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Optimization of Convective Heat Transfer Model of Cold Storage with Rectangular Pin Finned Evaporator Using Taguchi Regression, S/N Ratio and ANOVA Analysis

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Abstract

This work contains of design of experiments to optimize the various control factors of a cold storage evaporator space inside the cold room, in other words the heat absorption by evaporator will be maximize to minimize the use of electrical energy to run the system. Here we have use rectangular pin fin to maximize the heat absorption by evaporator. Taguchi orthogonal array with regression analysis have been used as a design of experiments. The control factors are Area of the evaporator with rectangular pin fin(A), temperature difference of the evaporator space (dT), and relative humidity inside the cold room(RH). The Taguchi S/N ratio analysis have used as an optimization technique. Larger the better type S/N ratio have 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.

Key Words

Taguchi orthogonal array, Convective heat transfer co-efficient, Rectangular pin fin area and arrangement, Regression analysis, Graphical representation of control factors with heat transfer,

S/N ratio analysis, ANOVA analysis.

1. Introduction

Cold storages form the most important element for proper storage and distribution of vide variety of perishables like fruits, vegetables and fish or meat processing. India is the largest producer of fruits and second largest producer of vegetables in the world. In spite of that per capita availability of fruits and vegetables is quite low because of post harvest losses that account for about 25 to 30% of production. Besides, quality of a sizable quantity of products also deteriorates by the time it reaches the consumer. As India is the second largest producer (45,343,600 tonnes at 2015) of potato after China and largest producer of the ginger (702000 metric tonnes i.e. 34.6% of the world total) without these there are many kind of food commodities are produce in our country so 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. Besides the role of stabilizing market prices and evenly distributing both on demand basis and time basis, the cold storage industry provides 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

2. Model Development

2.1 Range and Parameter Selection

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 of the evaporator with fin (A) of evaporator space are 9.201m2, 11.906m2 and 14.012m2 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.

Tab. 1. Control Factors with Their Range

Notation	Factors	Unit	Levels		
			1	2	3
A	Area of the evaporator with fin	m^2	9.201	11.906	14.012
dT	Temperature Difference	°C	2	5	8
RH	Relative Humidity	%	0.85	0.90	0.95

In this study, Mohitnagar cold storage (Jalpaiguri) & Teesta cold storage has been taken as a model of observation.

2.2 Regression Analysis

Regression analysis is the relationship between various variables. Using regression analysis one can construct a relationship between response variable and predictor variable. It demonstrates what will be the changes in response variable because of change in predictor variable. Simple regression equation is,

$$y = a + b\,x + e$$

where,

y = the value of the Dependent variable, what is being predicted or explained

x = the value of the Independent variable, what is predicting or explaining the value of y

e = the error term; the error in predicting the value of y, given the value of x

In this problem more than one predictor variable is involved and hence simple regression analysis cannot be used. We have to take the help of multiple regression analysis. There are two types of multiple regression analysis- i) Simple multiple regression analysis (regression equation of first order) ii) Polynomial multiple regression analysis (regression equation of second order or more).

Simple multiple regression analysis is represented by the equation of first order regression

$$Y= \beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\ldots\ldots\ldots+\varepsilon \qquad \ldots\ldots \quad \ldots\ldots\ldots(i)$$

Where β is constant terms & Y is response variable, X is the predictor variables & ε is the experimental error.

Polynomial multiple regression analysis equation is

$$Y=\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+ \beta_{11}X^2_{11}+ \beta_{22}X^2_{22}+ \beta_{33}X^2_{33}+ \beta_{12}X_1X_2+ \beta_{13}X_1X_3+ \beta_{23}X_2X_3 \quad \ldots \quad \ldots(ii)$$

The above equation is second order polynomial equation for 3 variables. Where β are constant, X1, X2, X3 are the linear terms, X12 X13 X23 are the interaction terms between the factors, and lastly X11 X22 X33 are the square terms.

Q (heat due to convection) = response variable & A, dT, RH= predictor variable.

