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MODIFIED CONVECTIVE HEAT TRANSFER MODELING OF A COLD STORAGE USING ANOVA AND TAGUCHI 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 and also heat enter in the cold store due to infiltration through cold room doors, more energy has to be wasted to maintain the evaporator space at the desired temperature range of 2-6 degree centigrade. In this paper we have proposed a modified theoretical heat transfer model of convective heat transfer in the evaporator space and heat enter in the cold store due to infiltration through cold room doors using Taguchi L9 orthogonal array. Velocity of air (V), Temperature difference (dT), Height of cold store door (H) 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- **Taguchi Design of Experiment (D.O.E), S/N ratio analysis, ANOVA 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, 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 comes down. 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. But also the heat enters in the cold store due to infiltration through cold room doors. In the cold stores infiltration (examined entry) to the room was exclusively through the main cold store doors. That’s why a mathematical modelling is absolutely necessary to predict the performance.

In this paper we have proposed a modified mathematical heat transfer model of convective heat transfer in the evaporator space and heat enter in the cold store due to infiltration through cold room doors using Taguchi L9 orthogonal array. Velocity of air (V), Temperature difference (dT), Height of cold store door (H) are the basic variable and three ranges are taken each of them in the model development. Graphical interpretations from the model justify the reality.

II. MATHEMATICAL MODEL DEVELOPMENT

In this study heat transfer in the evaporator space of the cold store and also heat enter in the cold store due to infiltration through cold room doors both are considered. Heat transfer in the evaporator space of the cold store and also heat enter in the cold store due to infiltration through cold room doors both are calculated in terms of velocity of air (V), temperature difference (dT) and height of the cold store door (H). On both occasion heat is transferred through convective heat transfer process.

Basic equation for heat transfer

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

$Q_{conv}=Ah_cdT$ & $Q_{condensation}=Ah_m(RH)h_{fg}$.

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 is

$Q_T=7.905V^{0.8}$ (dT + 2490 RH)....... (1).

Here

A=surface area of tubes in evaporator space 1872 m^2.h_c=convective heat transfer co-efficient.

h_m=convective mass transfer co-efficient.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.

The model developed by Gosney and Olama (1975) has been shown by Foster et al (2003) to provide the most accurate prediction of infiltration through cold room doors. The Gosney and Olama equation assumes that the air temperature within the cold room remains stable during door openings.

The equation developed by Gosney and Olama to provide the most accurate prediction of infiltration through cold room doors is

q= 0.221A (hi+lr-hr) pr $(1\text{-}pi/pr)^{0.5}(gH)^{0.5}$Fm

The final equation comes from the Gosney and Olama equation is

q=0.2518A [1.004*(dT) +2490]*$H^{0.5}$ …….. (2)

Here,

q=heat through infiltration (W), A=Area of cold store door (m^2), hi=Enthalpy of ambient air ($kJ.kg^{-1}$) hi=c_pdT[here, c_p =specific heat of air, dT=Temperature difference]

lr=Latent heat of refrigerated air (kJ/kg)

hr=Enthalpy of refrigerated air (kJ/kg), ρi=Density of ambient air ($kg.m^{-3}$), ρr= Density of refrigerated air ($kg.m^{-3}$) calculated from ρ=p/RT (here p=pressure in Pa(assumed to be 100,000), T=Temperature in K and R=universal gas constant(287)), g=Acceleration due to gravity (9.81 m/s2), H=Height of cold store door (m)

Fm= (2/ (1+ (ρr/ρi)0.333))1.5

= 0.9772

In calculations the RH in the cold store was assumed to be 90% (at low temperatures the enthalpy of the water content of the cold store air does not vary much and therefore the RH value used was not critical).

In case of cold store in one store entry to another ambient store was through one of the frozen chambers and therefore these additional door openings were added to the heat load on the frozen chamber.

