimize the cooling parameters.

3.1 Signal to Noise Ratios (S/N Ratios)

Taguchi recommends the use of the criterion he calls, "Signal to noise ratio "as performance statistic. The change in quality characteristic of a product under investigations in response to factor induced in the experimental design is the signal of the desired effect. The effect of external affairs (Uncontrollable factors) on the outcome of the quality characteristic under test is termed the noise.
From the quality point of view, there are three possible categories of quality characteristic. They are:

1. Smaller the better.
2. Nominal is the best.
3. Larger is better.

3.2 PROCEDURE AND STEPS OF TAGUCHI PARAMETER DESIGN

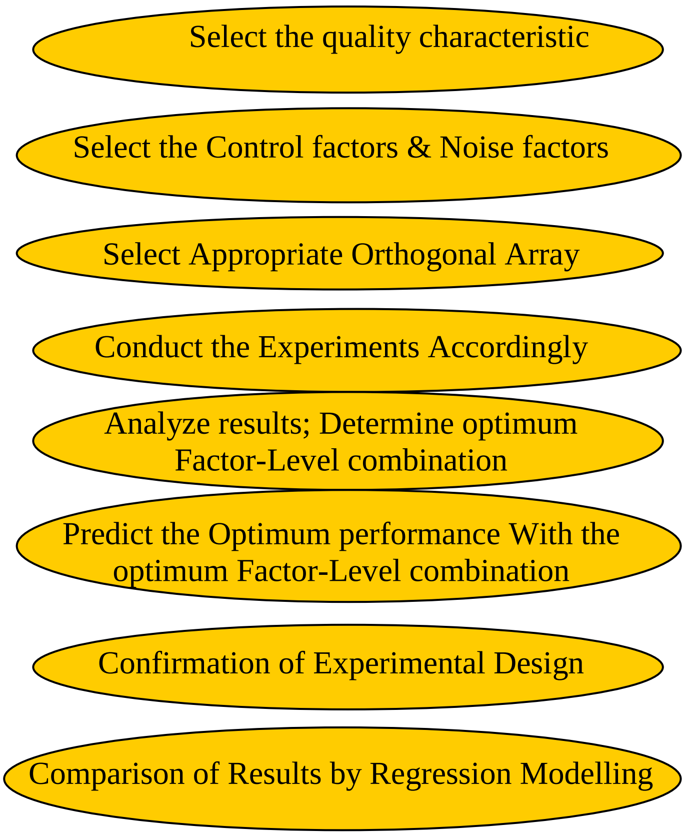


Figure 3.1 Procedure & Steps of Taguchi Parameter Design

3.3. Selection of Orthogonal Array

There are 9 basic types of three level arrays from standard Orthogonal Arrays (OA) from the Genichi Taguchi parameter design (Genichi Taguchi and Yu-in Wu, Offline Quality control, 1979). An L_9 Orthogonal Array is selected for this study. The layout of this L_9 OA is as mentioned in Table 3.1.

Experiment	P1	P2	P3	P4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 3.1 The Basic Taguchi L_9 Orthogonal Array**

(** Appendix B, 2nd edition, 2005, Taguchi Techniques for Quality Engineering, Philip J Ross[20], Tata McGraw-Hill Publishing Company limited)

The OA (Orthogonal Array) to be selected must satisfy the following conditions:

Since,
D.O.F. of O.A. selected ³ D.O.F. required.

The experiment under consideration has 6 D.O.F. and therefore requires an O.A with 9 or more D.O.F., Hence an O.A. with at least 9 experiments is to be selected to estimate the effect of each factor and the desired interaction.

