International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Volume 4, Issue 3 (May-June, 2016), PP. 326-332

MODIFIED CONVECTIVE HEAT TRANSFER MODELING OF A COLD STORAGE USING TAGUCHI L9 ORTHOGONAL ARRAY AND REGRESSION 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 developed by polynomial multiple regression analysis.**

Keywords: **Cold storage, Taguchi L9 orthogonal array, Regression 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

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

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

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

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

The final heat transfer equation is

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

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

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

The final equation comes from the Gosney and Olama equation is

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

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/s^2), H=Height of cold store door (m)

$$\mathbf{Fm= (2/ (1+ (\rho r/\rho i)^{0.333}))^{1.5}}$$

= 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

$$\mathbf{Q= Q_T + q}$$

$$\mathbf{Q= 7.905V^{0.8}\ (dT + 2490\ RH) + 0.2518A\ [1.004*(dT) +2490]*H^{0.5}}\ ....\ (3)$$

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 observation 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

III. REGRESSION ANALYSIS

Regression analysis is the relationship between various variables. By 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 the changes in predictor variable. Simple regression equation is

y=a+ b x

In this problem more than one predictor variable is involved and hence simple regression analysis can not be used. We have to take the help of multiple regression analysis. There are two types of multiple regression analysis- 1) Simple multiple regression analysis (regression equation of first order) 2) 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= β0+β1X1+β2X2+β3X3+………………….. +ε

Where β is constant terms & X is the variables & ε is the experimental error.

Polynomial multiple regression analysis equation is

Y = β0+ β1X1+β2X2+β3X3+ β 11X211+ β 22X222+ β33X233+ β12X1X2+ β13X1X3+ β23X2X3

The above equation is second order polynomial equation for 3 variables. Where β are constant, X_1 , X_2 , X_3 are the linear terms, X_{12} X_{13} X_{23} are the interaction terms between the factors, and lastly X_{11} X_{22} X_{33} are the square terms.

Q $_{\text{(heat due to conv+infiltration)}}$ = response variable, V, dT, H= predictor variable.

Polynomial regression equation becomes after replacing real problem variables

Q (heat due to conv+condensation) = β0+β1(V)+β2 (dT)+β3 (H)+ β 11 (V)*(V)+ β 22(dT)*(dT)+β33 (H)*(H)+ β12(V)*(dT)+ β13(dT)*(H)+ β23(H)*(V)

To solve this equation following matrix method is used

Y= [β][X]

[β]=Y [X-1]

where [β] is the coefficient matrix, Y is the response variable matrix; [X-1] is the inverse of predictor variable matrix.

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.

IV. COLD STORAGE DESCRIPTION

The overall dimensions of cold storage plant are 87.5mx34.15mx16.77m.The cold storage building is of five floors with each floor having 2 cold chambers of 43.25m x 17m sizes operating at different temperature as per the requirements of commodities. For our analysis purpose we only considered zone 1 which is referred as cold room.

V. PARAMETER AND RANGE SELECTION

The one chamber of cold storage Length ,Breath and Height 87.5m,34.15m and 16.77m respectively. The three values of air velocity(**V**) of evaporator space are 0.74m/s, 1.25m/s and 1.76m/s respectively. The three values of temperature difference (**dT**) of evaporator space are 2, 4 & 6 centigrade respectively. The three values of relative humidity (**RH**) of evaporative space are 0.85, 0.90 & 0.95 respectively.

VI. RESULT AND DISCUSSION

We get **nine**equations but number of unknowns are **ten.** Now we can solvethese equations-eliminate some of variables in terms of others. Then we get[X] matrix as [9*9]. We also get response variable matrix [Q] which is a [9*1] matrix. With the help of following equation we can get the co efficient values- [β]=[Q]*[X_{-1}] where [x]-denotes the variable matrix.
The proposed theoretical mathematical model for heat transfer in cold storage is –

Q (heat due to conv+infiltration) = 18300.6 + 1849.6 v + 1024.32 dT - 7639.96 H + 477.771 v*v - 806.55 v*dT +6519.08 v*H - 0.547583 dT*dT + 39.4533 H*H+0*dT*H