The modified convective heat transfer equation due to heat transfer in evaporator space in cold store and heat enter due to infiltration through cold room doors is

Q= QT + q

Q= 7.905V0.8 (dT + 2490 RH) + 0.2518A [1.004*(dT) +2490]*H0.5 ………… (3)

From equation number (3) we have Q1......9 values by putting the values of Air velocity (V), Height of cold store door (H) 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 Genechi Taguchi (1987).The number of rows of an orthogonal array represents the requisite number of experiments.

In this study TABLE – 1 shows the control parameters and their levels –

TABLE 1 control parameters and their levels

Notation	Factors	Unit	levels		
			1	2	3
V	Velocity of Air	m/s	0.74	1.25	1.76
dT	Temperature difference	centigrade	2	4	6
H	Height of the cold store door	m	2	2.25	2.5

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 observat table become:

Table 3 Observation table

TEST RUNS	V	dT	H	Q
1	0.74	2	2	15309.862
2	0.74	4	2.25	15496.200
3	0.74	6	2.5	15683.089
4	1.25	2	2.25	22733.973
5	1.25	4	2.5	22933.745
6	1.25	6	2	22611.843
7	1.76	2	2.5	32073.918
8	1.76	4	2	29271.350
9	1.76	6	2.25	29470.312

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 17 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- 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 minimise the heat flow from outside of wall to inside and In case of convection process we use larger-the-better type S/N Ratio to maximise the heat transfer in the evaporator space of the cold room.

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

Analysis of the S/N ratio

For modified convective heat transfer process we use s/n ratio larger is better type-

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/(15309.862)2/`1]= 83.6994Where, Q1=15309.862& n=1

For experiment no-2

SN2 = -10 log[Σ(1/(15496.200)2/`1]= 83.8045Where, Q2=15496.200& n=1

For experiment no-3

SN3 = -10 log[Σ(1/(15683.089)2/`1]= 83.9086Where, Q3=15683.089& n=1

For experiment no-4

SN4 = -10 log[Σ(1/(22733.973)2/`1]= 87.1335Where, Q4=22733.973& n=1

For experiment no-5

SN5 = -10 log[Σ(1/(22933.745)2/`1]= 87.2095Where, Q5=22933.745& n=1

For experiment no-6

SN6 = -10 log[Σ(1/(22611.843)2/`1]= 87.0867Where, Q6=22611.843 & n=1

For experiment no-7

SN7 = -10 log[Σ(1/(32073.918)2/`1]= 90.1230Where, Q7=32073.918 & n=1

For experiment no-8

SN8 = -10 log[Σ(1/(29271.350)2/`1]= 89.3289Where, Q8=29271.350 & n=1

For experiment no-9

SN9 = -10 log[Σ(1/(29470.312)2/`1]= 89.3877Where, Q9=29470.312 & n=1

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 = (83.6994+83.8045+83.9086)/3= 83.8042

A21= Mean of medium level values of Area

A21= (SN4 +SN5+ SN6) /3 = (87.1335+87.2095+87.0867)/3= 87.1432

A31= Mean of high level values of Area

A31= (SN7 +SN8+ SN9) /3 = (90.1230+89.3289+89.3877)/3= 89.6132

dT12= Mean of low level values of Temperature difference

dT12= (SN1 +SN4+ SN7) /3 = (83.6994+87.1335+90.1230)/3= 86.9853

dT22= Mean of medium level values of Temperature difference

dT22= (SN2 +SN5+ SN8) /3 = (83.8045+87.2095+89.3289)/3= 86.7809

dT32= Mean of high level values of Temperature difference

dT32= (SN3 +SN6+ SN9) /3 = (83.9086+87.0867+89.3877)/3= 86.7943

RH13= Mean of low level values of Relative humidity

RH13= (SN1 +SN6+ SN8)/3 = (83.6994+87.0867+89.3289)/3 = 86.7050

RH23= Mean of medium level values of Relative humidity

RH23= (SN2 +SN4+ SN9)/3 = (83.8045+87.1335+89.3877)/3 = 86.7752

RH33= Mean of high level values of Relative humidity

RH33= (SN3 +SN5+ SN7)/3 = (83.9086+87.2095+90.1230)/3 = 87.0804

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(SNo)
	Velocity of Air (V) (m/s)	Temperature Difference (dT) (0c)	Height of cold store door (H) (m)	
Low	83.8042	86.9853	86.7050	86.8535
Medium	87.1432	86.7809	86.7752	
High	89.6132	86.7943	87.0804	
Delta=larger-smaller	5.81	0.20	0.38	
Rank	1	3	2	

