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Optimization of Process Parameters of Direct Evaporative Cooling using Khus Material by Taguchi Method

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Abstract – *Direct evaporative cooling (DEC) has been investigated as an energy efficient and cost effective means for space conditioning in hot and arid climate. Along with the growing significance of environmental protection and energy conservation nowadays, the interest in direct evaporative cooling (DEC) has revived. However the optimal performance of direct evaporative cooling has thoroughly examined rarely. This research investigates optimization of parameters for humidification using Khus (Vetiver) cooling pad. In the present paper, Taguchi method is proposed to optimize the operating parameters of humidification in DEC. Air velocity and water flow are considered as the influencing parameters of humidification in DEC. An L9 (3^2) orthogonal array is used by three level variations of given parameters. Larger is better concept has been used to get higher humidification for given cooling pad. From response table for signal to noise ratios is found that optimum combination for air velocity of 1.0 m/s and water flow of 3.32 ×10^{-5} m^3/min give 69.8% RH for Khus material.*

Key Words: Taguchi method, Direct evaporative cooling, ANOVA, Optimization, Humidification, Vetiver.

1. INTRODUCTION

The fundamental governing process of evaporative cooling is heat and mass transfer due to the evaporation of water. In this process sensible heat of air converts into latent heat of water. Sensible heat is heat related with a change in temperature. As sensible heat changes affect temperature, it does not change the physical state of water. But, latent heat transfer responsible only changes in the physical state by condensation or evaporation. As water evaporates, it changes from liquid to vapor. This change of phase requires latent heat to be absorbed from the surrounding air and the remaining liquid water. As a result, the relative humidity of the air increases and the air temperature decreases. The maximum cooling condition can be achieved when air temperature reaches to the wet-bulb temperature (WBT) at which point the air would be completely saturated. The components of DEC system are centrifugal pump, fan, cooling or wetted pad and water tank.

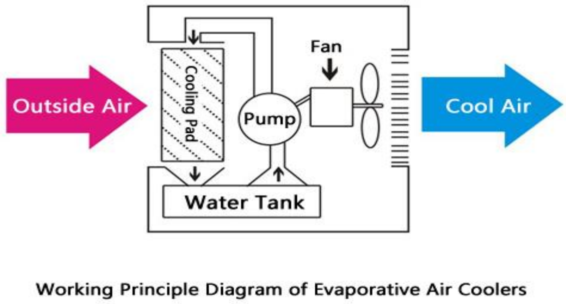

Fig. 1.1: Working Principle Diagram of Evaporative Air Cooler.

2. LITERATURE REVIEW

The literature review covers from the basics extending to the developments and other investigations in evaporative cooling reported by different researchers. The review is categorized into two different sections. Starting with experimental performance analysis and review of theoretical analysis, the review also covered use of other materials and configurations for evaporative cooling systems. Literature review is essential to have an insight into existing knowledge leading to the understanding of the previous works and researches carried out concerning the area keeping in mind the latest state of development. In the process a collection of research materials such as books, journal articles, reports, internet documents were used.

2.1. Experimental performance of different evaporative cooling pad materials.

Al-Sulaiman Faleh [1] found the performance of three natural fibers namely date palm, jute and luffa to be used as cooling pads in evaporative cooling. For comparative analysis a commercial cooling pad was selected. The output criteria included saturation efficiency, material performance and degradation of cooling efficiency. From their experimental results showed that saturation efficiency for jute, luffa, date palm and reference pads were in order of 62.1%, 55 %, 38.9 % and 49.9 % respectively. The degradation in cooling efficiency showed that luffa had advantage over the other fibers. The commercial and palm fibers indicated reduction significantly in the cooling efficiency but jute had highest deterioration. In terms of salt deposition Jute, palm and luffa were in increasing order. However, jute surface could be best choice in terms of higher mold resistance characteristics.