Polynomial regression equation becomes after replacing real problem variables

$Q_{(\text{heat due to convection})} = \beta_0+\beta_1(A)+\beta_2 (dT)+\beta_3 (RH)+ \beta_{11} (A)*(A)+ \beta_{22}(dT)*(dT)+\beta_{33} (RH)*(RH)+ \beta_{12}(A)*(dT)+ \beta_{13}(A)*(RH)+ \beta_{23}(dT)*(RH)$ ……… …..(1)

To solve this equation following matrix method is used

$Q= [\beta][X]$……… ………..(2)

$[\beta]=[Q] [X^{-1}]$ where [β] is the coefficient matrix, Y is the response variable matrix; $[X^{-1}]$ is the inverse of predictor variable matrix…………… ….(3)

In this problem there are 3 independent variables and each variable has 3 levels and hence from the Taguchi Orthogonal Array (OA) table L9 OA is best selected.

Tab. 2 Taguchi's L9 Orthogonal Array

Sl. No.	**Factorial combination**		
	A	**dT**	**RH**

1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	1
6	2	3	3
7	3	1	3
8	3	2	1
9	3	3	2

Experiments have been carried out using Taguchi's L9 Orthogonal array experimental design which consists of 9 combinations of area, relative humidity and temperature difference. It considers three process parameters to be varied three discrete levels.

In the equation (1) number of unknown constant (i.e. β) is ten and in using Taguchi's L9 Orthogonal array experimental design which consists of 9 combinations of area, relative humidity and temperature difference so to form X as a 10*10 matrix, β as a 10*1 matrix and Q as a 10*1 matrix we have taken a combination of area, relative humidity and temperature difference which does not match with any of combination of the L9 orthogonal array mentioned above.

As we are working on three level value of the factors and the first column of L18 orthogonal is of 2 level so have omit this and took a combination of next three column and we have chosen a combination 3, 1, 2 it does not match with any of combination of the L9 orthogonal array.

So the desired combination is,

Tab. 3. Modified L9 Orthogonal Array

Sl. No.	**Factorial combination**		
	A	**dT**	**RH**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2

5	2	2	1
6	2	3	3
7	3	1	3
8	3	2	1
9	3	3	2
10	3	1	2

In the equation (2) X is a 10*10 matrix, β is a 10*1 matrix and Q is a 10*1 matrix. By using the L9 Orthogonal array and its iteration terms we have to find out the betas(β) values.

Now there are nine test runs, so there will be nine values of Q and also nine equations. These equations are-

$Q_1=\beta_0+9.201\beta_1+2\beta_2+.85\beta_3+84.6584\beta_4+4\beta_5+0.7225\beta_6+18.402\beta_7+11.9068\beta_8+1.7\beta_9$

$Q_2=\beta_0+9.201\beta_1+5\beta_2+.90\beta_3+84.6584\beta_4+25\beta_5+.81\beta_6+46.005\beta_7+8.2809\beta_8+4.75\beta_9$

$Q_3=\beta_0+9.201\beta_1+8\beta_2+.95\beta_3+84.6584\beta_4+64\beta_5+.9025\beta_6+73.608\beta_7+8.7409\beta_8+7.6\beta_9$

$Q_4=\beta_0+11.906\beta_1+2\beta_2+.90\beta_3+141.7528\beta_4+4\beta_5+.81\beta_6+23.812\beta_7+10.7154\beta_8+1.8\beta_9$

$Q_5=\beta_0+11.906\beta_1+5\beta_2+.95\beta_3+141.7528\beta_4+25\beta_5+.9025\beta_6+59.53\beta_7+11.3107\beta_8+4.75\beta_9$

$Q_6=\beta_0+11.906\beta_1+8\beta_2+.85\beta_3+141.7528\beta_4+64\beta_5+.7225\beta_6+95.248\beta_7+10.1201\beta_8+6.8\beta_9$

$Q_7=\beta_0+14.012\beta_1+2\beta_2+.95\beta_3+196.3361\beta_4+4\beta_5+.9025\beta_6+28.024\beta_7+13.3114\beta_8+1.9\beta_9$

$Q_8=\beta_0+14.012\beta 1+5\beta_2+.85\beta_3+196.3361\beta_4+25\beta_5+.7225\beta_6+70.06\beta_7+11.9102\beta_8+4.25\beta_9$

$Q_9=\beta_0+14.012\beta_1+8\beta_2+.90\beta_3+196.3361\beta_4+64\beta_5+.81\beta_6+112.096\beta_7+12.6108\beta_8+7.2\beta_9$

