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

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Abstract- Energy crisis is one of the most important problems the world is facing now-a-days. 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. In this situation if the maximum heat energy(Q) is absorbed by the evaporator inside the cold room through convective heat transfer process in terms of – heat transfer due to convection and heat transfer due to condensation, more energy has to be wasted to maintain the evaporator space at the desired temperature range of 2- 8 degree centigrade. In this paper we have proposed a theoretical heat transfer model of convective heat transfer in cold storage using Taguchi L9 orthogonal array. Velocity of air (V), Temperature difference (dT), Relative Humidity (RH) are the basic variable and three ranges are taken each of them in the model development. Graphical interpretations from the model justify the reality through anova and s/n ratio calculation.

Index Terms - cold storage, convective heat transfer model, heat absorbed by evaporator, Taguchi Analysis.

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, chilies, 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 comes 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 modeling is absolutely necessary to predict the performance.[5]

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. Velocity of air (**V**), Temperature difference (**dT**), Relative Humidity (**RH**) are the basic variables and three ranges are taken each of them in the model development. Graphical interpretations from the model justifies the reality

II. MODEL DEVELOPMENT

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 velocity of air (**V**), temp. difference (**dT**) & relative humidity RH) . Only convection heat transfer effect is being considered in this study.

Basic equation for heat transfer

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

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

Here Q_{conv}=heat transfer due to convection & $Q_{condensation}$=heat transfer due to condensation & Q_T=Total heat transfer or absorb heat into refrigerant.

And $h_c/h_m=c_p\,(Le)^{2/3}$ & $h_cL/K=Nu=0.026(Re)^{0.8}(Pr)^{0.3}$

The final heat transfer equation due to velocity of air (**V**), temp. difference (**dT**) & relative humidity RH) is

$\mathbf{Q_T=7.905V^{0.8}(dT + 2490\ RH)}$**…….(1).** **[4]**

Hera **A**=surface area of tubes in evaporator space 1872 m^2.$\mathbf{h_c}$=convective heat transfer co-efficient. $\mathbf{h_m}$=convective mass transfer co-efficient.$\mathbf{h_{fg}}$=latent heat of condensation of moisture 2490 KJ/Kg-K.

C_p=specific heat of air 1.005 KJ/Kg-K. Le=Lewis number for air it is one.

From equation number (4) we have $Q_{1......9}$ values by putting the values of Air velocity (V), Relative humidity (RH) and temperature difference (dT). 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.

III. HEAT CALCULATION

L9 orthogonal array combination Tables with notation for Matrix design-

EX NO-	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

Table 1

V	dT	RH
0.74	2	0.85
0.74	5	0.90
0.74	8	0.95
1.25	2	0.90
1.25	5	0.95
1.25	8	0.85
1.76	2	0.95
1.76	5	0.85
1.76	8	0.90

Table 2

Levels	Velocity of air (V)(m/s)	Temperature difference(dT)(centrigade)	Relative humidity
1	0.74	2	0.85
2	1.25	5	0.90
3	1.76	8	0.95

Table 3

Heat absorbe(Q) at evaporator level calculated by equation…..(1)

Obs no -	V	dT	RH	Q
1	0.74	2	0.85	13162.61
2	0.74	5	0.90	13954.63
3	0.74	8	0.95	14746.05
4	1.25	2	0.90	21196.58
5	1.25	5	0.95	22401.23
6	1.25	8	0.85	20075.48
7	1.76	2	0.95	29416.29
8	1.76	5	0.85	26359.37
9	1.76	8	0.90	27944.56

Table 4

IV. SIGNAL-TO-NOISE RATIO(S/N RATIO)

Taguchi uses the loss function to measure the performance characteristic deviating from the desired value. The value of loss function is then further transformed to S/N ratio. Usually, there are three categories of the performance characteristic in the analysis of the S/N ratio, that is, the lower-the-better, the higher-the-better, and the nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis and the higher S/N ratio corresponds to the better heat transfer rate for better cooling effect inside evaporation space. Therefore, the optimal level of the process parameter is the level with the highest S/N ratio. S/N ratio calculation is done to find influence of the control parameters.

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[∑(1/(13162.61)2/`1]=82.3868