Egbal Ahmed Mohammed et al. [2] analyzed the output of three types of wetted pads namely celdek, straw and sliced wood pads in greenhouse. They used two performance analysis parameters of environmental and crop. The crop factors included leaves number and width, length, diameter and weight of fruit, dry matter and yield, length and diameter of stem. The relative humidity and temperature at 8 am, 1 pm and 6 pm were considered environmental factors. From experimental results showed that there was no considerable difference (0.05) inside the greenhouse. Considerable differences were revealed for relative humidity at 8 am for inside condition, at 1 pm between inside and outside of greenhouse. Besides, in greenhouses there were significant differences between all criterion inside and outside by considering the crop parameters. Finally they found that the sliced wood pad was good option than the other pads.

2.2. Theoretical Performance Analysis of Direct Evaporative Cooling.

R. K. Kulkarni et al. [3] examined the performance of rope bank of jute fiber as cooling pad media in evaporative coolers. The compact and the wide bank arrangement were taken into consideration for jute rope bank. Outside condition of 39.9°C and 32.8% relative humidity was chosen for summer season of central part of India, Bhopal (2008). The wet bulb temperature of incoming air was supposed to surface temperature of rope and concurrent heat and mass transfer theory was proposed. The outlet temperature, cooling efficiency and cooling capacity was determined by fluctuating air flow from 0.9 kg/s to 0.3 kg/s. The cooling efficiency varied from 74% to 87% and from 57% to 73 % for compact and wide bank respectively. Outlet air temperature is fluctuated in between of 29.4 ^{o}C - 27.4 ^{o}C and 31.7 ^{o}C - 29.4 ^{o}C for compact and widely spaced bank respectively. It's value determined by empirical relation. From experimental results, compact bank and widely spaced bank cooling capacity fluctuate in the range of 13384 kJ/h-33852 kJ/h and 11243 kJ/h -26381 kJ/h respectively. So finally they concluded that the compact arrangement was better option at the cost of high fan power consumption.

Ibrahim U. et al. [4] analyzed direct evaporative cooler performance in hot and arid climate of Kano area. The saturation effectiveness was varied between 50% and 90 % at different air speed. The outlet air temperature, cooling capacity, relative humidity and rate of water consumption were included in performance parameters. The result indicated leaving air temperature of 21.9 ^{o}C and relative humidity of 82% with 90% cooling effectiveness. The variation of water consumption and cooling capacity with respect to saturation effectiveness was found linear relation. Therefore direct evaporative coolers provided higher potential of thermal comfort in hot and less moisture areas when average air velocities were used with cooling pad materials of relatively higher saturation efficiency.

2.3 Research Gap

After reviewing several journal papers, articles and internet documents, are found

1. Lack of application of soft computing in the field of direct evaporative cooling.
2. Very few researches reported optimization technique in the evaporative cooling.

3. RESEARCH METHODOLOGY

In the recent years, there are various optimization techniques have been introduced [5]. In the current paper Taguchi method is employed. Taguchi optimization [6] is an experimental optimization technique that uses the standard orthogonal arrays for forming the matrix of experiments. The matrix will help to get maximum information from minimum number of experiments and also the best level of each parameter can be found. In this paper signal-to-noise (S/N) ratios are employed to find out the relative humidity as response. In this method, the term 'signal' represents the mean favorable value for the output characteristic and the term 'noise' represents the unfavorable value i.e. standard deviation (S.D.) for the output characteristic. So, the S/N ratio is the ratio of the average to the S.D. For analyzing S/N [7] three different types of performance characteristics is used: higher the better, lower the better and nominal the better. The use of ANOVA [8] (analysis of variance) is to find out the contribution of each parameters in terms of percentage.

3.1. MATERIALS (COOLING PAD)

Khus: Vetiver [9] is famous as khus in northern and western part of India. It is perennial bunchgrass of the Poaceae family having natural fragrance like soil. The specification of the Khus is as follow:
Size = 30 ×30 cm
Thickness = 1 inch.

Figure: 3.1. Khus cooling pad

Table -1.1: Control factors and their levels.

FACTOR / LEVEL	Air velocity(m/s) (A)	Water flow (liter/min.) (B)
Level -1	1	1.6
Level -2	1.5	3.2
Level -3	2	5.0

Table -1.2: Taguchi L9 (3^2) standard orthogonal array.