$Q_{10}=\beta_0+14.012\beta_1+2\beta_2+.90\beta_3+196.3361\beta_4+4\beta_5+.81\beta_6+28.024\beta_7+12.6108\beta_8+1.8\beta_9$

The values of A, dT, RH, A2, dT2, RH2, A*dT, A*RH, dT*RH can be found out by the following table-

Tab. 4. Observation Table with Square and Interaction Terms-

Test runs		A	dT	RH	A*A	dT*dT	RH*RH	A* dT	A*RH	dT*RH
1	1	9.201	2	0.85	84.6584	4	0.7225	18.402	11.9068	1.7
2	1	9.201	5	0.90	84.6584	25	0.81	46.005	8.2809	4.5
3	1	9.201	8	0.95	84.6584	64	0.9025	73.608	8.7409	7.6
4	1	11.906	2	0.90	141.7528	4	0.81	23.812	10.7154	1.8

5	1	11.906	5	0.95	141.7528	25	0.9025	59.53	11.3107	4.75
6	1	11.906	8	0.85	141.7528	64	0.7225	95.248	10.1201	6.8
7	1	14.012	2	0.95	196.3361	4	0.9025	28.024	13.3114	1.9
8	1	14.012	5	0.85	196.3361	25	0.7225	70.06	11.9102	4.25
9	1	14.012	8	0.90	196.3361	64	0.81	112.096	12.6108	7.2
10	1	14.012	2	0.90	196.3361	4	0.81	28.024	12.6108	1.8
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10

2.3 Heat Calculation

In this study heat transfer from evaporating space to refrigerant (which are in tube or pipe) only being considered.The transfer heat evaporating space to refrigerant are calculated in terms of Area of the evaporator with fin(A), temperature difference (dT) & relative humidity RH) . Only convection heat transfer effect is being considered in this study.

Basic equation for heat transfer

$Q_T = Q_{conv} + Q_{condensation}$.

$Q_{conv}=Ah_c dT$ & $Q_{condensation}=Ah_{m}(RH)h_{fg}$. [3]

Here Qconv=heat transfer due to convection &Qcondensation=heat transfer due to condensation &

QT=Total heat transfer or absorb heat into refrigerant.

$Q_T= Ah_c dT + Ah_{m}(RH)h_{fg}$

or, $Q_T= [Ah_c dT] + [(h_c/1.005).A.RH.h_{fg}]$

[As we know, $h_c/h_m=c_p(Le)^{2/3}$

or, $h_c/h_m=1.005(1)^{2/3}$

or, $h_c=h_m$]

or, $Q_T=Ah_c[dT+(RH.h_{fg})/1.005]$

or, $Q_T= A.h_c(dT + RH.h_{fg})$

The heat transfer equation due to area of the evaporator with fin (A), temperature difference (dT) & relative humidity RH) is QT=Ahc (dT + 2490 RH)……… ……….(4)[8]

Here, A=surface area of tubes in evaporator with fin

.hc=convective heat transfer co-efficient.

hm=convective mass transfer co-efficient,

hfg=latent heat of condensation of moisture 2490 KJ/Kg-K.

Cp=specific heat of air 1.005 KJ/Kg-K.

Le=Lewis number for air it is one.

Now we calcutate the value of convective heat transfer co-efficient (hc),

We know,

$$\mathbf{Nu} = \frac{\textit{Convective heat transfer}}{\textit{Conductive heat transfer}} = \mathbf{(h_c * L) / k}$$

Where:

Nu = Nusselt number

hc = convective heat transfer coefficient

k = thermal conductivity, W/mK

L = characteristic length, m

The convection heat transfer coefficient is then defined as following:

$$\mathbf{h_c} = \frac{\mathbf{Nu * K}}{\mathbf{L}} \quad \text{............................} \quad \text{.........(5)}$$

[2]

The Nusselt number depends on the geometrical shape of the heat sink and on the air flow. For natural

convection on flat isothermal plate the formula is given in table

Tab. 5. Nusselt Number Formula

	Vertical fins		Horizontal fins
Laminar flow	$Nu = 0.59 * Ra^{0.25}$	Upward laminar flow	$Nu = 0.54 * Ra^{0.25}$
Turbulent flow	$Nu = 0.14 * Ra^{0.33}$	Downward laminar flow	$Nu = 0.27 * Ra^{0.25}$
		Turbulent flow	$Nu = 0.14 * Ra^{0.33}$

Where:

$$\mathbf{Ra = Gr * Pr}$$

The Rayleigh number(Ra) defined in terms of Prandtl number (Pr) and Grashof number (Gr).

