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Theoretical heat conduction model development of a Cold storage using Taguchi Methodology

Prof. N. Mukhopadhaya[1], Raju Das[2]
[1](Asst. Professor, Department of Mechanical Engineering , Jalpaiguri Govt.Engg College, India
[2](P.G. Scholar, Department of Mechanical Engineering, Jalpaiguri Govt.Engg. College, India

Abstract: *In this project work a mathematical heat conduction model of a cold storage (with the help of computer program; and multiple regression analysis) has been proposed which can be used for further development of cold storages in the upcoming future. Taguchi L_{27} orthogonal array (OA) has been used as a design of experiments (D.O.E). Heat gain (Q) in the cold room taken as the output variable of the study. With the help of a computer program several data sets have been generated on the basis of the proposed model. From the graphical interpretation, the critical values of the predictor variables also proposed so as the heat flow from the outside ambience to the inside of the cold room will be minimum. Insulation thickness of the side walls (TW), area of the wall (AW), and insulation thickness of the roof(TR) have been chosen as predictor variables of the study.*
Keywords: *Cold storage refrigeration plant, Design of experiments(D.O.E),Orthogonal array(OA), regression analysis.*

I. Introduction

A major use of refrigeration is in the preservation, storage and distribution of perishable foods. Cold storage plays an important role in the preservation of perishables especially fruits and vegetables. It helps in scientific preservation of perishables, stabilizes prices by regulating marketing period and supplies. It also helps the primary producer from distress sale and encourages farmers to produce more. In view of the fall in prices of fruits and vegetables immediately after harvest and to avoid spoilage of fruits and vegetables worth crores of rupees, it has become necessary to create cold storage facility in the producing as well as consuming centers to take care of the existing and projected production of fruits and vegetables.

A cold storage is a building or a group of buildings with thermal insulation and a refrigerating system in which perishable food products can be stored for various lengths of times in set conditions of temperature and humidity. Such storage under controlled conditions slows the deterioration and spoilage that would naturally occur in an uncontrolled natural environment. Thus, cold storage warehouses play an important role in the storage of food products in the food delivery chain throughout the year under conditions specially suited to prevent their degradation. This function makes seasonal products available all year round. So it is very important to make cold storage energy efficient or in the other words reduce its energy consumption. The energy consumption of the cold storage can be reduced, by minimizing the heat flow from high temperature ambience to low temperature cold room. By setting optimum values of different control parameters the heat gain in the cold room can be reduced.

M.S. Soeylemez et al (1997)[1] has suggested A thermo economic optimization analysis is presented yielding a simple algebraic formula for estimating optimum insulation thickness for refrigeration applications. The effects of design parameters on the optimum insulation thickness are investigated for three test cities using an interactive computer code written in Fortran 77. The equivalent full load hour's method is used to estimate the energy requirements. N.Yusoff et al (2010)[2] has suggested that study presents a procedure for selecting optimization variables in a Refrigerated Gas Plant(RGP) using Taguchi method with $L_{27}(3^9)$ orthogonal arrays. Patel Amit M., Patel R. I., (2012)[3] has also studied effect of various control parameters on cold storage energy consumption with the help of $L_9(3^3)$ orthogonal array.

In this present study Taguchi L_{27} orthogonal array[4] have been used as a design of experiments (D.O.E) method. It is a 3factor 3 level design involving 27 test runs. With the help of the array and multiple regression analysis[5] a theoretical heat conduction model of a cold storage is proposed. After generating a computer program various data sets have been generated to see the variations of the response variable i.e. heat gain(Q) in the cold room with predictor variables. In this present study predictor variables are- insulation thickness of the side walls(TW), area of the side walls(AW), and the insulation thickness of the roof(TR). After graphical analysis critical values of the predictor variables have been identified for minimum heat transfer from the outside ambience to the inside of the cold room.

II. Methodology

D.O.E [6] techniques enable designers to determine simultaneously the individual and interactive effects of many control factors that could affect the output parameter. Simply put, DOE helps to pin point the sensitive parts and sensitive areas in designs that cause problems in Yield. It helps turn any design into robust one.

There are several D.O.E are available like factorial design, response surface methodology (RSM), Taguchi orthogonal array. The advantage of Taguchi methodology over other design of experiments is that it requires less number of test runs than the other methods. Thus saves the time and resource for data handling. This method uses a special set of arrays called orthogonal array. While there are many standard orthogonal arrays available, each of arrays is meant for a specific number of independent control variables and levels.

III. Theoretical Model development

Three control parameters, viz. insulation thickness of the side walls (TW), area of the walls (AW), insulation thickness of the roof (TR) taken as predictor variables and heat flow(Q) from outside to inside of the cold room taken as response variable.

The insulating material taken as PUF (Polly urethane foam) Panel for analysis. The available Panel Thicknesses are [7]- 40mm, 50mm, 60mm, 80mm, 100mm, 150mm, 200mm.out of the available insulation thicknesses only three values are taken for analysis. The cold storage building taken for the study is Penguin Cold Storage situated in the region of Khed Shivapur of Pune city. The overall dimensions of cold storage plant are 17m x 22m x 12m [6]. It consist four cold chambers. They are called cold rooms. The dimension of the cold rooms are 8m x 5m. The height of the cold chamber is 4m. Only one chamber is considered for this study. The levels of the AW are obtained by only varying the height of the chamber. TABLE 1 shows the control parameters and their levels.