The Graphical analysis of this equation is

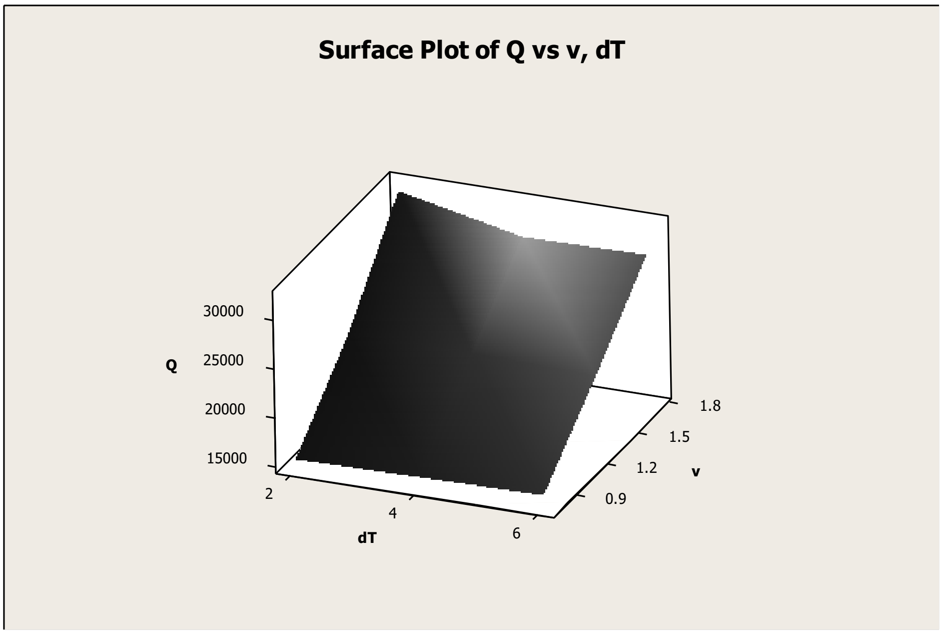

Fig-1: 3-D Surface Plot between Total Heat (Q), Air Velocity (V) and Temperature Difference (dT)

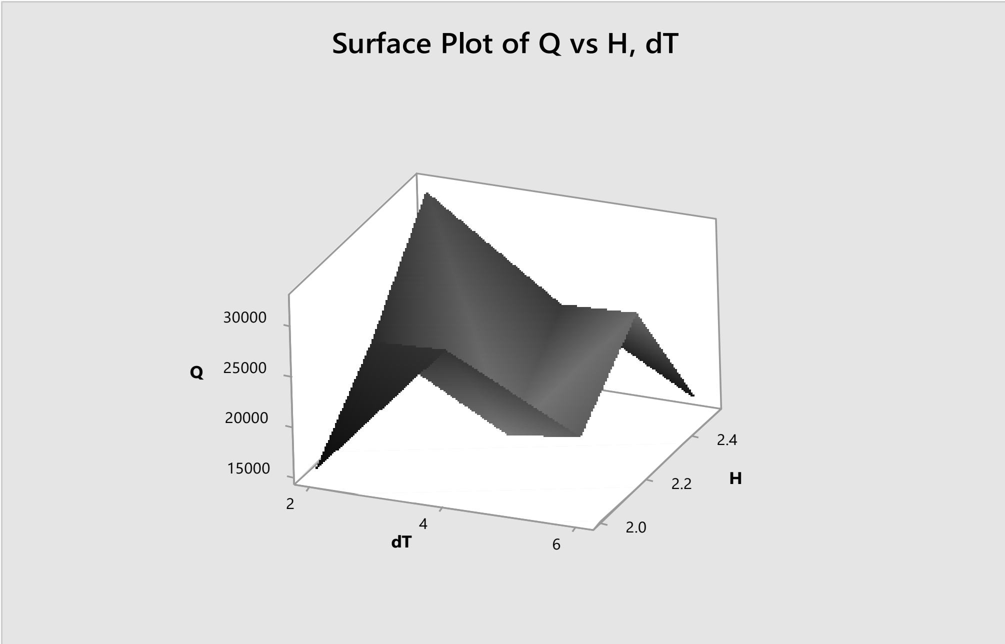

Fig-2: 3-D Surface Plot between Total Heat (Q), Height of Cold Store Door (H) and Temperature Difference (dT)

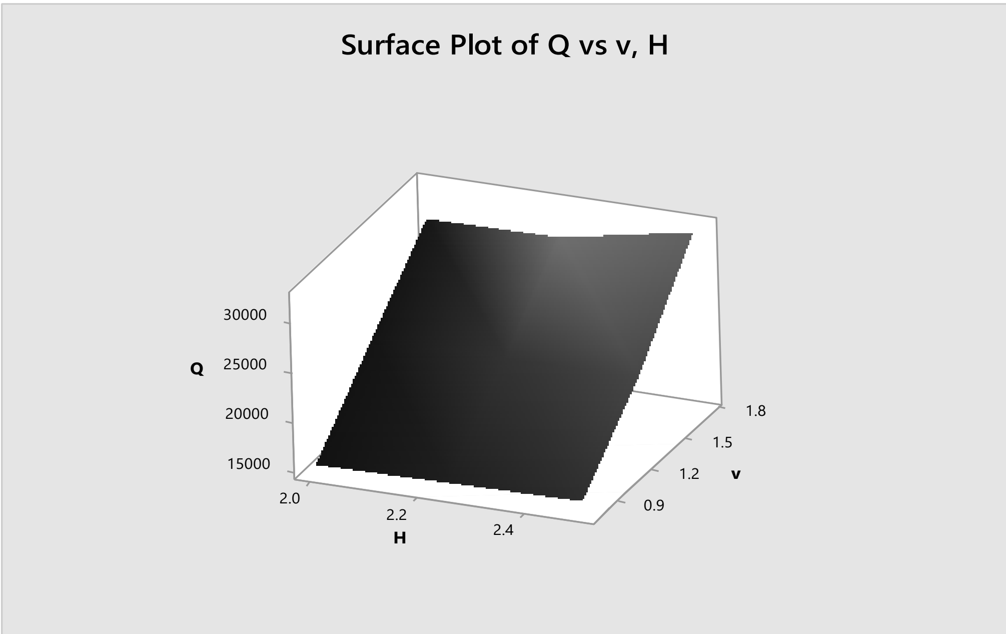

Fig-2: 3-D Surface Plot between Total Heat (Q),Air velocity (V) and Height of Cold Store Door (H)

VII. 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. Results obtained from the multiple regression analysis.
3. 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.
4. A theoretical proposed model is created by polynomial multiple regression analysis process.

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