If , Ra < 109the heat flow is laminar,

while Ra > 106the flow is turbulent.

Grashof number (Gr):

$$\mathbf{Gr} = \frac{g * L^3 * \alpha * (Ta - Tp)}{\eta^2} \qquad \text{[for natural convective heat transfer from a cold body]}$$

Where:

- g = acceleration of gravity = 9.81, m/s2

- L = longer side of the fin =30 foot =9.144 m

- α= air thermal expansion coefficient. For gases, is the reciprocal of the temperature in Kelvin:

$\alpha = \frac{1}{Ta}$, 1/K = (1/275.15) K

- T_p = Plate temperature, = 272.15 K

- T_a = Air temperature= 275.15 K

- η = air kinematic viscosity = 13.39 * 10^{-6} m^2/s [at air temp.=275.15 K & air pressure= 1 bar]

$$Gr = \frac{9.81*(9.144)^3*\left(\frac{1}{275.15}\right)*(275.15-272.15)}{(13.39*10^{-6})^2}$$

or, Gr = 4.56*10^{11}

Prandtl number (Pr):

$$\mathbf{Pr} = \frac{\mu * cp}{K}$$

Where:

- µ = air dynamic viscosity, is 1.725*10^{-5} kg/m.s at 275.15 K

- cp = air specific heat = 1005 J/(Kg*K) for dry air

- k = air thermal conductivity = 0.0244 W/(m*K) at 275.15 K

$$\mathbf{Pr} = \frac{1.725*10^{-5}*1005}{0.0244}$$

Or, Pr = 0.711

So,

Ra = Gr * Pr

Ra = 4.56*10^{11} * 0.711

Ra = 3.24*10^{11}

As, Ra > 10^9 = Turbulent flow

So, Nustle Number for turbulent flow,

Nu = 0.14 * $Ra^{0.33}$

$Nu = 0.14 * (3.24*10^{11})^{0.33}$

$Nu = 880.25$

So, <u>Convective Heat Transfer co-efficient(h_c) :-</u>

$$\mathbf{h_c} = \frac{880.25 * 0.0244}{9.144}$$

or, $\mathbf{h_c = 2.35}$

So, The final Heat Transfer equation when we replace the h_c in equation (4) we get,

$\mathbf{Q_T = 2.35*A(dT + 2490\ RH)}$ ....(6)

2.4 Rectangular Pin Fin

The configuration of the pin is shown in Figure. Pin's width and height were considered with D and H respectively. To calculate the steam wise dimension (Z), the fin surface area was considered equal to cylindrical fin.

Surface Area of rectangular pin-fin = 2(D.H + D.Z + H.Z)

