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OPTIMIZATION OF CONVECTIVE HEAT TRANSFER MODEL OF COLD STORAGE WITH EVAPORATOR FINS USING TAGUCHI S/N RATIO AND ANOVA ANALYSIS

Dr. N. Mukhopadhyay [1], Mohitosh Mondal[2]
Department of Mechanical Engineering,
Jalpaiguri Government Engineering College,
Jalpaiguri, India.
[1]nm1231@gmail.com, [2]mohitoshmondal21@gmail.com

***Abstract*— In this work design of experiments have been used to optimize various control factors of a cold storage evaporator space inside the cold room or in other words the heat absorbed from the inside of the cold room by evaporator will be maximized. Taguchi orthogonal array have been used as a design of experiments. Three control factors with three levels of each have been chosen for analysis. In the evaporator space the heat absorbed by the evaporator and fins a totally a convective heat transfer process. The control factors are area of the evaporator with fin (A), temperature difference of the evaporator space (dT), and relative humidity inside the cold room (RH). Different amount of heat gains in the cold room for different set of test runs have been taken as the output parameter. The objective of this work is to find out the optimum setting of the control factors or design parameters so as the heat absorb in the cold room by the evaporator will be maximum. The Taguchi S/N ratio analysis have used as an optimization technique. Larger the better type S/N ratio have been used for calculating the optimum level of control parameters, because it is a maximization problem. Analysis of variance (ANOVA) was also performed on the test results to find out the significant control factors.**

Index Terms—Design of Experiment (D.O.E), S/N ratio, ANOVA, a relative humidity inside the cold room. Area of the evaporator with fin, temperature difference in evaporator space

I. INTRODUCTION

Demand for cold storages have been increasing rapidly over the past couple of decades so that food commodities can be uniformly supplied all through the year and food items are prevented from perishing. India is having a unique geographical position and a wide range of soil thus producing variety of fruits and vegetables like apples, grapes, oranges, potatoes, chillies, ginger, etc. Marine products are also being produced in large quantities due to large coastal areas. The cold storage facilities are the prime infrastructural component for such perishable commodities. Besides the role of stabilizing market prices and evenly distributing both on demand basis and time basis, the cold storage industry provide other advantages and benefits to both the farmers and the consumers. The farmers get the opportunity to get a good return of their hard work. On the consumer sides they get the perishable commodities with lower fluctuation of price. Very little theoretical and experimental studies are being reported in the journal on the performance enhancement of cold storage. Energy crisis is one of the most important problems the world is facing nowadays. With the increase of cost of electrical energy operating cost of cold storage storing is increasing which forces the increased cost price of the commodities that are kept. So it is very important to make cold storage energy efficient or in the other words reduce its energy consumption. Thus the storage cost will eventually come down. In case of conduction we have to minimize the leakage of heat through wall but in convection maximum heat should be absorbed by refrigerant to create cooling uniformity thought out the evaporator space. If the desirable heat is not absorbed by tube or pipe refrigerant then temp of the refrigerated space will be increased, which not only hamper the quality of the product which has been stored there but reduces the overall performance of the plant. That’s why a mathematical modelling is absolutely necessary to predict the performance. In this paper we have proposed a theoretical heat transfer model of convective heat transfer model development of a cold storage using Taguchi L9 orthogonal array. Area of the evaporator with fin (A), Temperature difference (dT), Relative Humidity (RH)are the basic variables and three ranges are taken each of them in the model development. A graphical interpretation from the model justifies the reality.

II. MATHEMATICALMODEL DEVELOPMENT

The text of the paper should be written on the basis of Relationship between heat gain & energy consumption is given by E= (Q t)/COP [M.S.Soylemez, M.Unsal](1997) E=energy consumption of refrigeration system (kw/h), t=equivalent full load hours of operation of refrigeration system(hrs), COP= co-efficient of performance of refrigeration plant., Q= heat energy extracted from cold room (Joule) Response variable is heat transfer due to convection and condensation and predictor variables are Area of the Evaporator (A), Temperature difference (dT), Relative Humidity (RH) .With the help of Taguchi methodology the design matrix is constructed.

Orthogonal arrays provide a best set of well balanced (minimum) experiments .It was developed by C.R.Rao (1947) Popularized by Gene chi Taguchi (1987).The number of rows of an orthogonal array represents the requisite number of experiments

The Length, Breath and Height of each chamber of cold storage are 87.5m,34.15m and 16.77m respectively. The three values of Area(bare tube and plate fins) (A) of evaporator space are 10.75m^2per m^2 face area per row, 12.44 m^2per m^2 face area per row face area and 12.71m^2per m^2 face area per row respectively. The three values of temperature difference (dT) of evaporator space are 2, 5 & 8 centigrade respectively. The three values of relative humidity (RH) of evaporative space are 0.85, 0.90 & 0.95 respectively.