III. Results and Discussions

Fig 1 shows the main effect plot for S/N ratio for modified convective heat transfer in the evaporator space of the cold room and heat enter due to infiltration through cold room doors (Q)

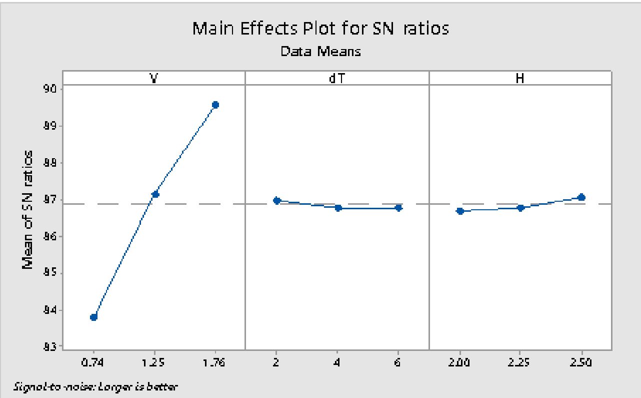

Fig - 1

Fig 2 shows the main effect plot for means for modified heat transfer in the evaporator space of the cold room and heat enter due to infiltration through cold room doors (Q)

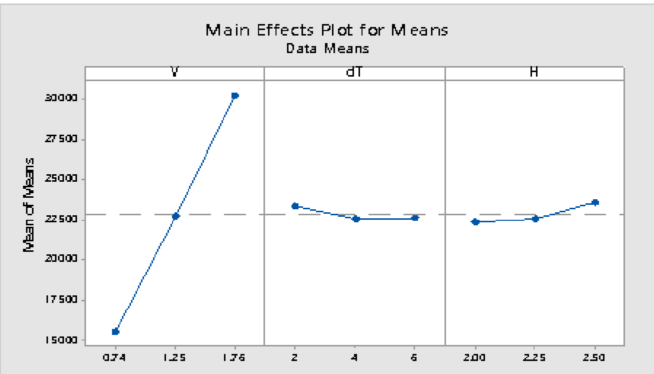

Fig –2

ANALYSIS OF VARIANCE (ANOVA) CALCULATION:

Table no: 6 ANOVA result for Q (at 95% confidence level)

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. The tests run data in were again analyzed using ANOVA at 95% confidence level (α=.05) for identifying the significant factors and their relative contribution on the output variable.

Source	Notation	Degrees of Freedom	Sum of Squares	Mean Squares	F Ratio	% of Contribution
V	Velocity of Air	2	327502936	163751468	239.45	98.4923
dT	Temperature Difference	2	1264184	632092	0.92	0.3802
H	Height of cold store door	2	2381452	1190726	1.74	0.7162
Error		2	1367741	683870		
Total		8	332516313			

The above calculations suggest that the velocity of air (V) has the largest influence with a contribution of 98.4923 %. Next is height of cold store door (H) with 0.71623% contribution and temperature difference (dT) has lowest contribution of 0.3802%

IV. 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 Velocity of Air (V)-1.25(m/s), Temperature difference (dT)-4(0c) and Height of cold store door (H)-2.25(m) in percentage. This optimality has been proposed out of the range of [V (0.74,1.25,1.76), dT (2,4,6), H (2, 2.25, 2.5)].So, increase the Velocity of Air is most important.
2. ANOVA analysis indicates Velocity of Air (V) is the most influencing control factor on Q and it is near about 98.4923%. height of cold store door (H) with 0.71623% 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 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 Velocity of Air (V) is the most significant control parameter followed by Height

of cold store door (H), and temperature difference (dT).

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