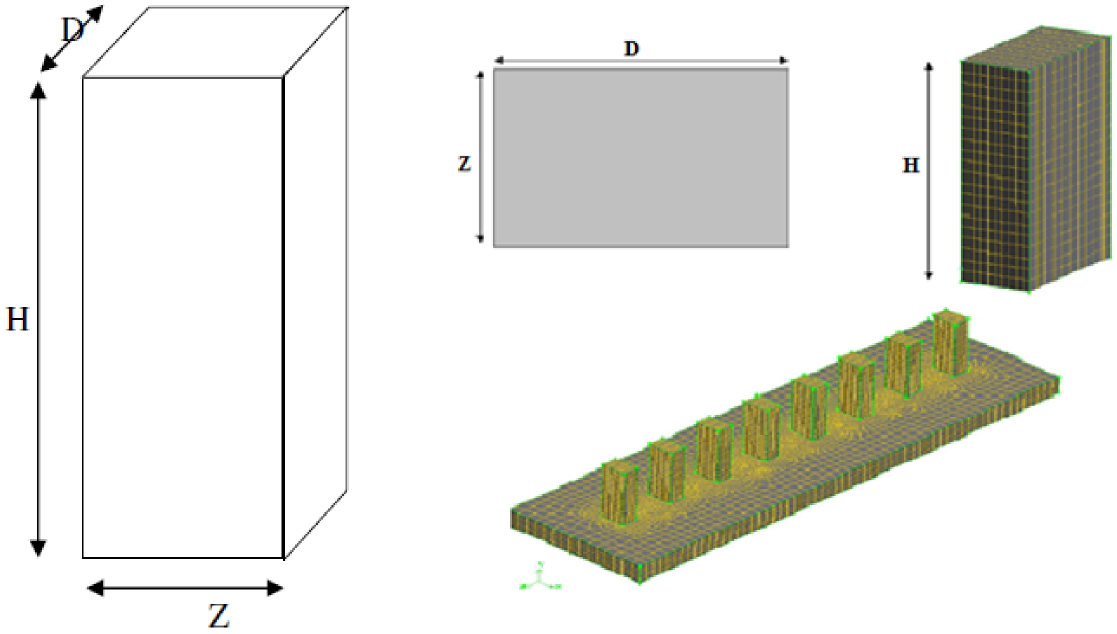

Fig.1. Configuration of Rectangular Pin fin

We assume,

Total Area(A_T) = $A_b + A_f$

Rectangular pin fin Area calculation,

Circumference of fin (C):

$C = 2(D+Z)$

Cross-sectional area of fin (A):

$A = D*Z$

Fin area available for heat transfer:

$$\mathbf{A_f = [2(D+Z)]*H*N}$$

Tube area available for heat transfer in finned tube heat exchanger:

$$\mathbf{A_b = (\Pi*R^2*L*n - N*D*Z)}$$

Where,

A_b = Area of bare tube

A_f = Area of fin

A_T = Total Area

A = Cross sectional area of fin

L = Length of bare tube

R = Outer radius of bare tube

D = Length of Rectangular pin fin

Z = Width of Rectangular Pin fin

H = Height of rectangular Pin fin

n = Number of bare tube = 1

N = Number of rectangular Pin fin

Chain ordering Pin fin arrangement:

Fig.2. Arrangements of Rectangular Pin fin

Where,

D = Length of Rectangular pin fin

Z = Width of Rectangular Pin fin (Z=0.5D)

S = Longitudal Fin Spacing (S=0.5D)

m = Margin (m=1D)

Now, from equation number (6) we have Q1……10 values by putting the values of Area of the evaporator with fin (A) from the equation of Area(A), Relative humidity (RH) and temperature difference (dT).

Tab. 6. Response variable matrix –

Q
45806.95
48563.80
51320.65
62757.12
66324.46
59441.60
77957.51
69857.17
74055.52
73857.95

Now using the equation number (3) we get the coefficient matrix [β]-

We use MATLAB software to find out the coefficient matrix [β],

Tab. 7. Regression Coefficient Table

B_0	36.0530
B_1	-0.2261
B_2	-0.7091
B_3	-73.1610
B_4	0.0066
B_5	0.0105
B_6	38.3437
B_7	2.3494
B_8	5851.5603
B_9	0.6811

After putting the values of regression coefficient in equation no- (1) The final regression equation becomes-

$Q_{(heat\ due\ to\ convection\ heat\ transfer)}$= 36.0530 -0.2261(A) - 0.7091(dT) - 73.1610(RH) + 0.0066(A) (A) + 0.0105(dT) (dT) + 38.3437(RH) (RH) + 2.3494 (A) (dT) + 5851.5603 (A) (RH) + 0.6811(dT) (RH)

This is the proposed regression equation. It establishes the relationship between the response variable Q and the predictor variables i.e. control variables A, dT, and RH. By the help of above equation, the heat transfer evaporator space to evaporator coil can easily be computed. With the help of the multiple regression equation a computer program has been generated to check the effect of variations of control parameters on output variable. With the help of data sets generated by the program various graphs are drawn.