TABLE 1 control parameters and their levels

Notation	Factor	Unit	Levels		
			1	2	3
A	Area	m^2	10.75	12.44	12.71
dT	Temperature Difference	0_c	2	5	8
RH	Relative Humidity		0.85	0.90	0.95

The following equation is used for calculating the values Q:

$$Q_{conv}=Ah_c dT$$

$$Q_{T=}Ah_c(dT+RH*h_{fg})$$

$$\mathbf{Q_T=7.905A\ (dT + 2490\ RH)}$$

Hera,
A=surface area of tubes & plate fins in evaporator in m^2,
hc= convective heat transfer co-efficient
hfg= latent heat of condensation of moisture 2490 KJ/Kg-K.
RH= Relative humidity
Bare tube area, A_b=(tube perimeter)x(number of fin passages)x(number of tube)x(width of each passage)
= [(πd_0/1000)(1000/D)(1000/B)(D-t)/1000]
A_b= [(D-t)/DB] πd_0 m^2per m^2 face area per row

Fin area, A_f = (number of fins)x(two sides of fins) x{width of the fin per row –(number of tubes x area of cross section of each tube)} =[(1000/D)(2){(1xC/1000) – (1000/B)} π (d_0/1000)^2/4]
A_f=2/D[C –πd_0^2/4B] m^2per m^2 face area per row
A= [A_b + A_f]
A= [(D-t)/DB]πd_0^2+2/D[C-(πd_0^2/4B)] m^2per m^2 face area per row
A=total area of the fins & bare tube in m^2,
B=vertical spacing between the tubes in a raw in m,
C=spacing between the tubes in different raw in m,
t=thickness of the fins in m,
D=center to center spacing between fins in m,
d_0=outer diameter of bare tube in m.

Table 2 shows the L9 OA combinations among various control factors.

Test Runs	Control Factors		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1

9	3	3	2

Here 1, 2, 3 indicates the levels of each control factor. Using the level values of control factors from Table 2 and the observation table become:

Table 3 shows the L9 OA combinations among various control factors./Observation Table

Test Runs	A	dT	RH	Q
1	10.75	2	0.85	179913.61
2	10.75	5	0.90	190741.55
3	10.75	8	0.95	201569.49
4	12.44	2	0.90	220427.75
5	12.44	5	0.95	232957.64
6	12.44	8	0.85	208782.33
7	12.71	2	0.95	237735.14
8	12.71	4	0.85	213032.78
9	12.71	8	0.90	225032.50

To find out best set of combinations of control variables to attain the maximum heat transfer (Q) in the evaporator space of the cold room, Taguchi S/N ratio has been used. 'Larger- the -better' type S/N ratio has been chosen for the analysis. MINITAB 15 software has been used for data analysis.

S/N ratio

The signal to noise ratios (S/N), which are log functions of desired output, serve as the objective functions for optimization, help in data analysis and the prediction of the optimum results. There are 3 types of S/N ratios are available hi-fen -namely smaller-the –better, larger –the better & nominal-is–the best. In this problem we both use smaller-the-better and larger-the-better types S/N ratio. In case of conduction process we use smaller-the-better type S/N ratio to minimize the heat flow from outside of wall to inside and incase of convection process we use larger-the-better type S/N Ratio to maximize the heat transfer in the evaporator space of the cold room.

For conduction process

Smaller-the-better

This is expressed as – (S/N)= -10log10 (mean of sum of squares of measured data).This is usually the chosen S/N ratio for all the undesirable characteristics like "defects" for which the ideal value is zero. When an ideal value is finite and its maximum or minimum value is defined (like the maximum purity is 100% or the maximum temperature is 92 K or the minimum time for making a telephone connection is 1 sec) then the difference between the measured data and the ideal value is expected to be as small as possible. Thus, the generic form of S/N ratio becomes-(S/N) =─10Log10 {mean of sum of squares of (measured-ideal) data}

For convection and condensation process

Larger-the-better

For calculating S/N ratio for larger the better for maximum heat transfer, the equation is

SNi = -10 log [∑(1/(Qi)2/n]

Where n= number of trials in a row

Qi= calculated value in the test run or row.

