RESEARCH ARTICLE OPEN ACCESS

Optimization of Combined Conductive and Convective Heat Transfer Model of Cold Storage Using Taguchi Analysis

Dr. N Mukhopadhyay[1], Priyankar Mondal[2]
[1] Assistant professor, Department of Mechanical Engineering, Jalpaiguri Government Engineering College, W.B, India
[2]Post Graduate scholar, Department of Mechanical Engineering, Jalpaiguri Government Engineering College, W.B, India

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 conductive and convective heat transfer process in terms of –heat transfer due to conduction, 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 in cold storage due to conduction and convection process using Taguchi L9 orthogonal array. Thickness of insulation wall of cold storage (X), 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.
***KEYWORDS**:* cold storage, conductive heat transfer model, convective heat transfer model, and Taguchi Analysis etc…

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 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 modeling is absolutely necessary to predict the performance. In this paper we have proposed a theoretical model of heat transfer due to conduction and convection process of a cold storage using Taguchi L9 orthogonal array. Thickness of insulation wall of cold storage (**X**), 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 justify the reality.

II. MODEL DEVELOPMENT

Relationship between heat gain & energy consumption is given by E= (Qt)/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 conduction, convection and condensation and predictor variables
are Thickness of insulation wall of cold storage (X), 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.

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+ bx 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- 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, 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, X, dT, RH= predictor variable. Polynomial regression equation becomes after replacing real problem variables Q (heat due to conduction+convection) = β0+β1(X)+β2 (dT)+β3 (RH)+ β 11 (X)*(X)+ β 22(dT)*(dT)+β33 (RH)*(RH)+ β12(X)*(dT)+ β13(dT)*(RH)+ β23(RH)*(X) 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.

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.

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 Thickness of insulation wall of cold storage (**X**) are 100mm, 150mm and 200mm respectively. The three values of temperature difference (**dT**) due to conduction and convection process are 23, 25 & 28 centigrade respectively. The three values of relative humidity (**RH**) of evaporative space are 0.85, 0.90 & 0.95 respectively.

CALCULATION

In this study heat transfer due to conduction and convection process only being considered. The heat transfer from outside wall of cold storage to evaporating space is calculated in terms of Thickness of insulation wall of cold storage (X), temp. difference (**dT**) & relative humidity RH) . Both conduction and convection heat transfer effect is being considered in this study. Basic equation for heat transfer QT = Qcond.+ Qconv. Qcond.=K*A*dT/X and Qconv.=7.905$V^{0.8}$(dT+2490RH). Here Qcond. =heat transfer due to conduction & Qconv. =heat transfer due to convection & QT=Total heat transfer or absorb heat into refrigerant.

The final heat transfer equation due to Thickness of insulation wall of cold storage (**X**), temp. difference (**dT**) & relative humidity (**RH**) is **QT= K*A*dT/X+7.905$V^{0.8}$(dT+2490RH).** Hera X= Thickness of insulation wall of cold storage, A=Cross sectional area of wall, K= Thermal conductivity of insulating material, V= Velocity of air in evaporator space. After getting the full observation table which include all the predictor variables and response variable, values can be computed easily in the following equation- Q (heat due to cond+conv) = β0+β1(X)+β2 (dT)+β3 (RH)+ β 11 (X)*(X)+ β 22(dT)*(dT)+β33 (RH)*(RH)+ β12(X)*(dT)+ β13(X)*(RH)+ β23(dT)*(RH) We get **nine** equations but number of unknowns are **ten.** Now we can solve these 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 – **$Q_{(heat\ due\ to\ cond.+conv.)}$=7080-**

38727(X)+223551(dT)-306(RH)-57468(X)(X)+111(dT)(dT)+14(RH)(RH)-717(X)(dT)+20128(X)(RH)+17457(dT)(RH)

IV. RESULTS AND DISCUSSIONS

L_9 OA Combination Table with notation for Matrix design **L_9 (3^3)**

Exp. 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

Level	Thickness of insulation(for wall) (X) m	Temp. difference (dT)^{0}c	Relative Humidity(RH)
1	0.100	23	0.85
2	0.150	25	0.90
3	0.200	28	0.95

