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Optimization of Convective Heat Transfer Model of Cold Storage with Circular Fins Evaporator using Taguchi S/N Ratio and ANOVA

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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, in other words the heat absorb from the inside of the cold room by evaporator will be maximize. Already we have study about evaporator with rectangular plate fin now we have use circular plate fin.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 absorbs by the evaporator and fins totally a convective heat transfer process. The control factors are Area of the evaporator with circular 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 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.

Keywords *:* Design of Experiment (D.O.E),Area of the circular plate fin evaporator, relative humidity inside the cold room, temperature difference in evaporator space, S/N ratio, Analysis of variance (ANOVA).

1. Introduction

India is the second largest producer (12.0% of the world total) of potato after China and largest producer of the ginger (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. 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.

2. Mathematical model development

The text of the paper should be written in two column Relationship between heat gain & energy consumption is given by E= (Q t)/COP [M.S.Soylemez, M.Unsal](1997) [1] 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(A), Temperature difference (dT), Relative Humidity (RH) .With the help of Taguchi methodology we construct our design matrix.

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 one chamber of cold storage length, breath and height 87.5m,34.15m and 16.77m respectively. The three values of Area of the evaporator with circular fin (A) of evaporator space(bare tube and plate fins) are15.7136 m^2,18.3962 m^2, 21.2615 m^2. 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 of the evaporator	m^2	15.7136	18.3962	21.2615
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:

$Q_{conv}=Ah_c dT$

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

$\mathbf{Q}_T$ = Convective Heat transfer.

A= area of the evaporator for one row and one meter.

dT = temperature difference in cold storage.

RH= relative humidity.

$\mathbf{A = A_b + A_f}$

$\mathbf{A_b =} \pi r^2 \times L$

$A_f = n \times (1000/22) \times 2 \times \pi(R^2 - r^2)$

R =Circular fin radius (0.092 m)

r = Bare tube radius (0.0225 m)

A= area of the evaporator for one row and one meter.

A_b = area of the bare tube for one row.

A_f = area of the fin of one row.

N = no. of bare tube in one row

L= length of each bare tube(here one meter)

Table 2 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 L9 OA combinations among various control factors Observation Table

Test Runs	A	dT	RH	Q
1	15.7136	2	0.85	263151.6129
2	15.7136	5	0.90	278989.1540
3	15.7136	8	0.95	294826.6950
4	18.3962	2	0.90	326181.4585
5	18.3962	5	0.95	344722.7586
6	18.3962	8	0.85	308948.9561
7	21.2615	2	0.95	397910.8329
8	21.2615	4	0.85	356565.0821
9	21.2615	8	0.90	377994.2822

In the above table Area (A), Temperature difference (dT), Relative humidity (RH) of the cold storage have been experimentally observed within the range of maximum, minimum and average mid value and thereafter heat transfer quantity (Q) is being calculated theoretically.

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.

3. Results and discussions

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

In this problem we both use 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

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

For experiment no-1

SN1 = -10 log[Σ(1/(263151.6129)2/`1]=108.404Where, Q1=263151.6129& n=1

For experiment no-2

SN2 = -10 log[Σ(1/(278989.1540)2/`1]=108.912Where, Q2=278989.1540& n=1

For experiment no-3

SN3 = -10 log[Σ(1/(294826.6950)2/`1]=109.391Where, Q3=294826.6950& n=1

For experiment no-4

SN4 = -10 log[Σ(1/(326181.4585)2/`1]=110.269Where, Q4=326181.4585& n=1

For experiment no-5

SN5 = -10 log[Σ(1/(344722.7586)2/`1]= 110.749Where, Q5=344722.7586 & n=1

For experiment no-6

SN6 = -10 log[Σ(1/(308948.9561)2/`1]=109.798Where, Q6=308948.9561 & n=1

For experiment no-7

SN7 = -10 log[Σ(1/(397910.8329)2/`1]=111.996Where, Q7=397910.8329 & n=1

For experiment no-8

SN8 = -10 log[Σ(1/(356565.0821)2/`1]=111.043Where, Q8=356565.0821 & n=1

For experiment no-9

SN9 = -10 log[Σ(1/(377994.2822)2/`1]=111.550Where, Q9=377994.2822 & 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	15.7136	2	0.85	263151.6129	108.404
2	1	2	2	15.7136	5	0.90	278989.1540	108.912
3	1	3	3	15.7136	8	0.95	294826.6950	109.391
4	2	1	2	18.3962	2	0.90	326181.4585	110.269
5	2	2	3	18.3962	5	0.95	344722.7586	110.749
6	2	3	1	18.3962	8	0.85	308948.9561	109.798
7	3	1	3	21.2615	2	0.95	397910.8329	111.996
8	3	2	1	21.2615	5	0.85	356565.0821	111.043
9	3	3	2	21.2615	8	0.95	377994.2822	111.550

In this table S/N Ratio is being calculated considering "Larger the better" criteria

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=(108.404+108.912+109.391)/3= 108.9