Experimental trial number	Factor (A)	Factor(B)
1	1	1
2	2	1
3	3	1
4	1	2
5	2	2
6	3	2
7	1	3
8	2	3
9	3	3

4. RESULTS AND DISCUSSION

In table 1.3 shows nine experimental trial runs of khus material cooling pad in DEC for given two factors of air velocity (A) and water flow (B) . In this table relative humidity and their corresponding S/N ratio is shown.

Table-1.3: Signal to noise ratio for RH % of Khus wetted pad.

Exp. No.	A (m/s)	B (L/min.)	RH %	S/N
1	1	1.6	64.6	36.19
2	1	1.6	69.8	36.88
3	1	1.6	59.4	35.49
4	1.5	3.2	61.2	35.74
5	1.5	3.2	69.8	36.87
6	1.5	3.2	59.3	35.46
7	2	5	56.7	35.08
8	2	5	70.5	36.97
9	2	5	60.5	35.65

4.1. Taguchi Design:

Taguchi Orthogonal Array Design

L9 (3^2)
Factors: 2
Runs: 9

Table 1.4: Response Table for Signal to Noise Ratios.

Level ↓	A	B
1	36.19	35.68
2	36.03	36.91
3	35.90	35.54
Delta →	0.29	1.37
Rank →	2	1

Graph1.1: Main Effects Plot for SN ratios.

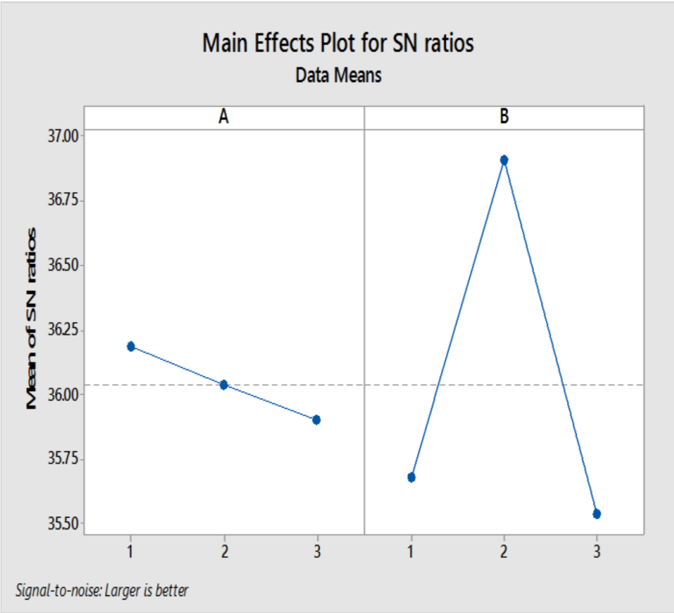

Table 1.5 – ANOVA For SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	0.123	0.123	0.061	0.47	0.653
B	2	3.402	3.402	1.701	1 3.13	0.017
Residual Error	4	0.518	0.518	0.129		
Total	8	4.043				

4.2. DISCUSSION

From table 1.5 and graph 1.1, A1 and B2 are optimum combination. It means air velocity of 1.0 m/s & water flow of 3.32×10^{-5} m^3/min combination give maximum RH%. Percentage contribution of A & B from table1.5 is calculated for A as (0.123/4.043)×100=3.042% and for B as (3.402/4.043) ×100=84.14%.

From graph 1.1 shows parameter B (water flow) has the main effect and its contribution is more than that of A (air velocity). Its optimum combination is A1 and B2.

5. CONCLUSIONS

Total nine computational trial runs were carried out using MINITAB 17 software. By applying the Taguchi technique, operating parameters air velocity and water flow were optimized for humidification in DEC system.
The following conclusions have been drawn:

1. Percentage contribution of water is dominant; air contribution is negligible as compared to water.
2. Its optimum combination is A1 and B2.
3. In terms of maximum Humidity % of Khus wetted pad is 69.8%

NOMENCLATURE

Symbol	description	unit
A	air velocity	m/s
ANOVA	analysis of variance	
Adj MS	adjusted mean of square	
Adj SS	adjusted sum of square	
B	water flow	L/min
DBT	dry bulb temperature	^oC
DF	degree of freedom	
DEC	direct evaporative cooling	
F	value for terms or model	
P	probability	
RH	relative humidity	
SN	signal to noise ratio	
WBT	wet bulb temperature	^oC

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