TABLE-2

X	dT	RH
0.100	23	0.85
0.100	25	0.90
0.100	28	0.95
0.150	23	0.90
0.150	25	0.95
0.150	28	0.85
0.200	23	0.95
0.200	25	0.85
0.200	28	0.90

TABLE-3

Obs. No.	X	dT	RH	Q
1	0.100	23	0.85	25720.5
2	0.100	25	0.90	27393.6
3	0.100	28	0.95	29316.1
4	0.150	23	0.90	25062.4
5	0.150	25	0.95	26576.8
6	0.150	28	0.85	24730.5
7	0.200	23	0.95	25322.1
8	0.200	25	0.85	23227.1
9	0.200	28	0.90	24790.7

Using the data from table no.-3 the following graph can be generated-

Variation of combined conductive and convective heat transfer with insulation thickness of the side walls can be represented as-

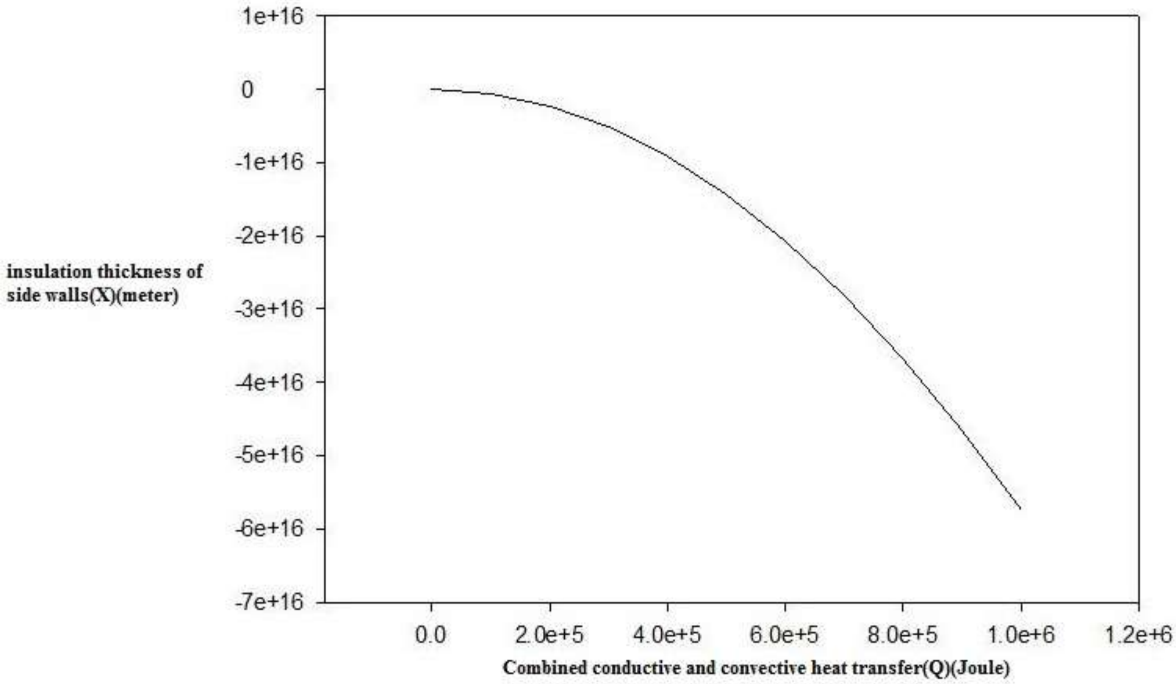

Fig 1: variation of combined conductive and convective heat transfer (Q) with insulation thickness of the side walls(X) in the cold room

From the above graph it can be seen that as insulation thickness of the side wall(X) increases the heat transfer (Q) decreases, it can be seen that for X=0.200m the heat transfer in the cold room (Q) becomes minimum.