where Q1=13162.61 & n=1

for experiment no-2

SN2 = -10 log[∑(1/(13954.63)2/`1]=82.8944

where Q2=13954.63 & n=1

for experiment no-3

SN3 = -10 log[∑(1/(14746.05)2/`1]=83.3735

where Q3=14746.05 & n=1

for experiment no-4

SN4 = -10 log[∑(1/(21196.58)2/`1]=86.5253

where Q4=21196.58 & n=1

for experiment no-5

SN5 = -10 log[∑(1/(22401.23)2/`1]=87.0054

where Q5=22401.23 & n=1

for experiment no-6

SN6 = -10 log[∑(1/(20075.48)2/`1]=86.0533

where Q6=20075.48 & n=1

for experiment no-7

SN7 = -10 log[∑(1/(29416.29)2/`1]=89.3718

where Q7=29416.29 & n=1

for experiment no-8

SN8 = -10 log[∑(1/(26359.37)2/`1]=88.4187

where Q8=26359.37 & n=1

for experiment no-9

SN9 = -10 log[∑(1/(27944.56)2/`1]=88.9259

where Q9=27944.56 & n=1

Exp. no.	**parameter**						**Heat transfer (KJ)**	**S/N Ratio for Larger the better**
	Combination of control parameters			**Control parameter**				
				Air velocity (m/s)	**Temperature difference (0^c)**	**Relative humidity (%)**		
1	1	1	1	0.74	2	0.85	13162.61	82.3868
2	1	2	2	0.74	5	0.90	13954.63	82.8944
3	1	3	3	0.74	8	0.95	14746.05	83.3735
4	2	1	2	1.25	2	0.90	21196.58	86.5253
5	2	2	3	1.25	5	0.95	22401.23	87.0054
6	2	3	1	1.25	8	0.85	20075.48	86.0533
7	3	1	3	1.76	2	0.95	29416.29	89.3718
8	3	2	1	1.76	5	0.85	26359.37	88.4187
9	3	3	2	1.76	8	0.90	27944.56	88.9259

Table no-5 S/N Ratio Table for Larger the Better

V. OVERALL MEAN OF S/N RATIO

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

V11= Mean of low level values of Air velocity

V11=(SN1 +SN2+ SN3) /3=(82.3868+82.8944+83.3735)/3 = 82.8849

V21= Mean of medium level values of Air velocity

V21=(SN4 +SN5+ SN6) /3=(86.5253+87.0054+86.0533)/3 = 86.5280

V31= Mean of high level values of Air velocity

V31=(SN7 +SN8+ SN9) /3=(89.3718+88.4187+88.9259)/3 = 88.9055

dT12= Mean of low level values of Temperature difference

dT12=(SN1 +SN4+ SN7) /3=(82.3868+86.5253+89.3718)/3 = 86.0946

dT22= Mean of medium level values of Temperature difference

dT22=(SN2 +SN5+ SN8) /3=(82.8944+87.0054+88.4187)/3 = 86.1062

dT32= Mean of high level values of Temperature difference

dT32=(SN3 +SN6+ SN9) /3=(83.3735+86.0533+88.9259)/3 = 86.1176

RH13= Mean of low level values of Relative humidity

RH13=(SN1 +SN6+ SN8) /3=(82.3868+86.0533+88.4187)/3 = 85.6196

RH23= Mean of medium level values of Relative humidity

RH23=(SN2 +SN4+ SN9) /3=(82.8944+86.5253+88.9259)/3 = 86.1152

RH33= Mean of high level values of Relative humidity

RH33=(SN3 +SN5+ SN7) /3=(83.3735+87.0054+89.3718)/3 = 86.5836

Level	Average S/N ratio by factor level			Overall mean of S/N ratio(SN_o)
	Air velocity (m/s)	Temperature difference (0^c)	Relative humidity (%)	
Low	82.8849	86.0946	85.6196	86.1061
Medium	86.5280	86.1062	86.1152	
High	88.9055	86.1176	86.5836	
Delta=larger-smaller	6.0206	0.0230	0.9640	
Rank	1	3	2	

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

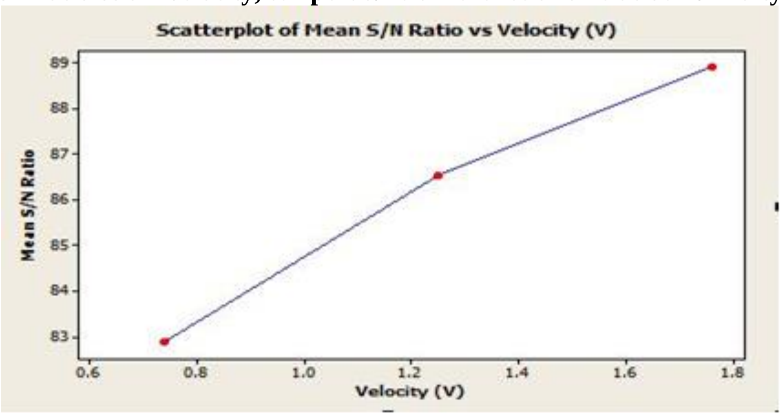

Fig 1: variation of mean of S/N ratio with air velocity.

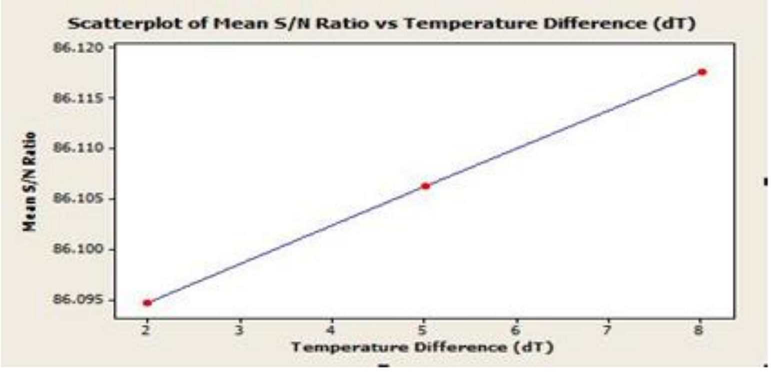

Fig 2: variation of mean of S/N ratio with temperature difference.