3. Results and Discussions

3.1 Regression Analysis

A computer program has been written in 'C' language on the basis of the 2nd order nonlinear equation which is obtained through regression analysis. The program consists of three parts each for analyzing the variation of control factor with the output parameter. While varying one control factor with the output other two factors were kept at a constant value.

a. Effect of area of the evaporator on heat transfer rate –

The values of dT and RH remain constant. Enter the value for A within the range 9.201 to 14.012, Start with 9.201 keeping dT= 2 and RH= 0.95 and incrementing the value of A by 0.5, the corresponding values of Q. Graph 1 of Figure No.3 shows that heat absorption increase with area of the evaporator increases. By using computer program data set the variation of A with Q can be graphically represented as

b. Effect of temperature difference on heat transfer rate-

The values of A and RH remain constant. Enter the value for dT within the range 2 to 8, Start with 2.0, Keeping A= 11.906 and RH= 0.95 and incrementing the value of dT by 0.5, the corresponding values of Q. By using the computer program data set the variation of dT with Q can be graphically represented on graph 2 of Figure No.3.

c. Effect of relative humidity on heat transfer rate-

First, the values of A and dT remain constant. Enter the value for RH within the range 0.85 to 0.95, Start with 0.85 Keeping A= 11.906 and dT= 2 and incrementing the value of RH by 0.01, the corresponding values of Q. By using the computer program data set the variation of RH with

Q can be graphically represented on graph 3 of Figure No. 3.

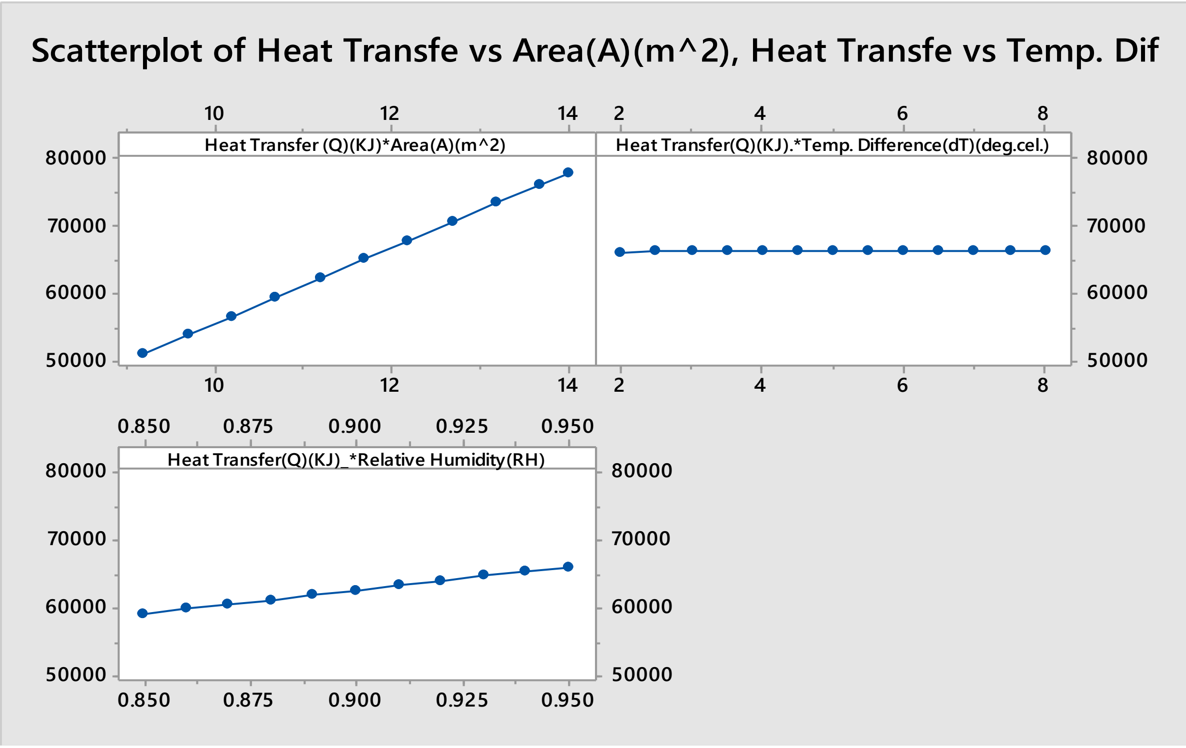

Fig.3. Variation of Heat Transfer with area, temp. Difference & relative humidity

3.2 S/N Ratio Analysis

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-namely smaller the better, larger the better & nominal is the best.