Trial number = i

SNi = S/N ratio for respective result

SNi = S/N ratio for respective result

For experiment no-1

SN1 = -10 log [Σ(1/(179913.61)2/`1]=105.101

Where, Q1=179913.61& n=1

For experiment no-2

SN2 = -10 log [Σ(1/(190741.55)2/`1]=105.609

Where, Q2=190741.55& n=1

For experiment no-3

SN3 = -10 log [Σ(1/(201569.49)2/`1]=106.088

Where, Q3=201569.49& n=1

For experiment no-4

SN4 = -10 log [Σ(1/(220427.75)2/`1]=106.865

Where, Q4=220427.75& n=1

For experiment no-5

SN5 = -10 log[Σ(1/(232957.64)2/`1]= 107.346

Where, Q5=232957.64& n=1

For experiment no-6

SN6 = -10 log [Σ(1/(208782.33)2/`1]=106.394

Where, Q6=208782.33& n=1

For experiment no-7

SN7 = -10 log [Σ(1/(237735.14)2/`1]=107.522

Where, Q7=237735.14& n=1

For experiment no-8

SN8 = -10 log [Σ(1/(213032.78)2/`1]=106.569

Where, Q8=213032.78& n=1

For experiment no-9

SN9 = -10 log [Σ(1/(225032.50)2/`1]=107.045

Where, Q9=225032.50& n=1

Table 4 S/N Ratio Larger the better

Exp. No.	Parameter						Heat Transfer (KJ)	S/N Ratio Larger The Better
	Combination of Control Parameter			Control Parameter				
				Area (m^2)	Temperature difference(0_c)	Relative Humidity (%)		
1	1	1	1	10.75	2	0.85	179913.61	105.101
2	1	2	2	10.75	5	0.90	190741.55	105.609
3	1	3	3	10.75	8	0.95	201569.49	106.088
4	2	1	2	12.44	2	0.90	220427.75	106.865
5	2	2	3	12.44	5	0.95	232957.64	107.346
6	2	3	1	12.44	8	0.85	208782.33	106.394
7	3	1	3	12.71	2	0.95	237735.14	107.522
8	3	2	1	12.71	5	0.85	213032.78	106.569
9	3	3	2	12.71	8	0.95	225032.50	107.045

OVERALL MEAN OF S/N RATIO

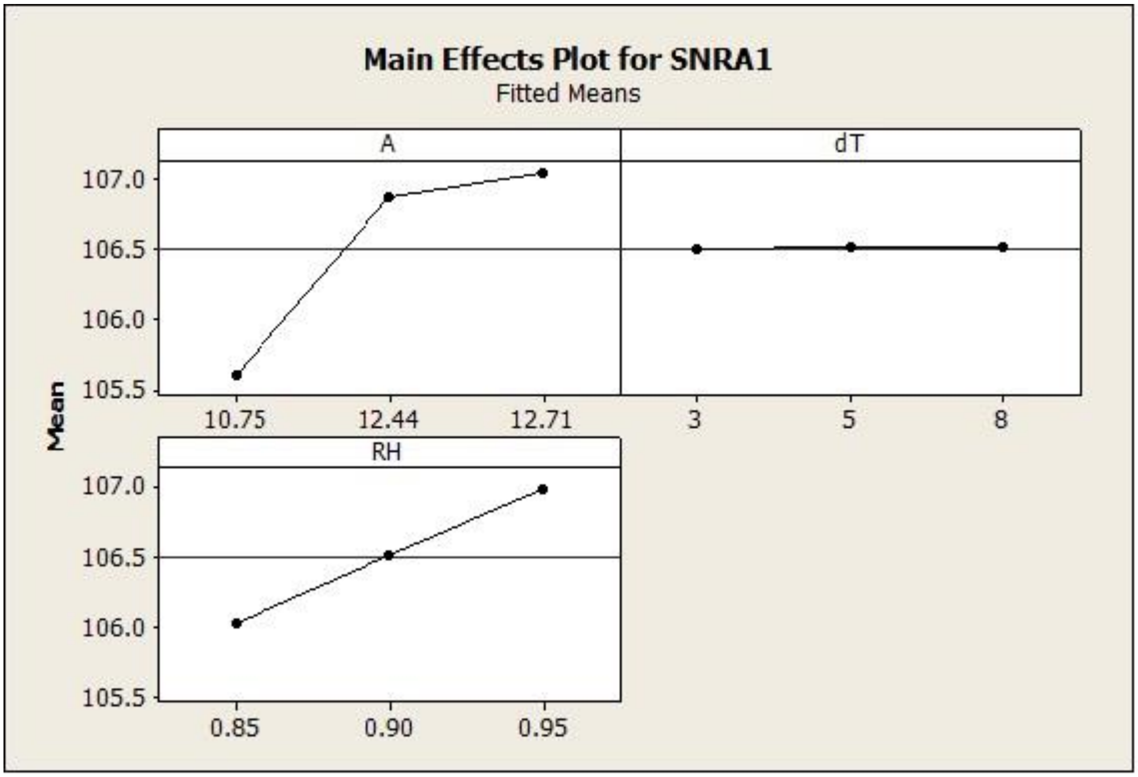
The calculation of overall mean is done by the following process:-