Similarly the variation of combined conductive and convective heat transfer with temp. difference can be represented as-

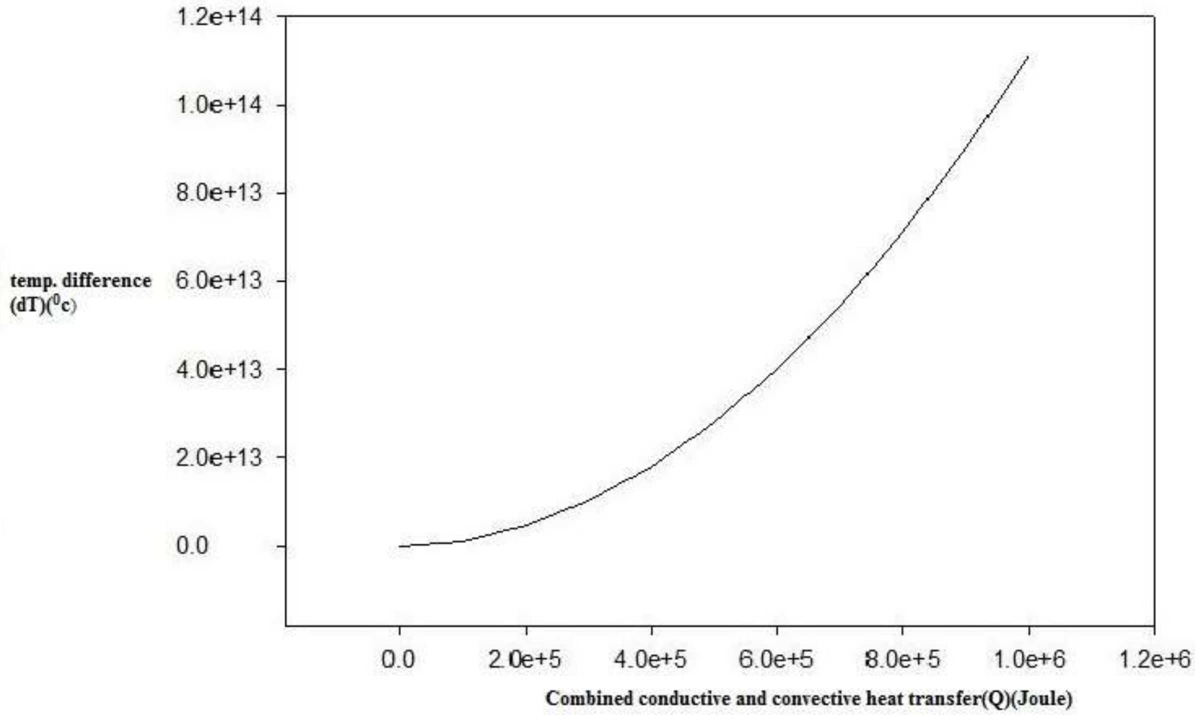

Fig 2: variation of combined conductive and convective heat transfer(Q) with temp. difference (dT) in the cold room

Figure 2 shows that heat absorption increase with temperature difference increase and lower temperature difference is more effect than higher temperature difference

And the variation of combined conductive and convective heat transfer with relative humidity can be represented as-