3.4 Selection of factor levels

S.N.	Process Parameter Design	Process Parameter	Levels		
			Low	Medium	High
1.	A	Water Flow Rate (m^3/hr)	0.50	1.0	1.5
2.	B	Heat Load (kCal/hr)	300	350	400
3.	C	Inlet water temp.(^{0}C)	38	42	46
4.	D	Air flow rate (m^3/hr)	0.5	1.0	1.5

Table 3.2 Process Parameters and their Levels

4. STATISTICAL ANALYSIS

Statistical analyses (S/N ratio, regression) are carried out:

4.1. Signal to Noise Ratio or S/N Ratio

The response variable considered in this study is cooling Effectiveness, which is of larger the better kind. Therefore, signal to noise ratio is defined by

S/N RATIO (Hi) = -10 Log10 [(1/n) *_i (1/ Yi2)] --- (i)

S.No.	Exp. No.	Outlet Water Temp. (°C) (I)	Outlet Water Temp. (°C) (II)	Mean Outlet Water Temp. (°C) (I + II)/2	S/N ratio (dB) H_i
1	1	29.16	29.46	29.31	-29.34
2	2	32.46	33.12	32.79	-30.31
3	3	34.63	33.86	34.24	-30.69
4	4	31.60	31.31	31.45	-29.95
5	5	35.16	36.00	35.58	-31.20
6	6	30.21	31.58	30.89	-29.79
7	7	35.78	34.30	35.04	-30.89
8	8	30.48	31.26	30.87	-29.79
9	9	36.67	37.39	37.03	-31.37

Average of S/N Ratio = -30.34 dB

Table 4.1 Outlet Water temperature & S/N Ratio Summary Sheet

5. MODELLING OF PARAMETERS

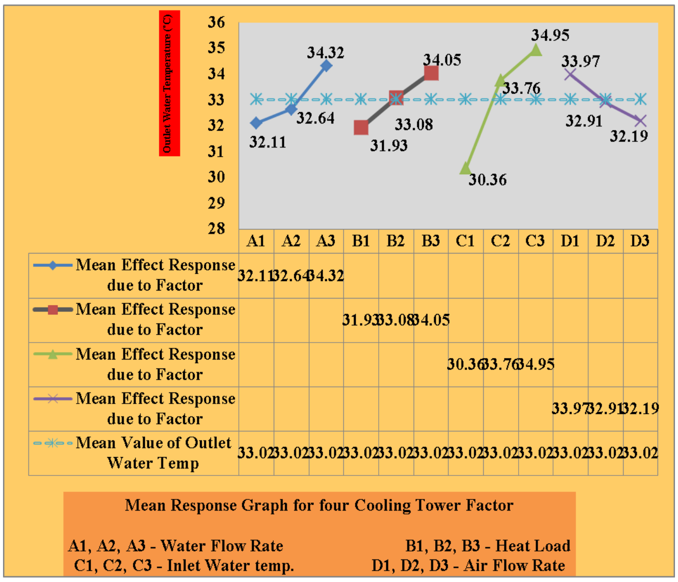
To generalize the results, the Modelling of input parameters (Water Flow, Air Flow and Water Temperature) and output parameter (Cooling Effectiveness) is done using REGRESSION MODELLING and MATLAB Software R2008a.The Cooling Effectiveness is a function of Water Flow, Air Flow and Water temperature has been adopted.

Y=0.6922* (Water Flow Rate) $^{0.1444}$ * (Heat Load) $^{0.2147}$ * (Inlet Water Temp.) $^{0.8262}$* (Air flow rate) $^{0.3084}$ ----- (ii)

6. DETERMINATION OF OPTIMAL FACTOR LEVELS

The values obtained from the response Table are plotted to visualize the effect of the three factors at three levels. From the Mean response graph, observational findings are illustrated as follows:

1. Level I for Water Flow Rate, A1 = 0.50 m^3/hr indicated as the optimum situation in terms of Outlet Water Temperature values.
2. Level I for Heat Load, B1 = 300 kcal/hr indicated as the optimum situation in terms of Outlet Water Temperature values.
3. Level I for Inlet Water Temperature, C1 = 38 °C indicated as the optimum situation in terms of Outlet Water Temperature values.
4. Level III for Air flow rate, D3 = 1.5 °C indicated as the optimum situation in terms of Outlet Water Temperature values.



Graph 6.1 Mean Response Graph for four Cooling Factors

7. COMPARISON OF RESULTS

The results obtained from the confirmation experiments are hereby compared by the predicted result of Taguchi Design experiment.