A11= Mean of low level values of Area
A11= (SN1+SN2+SN3)/3
= (105.10+105.61+106.09)/3= 105.60
A21= Mean of medium level values of Area
A21= (SN4+SN5+SN6)/3=
(106.87+107.35+106.39)/3= 106.90
A31= Mean of high level values of Area
A31= (SN7+SN8+SN9)/3
= (107.52+106.57+107.04)/3= 107
dT12=Mean of low level values of Temperature difference
dT12= (SN1+SN4+SN7)/3
= (105.1+106.87+107.52)/3= 106.50
dT22=Mean of medium level values of Temperature difference
dT22= (SN2+SN5+SN8)/3
= (105.61+107.35+106.57)/3= 106.51
dT32= Mean of high level values of Temperature difference
dT32= (SN3+SN6+SN9)/3
= (106.09+106.39+107.04)/3= 106.50
RH13= Mean of low level values of Relative humidity
RH13= (SN1+SN6+SN8)/3
= (105.10+106.39+106.57)/3 = 106.00
RH23= Mean of medium level values of Relative humidity
RH23= (SN2+SN4+SN9)/3
= (105.61+106.87+107.04)/3 = 106.50
RH33= Mean of high level values of Relative humidity
RH33= (SN3+SN5+SN7)/3
= (106.09+107.35+107.52)/3 = 107

Table 5 Overall mean of S/N Ratio (Response Table for Signal to Noise Ratios Larger is better)

Level	Average S/N Ratio by Factor Level			Overall Mean of S/N Ratio(SN_0)
	Area(m^2)	Temperature Difference(0_c)	Relative Humidity (%)	
Low	105.60	106.50	106.00	106.50
Medium	106.90	106.50	106.50	
High	107.00	106.50	107.00	
Delta=larger-smaller	1.4	0.0	1.0	
Rank	1	2	3	

Mean S/N ratio vs Area, temperature difference and relative humidity figure.



ANALYSIS OF VARIANCE (ANOVA) CALCULATION

The ANOVA strategy is also applied for identifying the significant factors and their relative contribution on the output variable. Taguchi method cannot judge and determine effect of individual parameters on entire process while percentage contribution of individual parameters can be well determined using ANOVA. The tests run data analyzed using ANOVA at 95% confidence level (α=.05) for identifying the significant factors and their relative contribution on the output variable.

The analysis was carried out in MINITAB software. The following table shows ANOVA table

Source	Notation	Degrees of Freedom	Sum of Squares	Mean Squares	F Ratio	% of Contribution
A	Area of the Bare tube & Fin	2	3.73086	1.86543	16377.86	72.7947
dT	Temperature Difference	2	0.00030	0.00015	1.34	0.0058
RH	Relative Humidity	2	1.39379	0.69689	6118.50	27.1949
Error		2	0.00023	0.00011		
Total		8	5.12518			

The above calculations suggest that the area of the Evaporator has the largest influence with a contribution of 72.7947 %. Next is relative humidity with 27.1949% contribution and temperature difference has lowest contribution of 0.0058%

III. CONCLUSION

In this project work Taguchi method of design of experiment has been applied for optimizing the control parameters so as to increase heat transfer rate evaporating space to evaporating level. From the analysis of the results obtained following conclusions can be drawn-

1. From the Taguchi S/N ratio graph analysis the optimal settings of the cold storage are Area of the Evaporator (A)-12.71(m^2), Temperature difference (dT)-3(0c) and Relative humidity (RH)-0.95 in percentage. This optimality has been proposed out of the range of [A(10.75,12.44,12.71), dT (2,5,8), RH (0.85, 0.90, 0.95)].So, increase the evaporator Area is most important.
2. ANOVA analysis indicates Area of evaporator (A) is the most influencing control factor on Q and it is near about 72.7947%.
3. Results obtained both from Taguchi S/N ratio analysis and the multiple regression analysis are also bearing the same trend.
4. The proposed model uses a theoretical heat convection model through cold storage using multiple regression analysis. By developing computer program (Java language), the model has been analysed by Origin.
5. Taguchi L9 orthogonal array has used as design of experiments. The results obtained from the S/N ratio analysis and ANOVA are close in values. Both have identified Area of the Evaporator (A) is the most significant control parameter followed by relative humidity (RH), and temperature difference (dT).

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