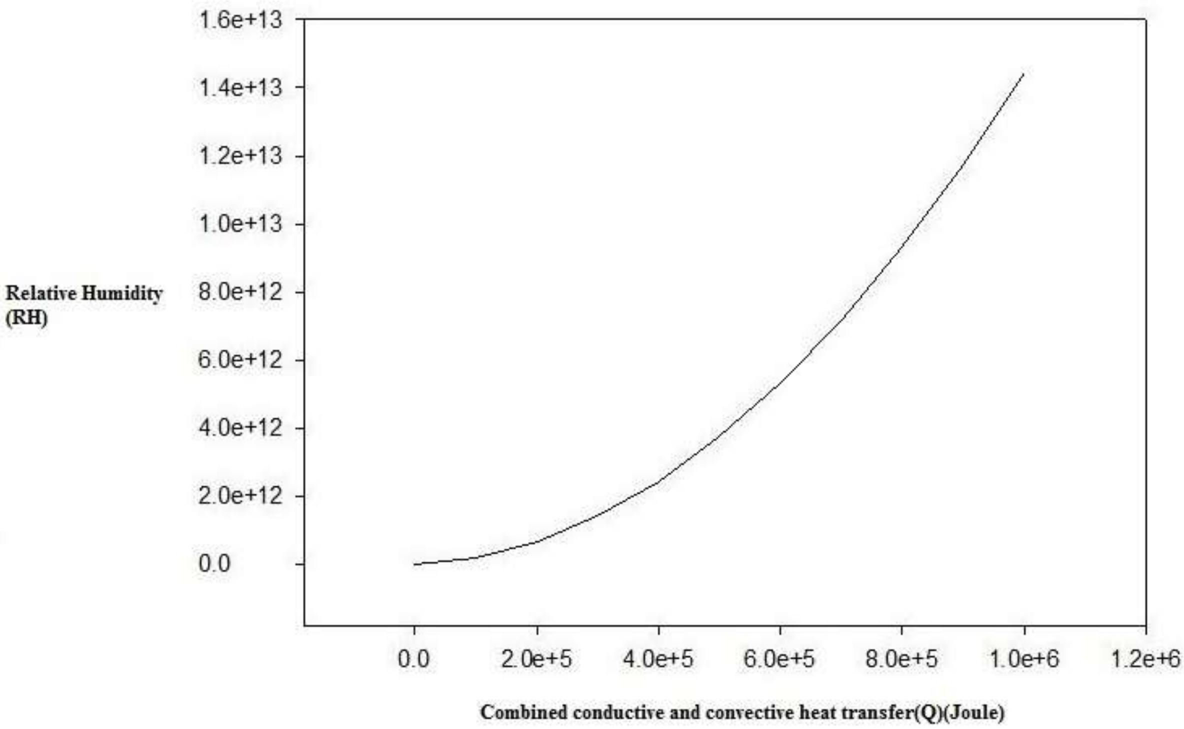

Fig 3: variation of combined conductive and convective heat transfer (Q) with relative humidity (RH)

Figure 3 shows that heat transfer increase with increase in relative humidity

V. CONCLUSION

The present study discusses about the application of Taguchi methodology to investigate the effect of control parameters on heat gain (Q) in the cold room, and also to propose a mathematical model with the help of regression analysis. From the analysis of the results obtained following conclusion can be drawn-

1. From the graphical analysis the optimal settings of the cold storage are insulation thickness of the side wall (X) -.200m; temp. diff. (dT)-23 (0c) and relative humidity (RH)-0.95. This optimality has been proposed out of the range of [X (0.100, 0.150,0 .200), dT (23, 25, 28), RH (0.85, 0 .90, 0.95)].
2. For X=X3, dT =dT1, RH=RH1 the heat flow into the cold room (Q) will be minimum.
3. The thermal conductivity (K) of material decides the insulation property of the material. Lower the K value better is the insulation property.

REFERENCE

[1] Patel Amit M., Patel R. I., Optimization of different parameter of cold storage for energy conservation, International Journal of Modern Engineering Research, Vol.2, Issue.3, May-June 2012 pp-1001-1005.

[2] Prof. N. Mukhopadhaya, Raju Das, ”Theoretical heat conduction model development of a Cold storage using Taguchi Methodology” International Journal Of Modern Engineering Research (IJMER) | IJMER | ISSN: 2249–6645 | www.ijmer.com | Vol. 4 | Iss. 6| June. 2014 | 77|

[3] Dr. N. Mukhopadhyay, Suman Debnath,” Theoretical Convective Heat Transfer Model Developement of Cold Storage Using Taguchi Analysis” Int. Journal of Engineering Research and Application, ISSN : 2248-9622, Vol. 5, Issue 1, (Part -6) January 2015, pp.13-17 www.ijera.com.

[4] ASHRAE Handbook of Fundamentals, 1993.

[5] Process heat transfer by DONAL Q. KERN (MCGRAW-HILL).

[6] Dr. Nimai Mukhopadhyay ,” Theoretical Study of Heat Load Calculation of a Cold Storage System” Proc. 6th.WMVC-2014, November 1-3,2014 52 Siliguri (Darjeeling) pp.52-57.email:nm1231@gmail.com