In this problem we use both Smaller-the-better and larger-the-better types S/N ratio.

In case of conduction process, we use larger-the-better type S/N ratio to maximize the heat flow from inside of the cold room to outside through the evaporator. 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

$SN_i = -10 \log[\sum\{1/(Q_i)^2\}/n]$ ……. (7)

Where n= number of trials in a row

Q_i= calculated value in the test run or row.

Trial number = i

SN_i = S/N ratio for respective result

For experiment no-1

SN1 = $-10 \log[\Sigma\{1/(45806.95)^2\}/1]$=93.2186 Where, Q1=45806.95 & n=1

For experiment no-2

SN2 = $-10 \log[\Sigma\{1/(48563.80)^2\}/1]$=93.7262 Where, Q2=48563.80 & n=1

For experiment no-3

SN3 = $-10 \log[\Sigma\{1/(51320.65)^2\}/1]$=94.2058 Where, Q3=51320.65& n=1

For experiment no-4

SN4 = $-10 \log[\Sigma\{1/(62757.12)^2\}/1]$=95.9532 Where, Q4=62757.12& n=1

For experiment no-5

SN5 = $-10 \log[\Sigma\{1/(66324.46)^2\}/1]$= 96.4334 Where, Q5=66324.46 & n=1

For experiment no-6

SN6 = $-10 \log[\Sigma\{1/(59441.60)^2\}/1]$=95.4818 Where, Q6=59441.60 & n=1

For experiment no-7

SN7 = $-10 \log[\Sigma\{1/(77957.51)^2\}/1]$=97.8371 Where, Q7=77957.51 & n=1

For experiment no-8

SN8 = $-10 \log[\Sigma\{1/(69857.17)^2\}/1]$=96.8842 Where, Q8=69857.17 & n=1

For experiment no-9

SN9 = $-10 \log[\Sigma\{1/(74055.52)^2\}/1]$=97.3911 Where, Q9=74055.52 & n=1

Tab. 8. 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	9.201	2	0.85	45806.95	93.2186
2	1	2	2	9.201	5	0.90	48563.80	93.7262
3	1	3	3	9.201	8	0.95	51320.65	94.2058
4	2	1	2	11.906	2	0.90	62757.12	95.9532
5	2	2	3	11.906	5	0.95	66324.46	96.4334
6	2	3	1	11.906	8	0.85	59441.60	95.4818
7	3	1	3	14.012	2	0.95	77957.51	97.8371
8	3	2	1	14.012	5	0.85	69857.17	96.8842
9	3	3	2	14.012	8	0.95	74055.52	97.3911

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=(93.2186+93.7262+94.2058)/3= 93.7168

A21= Mean of medium level values of Area

A21=(SN4 +SN5+ SN6) /3=(95.9532+96.4334+95.4818)/3= 95.9561

A31= Mean of high level values of Area

A31=(SN7 +SN8+ SN9) /3=(97.8371+96.8842+97.3911)/3= 97.3708

dT12= Mean of low level values of Temperature difference

dT12=(SN1 +SN4+ SN7) /3=(93.2186+95.9532+97.8371)/3= 95.6696

dT22= Mean of medium level values of Temperature difference

dT22= (SN2 +SN5+ SN8) /3=(93.7262+96.4334+96.8842)/3= 95.6812

dT32= Mean of high level values of Temperature difference

dT32=(SN3 +SN6+ SN9) /3=(94.2058+95.4818+97.3911)/3= 95.6929

RH13= Mean of low level values of Relative humidity

RH13=(SN1 +SN6+ SN8)/3=(93.2186+95.4818+96.8842)/3 = 95.1948

RH23= Mean of medium level values of Relative humidity

RH23=(SN2 +SN4+ SN9)/3=(93.7262+95.9532+97.3911)/3 = 95.6901

RH33= Mean of high level values of Relative humidity

RH33= (SN3 +SN5+ SN7)/3=(94.2058+96.4334+97.8371)/3 = 96.1587

Tab. 9. 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	93.7168	95.6696	95.1948	95.6812
Medium	95.9561	95.6812	95.6901	
High	97.3708	95.6929	96.1587	
Delta=larger-smaller	3.654	0.0233	0.9639	
Rank	1	2	3	