7.1. *Actual Result*

Mean of Response value (Outlet Water temperature) = 29.27 ˚C

7.2. *Predicted Result (By Taguchi Method)*

Predicted mean = A1 + B1+ C1 + D3 – 3* Y

= 32.14 + 31.90 + 30.34 + 32.22 – (3 * 33.06)

Predicted mean Breaking Strength = 27.40 ˚C

Variation % = + {(27.92 – 27.40) / 27.92} × 100

= 1.862 %

7.3. *Predicted Result (By Mathematical Regression Modelling)*

From the factor level combinations to validate the optimum cooling conditions (A1, B1, C1 and D3); the result is predicted by using the regression Modelling:

Average Outlet Water Temperature = C_o (Flow Rate)^{C_1} (Heat Load)^{C_2} (Inlet Water temperature)^{C_3} (Approach)^{C_4}

Y=0.6922* (Flow Rate) $^{0.1444}$ * (Heat Load) $^{0.2147}$ * (Inlet Water Temp.) $^{0.8262}$* (Approach)$^{-0.3084}$ ---- (xi)

By putting the values of A1, B1, C1 and D3 in above equation (xi), we get

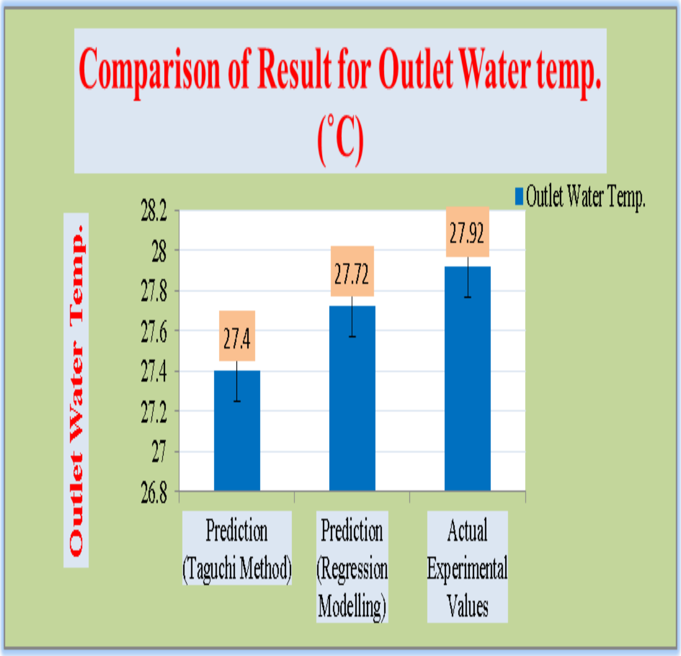
Mean Response value (Outlet Water temperature) is found to be;

Y=0.6922*(19.5) $^{0.1444}$ * (28.2) $^{0.2147}$ *(38.20) $^{0.8262}$* (4.52)$^{-0.3084}$ ----(xii)

Y= 27.73 ˚C

% Variation = {(27.92-27.73)/27.92} * 100 = 0.680 %

The final comparison of the confirmation experiment for cooling effectiveness with the values obtained from Taguchi parametric design & Regression modelling is obtained in Table 8.1. The comparison is also shown in Graph 7.1 as given below.



Graph 7.1 Comparisons of Results for Lowest Outlet Water Temperature

8. CONCLUSIONS

The outcome of the calculations and formulation for the optimization by the methods i.e. Prediction by Taguchi Method and By MATLAB regression modelling. By using the optimum factor – level combination suggested by Taguchi methodology the experiments are conducted and the results are summarized in the Table 8.1

parameters	Prediction (Taguchi Method)	Prediction (Regression Modelling)	Actual Experimental Values
Level	A1B1C1D3	A1B1C1D3	A1B1C1D3
Outlet Water Temperature (˚C)	27.40	27.72	27.92

Table 8.1 Final Comparison of the Confirmation Experiment for Outlet Water Temperature

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