A21= Mean of medium level values of Area

A21=(SN4 +SN5+ SN6) /3=(1110.269+110.749+109.798)/3= 110.3

A31= Mean of high level values of Area

A31=(SN7 +SN8+ SN9) /3=(111.996+111.043+111.550)/3= 111.5

dT12= Mean of low level values of Temperature difference

dT12=(SN1 +SN4+ SN7) /3=(108.404+110.269+111.996)/3= 110.2

dT22= Mean of medium level values of Temperature difference

dT22= (SN2 +SN5+ SN8) /3=(108.912+110.749+111.043)/3= 110.2

dT32= Mean of high level values of Temperature difference

dT32=(SN3 +SN6+ SN9) /3=(109.391+109.798+111.550)/3= 110.2

RH13= Mean of low level values of Relative humidity

RH13=(SN1 +SN6+ SN8)/3=(108.404+109.798+111.043)/3 = 109.7

RH23= Mean of medium level values of Relative humidity

RH23=(SN2 +SN4+ SN9)/3=(108.912+110.269+111.550)/3 = 110.2

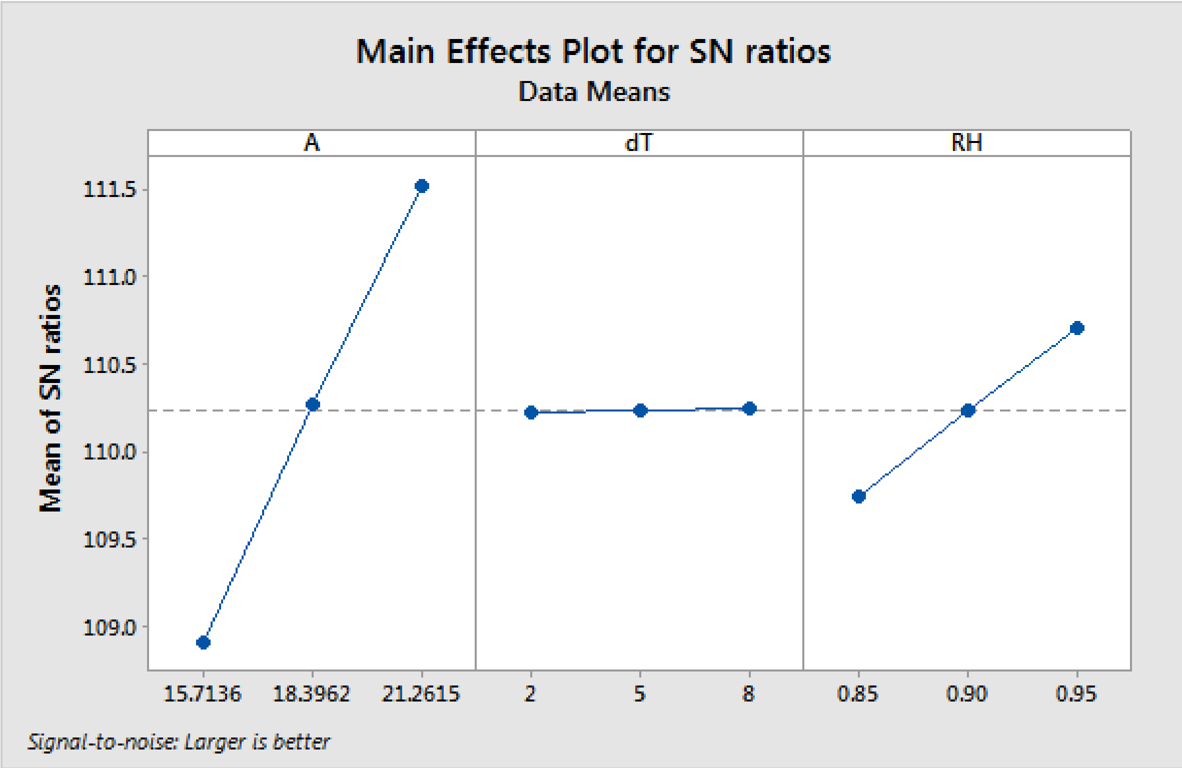
RH33= Mean of high level values of Relative humidity

RH33= (SN3 +SN5+ SN7)/3=(109.391+110.749+111.996)/3 = 110.7

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	108.9	110.2	109.7	110.21
Medium	110.3	110.2	110.2	
High	111.5	110.2	110.7	
Delta=larger-smaller	2.6	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 test runs results were again analysed using ANOVA for identifying the significant factors and their relative contribution on the output variable. Taguchi method can not 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.

Table 6 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 Contribu-tion
A	Area of the Bear tube & Fin	2	14558905454	7279452727	954.32	87.9382
dT	Temperature Difference	2	8970118	4485059	0.59	0.0541
RH	Relative Humidity	2	1972714406	986357203	129.31	11.9155
Error		2	15255742	7627871		
Total		8	16555845720			

The above calculations suggest that the area of the Evaporator has the largest influence with a contribution of 87.9382 %. Next is relative humidity with 11.9155% contribution and temperature difference has lowest contribution of 0.0541%.

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)-18.3962(m^2), Temperature difference (dT)-5(0c) and Relative humidity (RH)-0.95 in percentage. This optimality has been proposed out of the range of [A (15.7136, 18.3962, 21.2615), 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 87.9382%.Next is relative humidity 11.9155% 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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