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

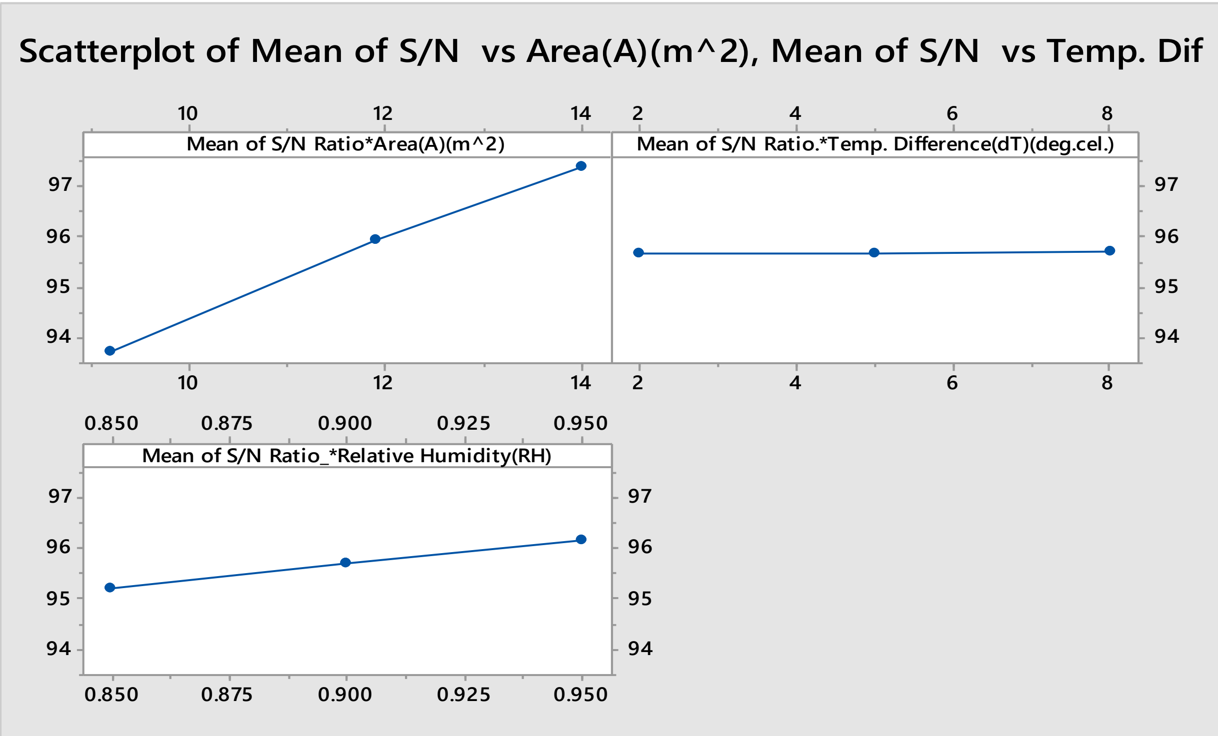

Fig. 4. Variation of Mean S/N Ratio with area, temp. Difference & relative humidity**3.**

Analysis of Variance (ANOVA) Calculation

The test runs results were again analysed using ANOVA 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 in were again analysed using ANOVA at 95% confidence level (α=.05) for identifying the significant factors and their relative contribution on the output variable.

Tab.10. 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**	**P Value**	**% Contribution**
A	Area of the Bear tube & Fin	2	972199410	486099705	947.53	0.001	93.1297
dT	Temperature Difference	2	673657	336828	0.66	0.604	0.0645
RH	Relative Humidity	2	70020595	35010298	68.24	0.014	6.7075
Error		2	1026034	513017			0.0982
Total		8	1043919696				100

The above calculations suggest that the area of the Evaporator has the largest influence with a contribution of 93.1297 %. Next is relative humidity with 6.7075% contribution and temperature difference has lowest contribution of 0.0645%.

Conclusion

In this work study 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) 14.012(m^2), Temperature difference (dT) 2 (^{0}c) and Relative humidity (RH) 0.95 in percentage. This optimality has been proposed out of the range of [A (9.201, 11.906, 14.012), 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 93.1297 %Next is relative humidity 6.7075% contribution

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.

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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