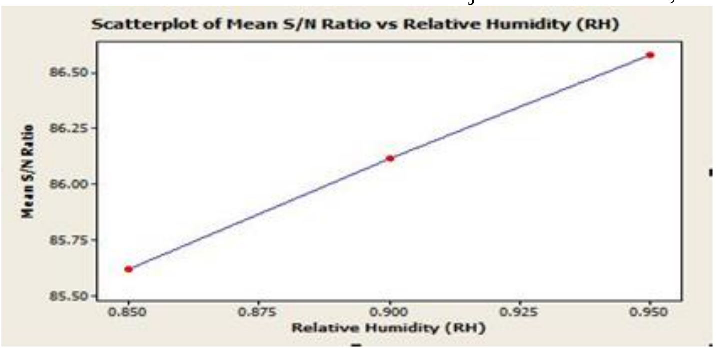

Fig 3: variation of mean of S/N ratio with relative humidity.

VI. ANALYSIS OF VARIANCE (ANOVA) CALCULATION

The test runs results were again analyzed 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.

Effect of each parameter can be determined by subtraction of each value of table no.11 to the overall average of S/N ratio (86.1061).After subtraction, the effect of each parameter obtained as follows:-

	Air velocity (m/s)	**Temperature difference (0^c)**	**Relative humidity (%)**
Low	-3.2212	-0.0115	-0.4865
Medium	0.4219	0.0001	0.0091
High	2.7994	0.0115	0.4775

Table 6: Effect of each parameter

SS= Sum of square of each parameter air velocity = Σ (Vij - SNO) 2 *n

Vij =Average S/N ratio values from table 11 for each parameter (low, medium and high level)

SNO = Overall mean of S/N ratio n= 3
SS Air velocity=[(-3.22122)*3 +(0.42192)*3+(2.79942)*3] =31.1284+0.5340+23.5099 =55.1723

SS temperature difference=[(-0.01152)*3 +(0.00012)*3+(0.01152)*3] =0.0004+0.0000+0.0004 =0.0008
SS Relative humidity=[(-0.48652)*3 +(0.00912)*3+(0.47752)*3 =0.7100+0.0002+0.6840 =1.3942

Total sum of square(TSS)=[(SN i) 2] – [(Σ SN i) 2 / 9]
SN i=S/N ratio values for each experiment
i= varies from 1…… 9

$=[(82.3868)^2+ (82.8944)^2 + (83.3735)^2 + (86.5253)^2 +(87.0054)^2+ (86.0533)^2+ (89.3718)^2 + (88.4187)^2 + (88.9259)^2] - [(774.9551)^2 / 9]$

= 66784.9453-66728.3786 =56.5667

Sum of squared error(SSE) = TSS – Σ(SS Air velocity + SS $_{Temperature}$ difference + SS $_{Relative}$ humidity)
= 56.5667-(55.1723+0.0008+1.3942) = 0.0006

Mean square error (MSE)= $SS_{each\ factor}$ / dof $_{each\ factor}$

F value =$MSE_{each\ factor}$ / SSE

Another term appeared in the ANOVA table is percentage contribution of each factor. The formula for percentage contribution= $\left(\frac{sum\ of\ square\ of\ factor}{total\ \ sum\ of\ squres}\right)\times 100$

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

Table no: 7 ANOVA result for Q (at 95% confidence level)

Source	Notation	Degrees of freedom	Sum of squares(SS)	Mean squares(MS)	F ratio	P	% contribution
Air velocity (m/s)	V	2	292173121	146086561	949.68	0.001	97.13
Temperature difference (0^c)	dT	2	238398	119199	0.77	0.563	0.08
Relative humidity (%)	RH	2	8087833	4043917	26.29	0.037	2.69
Error		2	307655	153828			0.1
Total		8	300805007				100

The above calculations suggest that air velocity has the largest influence with a contribution of 97.13%. Next is relative humidity with 2.69% contribution and temperature difference has lowest contribution of 0.08%

VII. 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 Air velocity (V)-1.76(m/s), Temperature difference(dT)-2(0c) and Relative humidity (RH)-0.95 in percentage. This optimality has been proposed out of the range of [V (0.74, 1.25, 1.76), dT (2,5,8), RH (0.85, 0.90, 0.95)].
2. ANOVA analysis indicates Air velocity (V) is the most influencing control factor on Q and it is near about 97%.
3. We have also proposed a theoretical heat convection model through cold storage using multiple regression analysis. By developing computer program (Java language), the model has been analyzed by Origin.
4. Results obtained both from Taguchi S/N ratio analysis and the multiple regression analysis are also bearing the same trend.
5. L9 orthogonal array has used as design of experiments. The findings obtained from the S/N ratio analysis and ANOVA are in close agreement. Both have identified air velocity (V) is the most significant control parameter followed by relative humidity (RH), and temperature difference (dT).

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