Table 1 control parameters and their levels

Notation	Factors	Unit	Levels		
			1	2	3
TW	Insulation thickness of the side wall	m	0.100	0.150	0.200
AW	Area of the side wall	m^2	78	104	130
TR	Insulation thickness of the roof	m	0.080	0.100	0.150

The following equation is used for calculating the values Q:

$$Q=\frac{k\times A\times TD}{X} \quad (1)$$

Where,

K= thermal conductivity of insulating material =.023 W/mk

A= area

TD= temperature difference.

X= insulation thickness.

The temperature inside the cold room is taken as 2°C and assume that it is constant throughout the cold room. With the help of equation(1) Q values are computed.

Multiple regression analysis has been used to set up the relationship between the predictor variables and the response variable. The proposed model analyses the influence of predictor variables on response variable. The general polynomial regression equation can be expressed as-

$$Y=\beta_0+\sum_{i=1}^{m}\beta_i X_i+\sum_{i=1}^{m}\beta_{ii}X_i^2+\sum_{\substack{i,j=1\\ j>1}}^{m}\beta_{ij}X_iX_j+\varepsilon \quad (2)$$

Where Y= response variable, X=predictor variables, m= number of variables, β=regression coefficients, and ε= error.

In this present work, response variable is Q, & the predictor variables are TW (insulation thickness of the side walls), AW (area of the side walls), & TR (insulation thickness of the side walls). So that m=3. After expanding the equation no (2) the general form of the polynomial equation becomes-

$$Q= \beta_0+ \beta_1(TW)+ \beta_2(AW)+ \beta_3(TR)+ \beta_4(TW^2)+ \beta_5(AW^2)+ \beta_6(TR^2)+ \beta_7(TW*AW)+ \beta_8(TW*TR) + \beta_9(AW*TR) \quad (3)$$

To establish the prediction model, a software package MiniTab has used to determine the regression coefficients.

The present work is a three factor three level problem, the available Taguchi orthogonal array is L_9 & L_{27}.In order to determine which one is suitable, degrees of freedom (D.O.F) in both cases have to be determined. D.O.F tells about the minimum number of test runs required for a particular problem. The following formula is used to determined D.O.F-

D.O.F=m(l-1)+n(l-1)(l-1)+1 [8] (4)

Where m= number of variables, l= number of levels, n=number of interaction terms. From equation (3) it can be seen that number of interaction terms n=3(TW*AW, TW*TR, AW*TR). So m=3, l=3, n=3. After putting these values in equation (4) D.O.F becomes=19. So the minimum number of test runs required for this problem is 19. But L_9 orthogonal array only provides 9 test runs, which is less than 19. So the appropriate orthogonal array is L_{27} which provides 27 test runs. The following table shows L_{27} OA with the response variable. The values of response variable calculated by using equation (1)

Table 2 Observation table

Obs No-	TW	AW	TR	Q
1	0.1	78	0.08	706.56
2	0.1	78	0.1	651.36
3	0.1	78	0.15	577.76
4	0.1	104	0.08	850.08
5	0.1	104	0.1	794.88
6	0.1	104	0.15	721.28
7	0.1	130	0.08	993.6
8	0.1	130	0.1	938.4
9	0.1	130	0.15	864.8
10	0.15	78	0.08	563.04
11	0.15	78	0.1	507.84
12	0.15	78	0.15	434.24
13	0.15	104	0.08	658.72
14	0.15	104	0.1	603.52
15	0.15	104	0.15	529.92
16	0.15	130	0.08	754.4
17	0.15	130	0.1	699.2
18	0.15	130	0.15	625.6
19	0.2	78	0.08	491.28
20	0.2	78	0.1	436.08
21	0.2	78	0.15	362.48
22	0.2	104	0.08	563.04
23	0.2	104	0.1	507.84
24	0.2	104	0.15	434.24
25	0.2	130	0.08	634.8
26	0.2	130	0.1	579.6
27	0.2	130	0.15	506

IV. Result and Discussion

By using statistical software package MiniTab and with the help of Table 2 the proposed multiple regression equation becomes-

Q = 1043 - 5741 TW + 8.13 AW - 6072 TR + 19136 TW*TW - 0.00000 AW*AW + 18400 TR*TR - 27.6 TW*AW – 0.00 TW*TR - 0.00 AW*TR (5)

It represents the relationship between the response variable and predictor variables involving the linear, quadric, and interaction terms. On the basis of the above proposed equation a computer program has been generated. With the help of the computer program various data sets have been generated. These data sets depict the variation of the response variable with the proctor variables. These data sets also used for graphical interpretation. The following Table shows one of the data stes generated by the computer program-

Table 3 variation of Q with TW

TW	Q
0.1	795.54
0.105	772.0974
0.11	749.6116
0.115	728.0826
0.12	707.5104
0.125	687.895
0.13	669.2364
0.135	651.5346
0.14	634.7896
0.145	619.0014
0.15	604.17
0.155	590.2954
0.16	577.3776
0.165	565.4166
0.17	554.4124
0.175	544.365
0.18	535.2744
0.185	527.1406
0.19	519.9636
0.195	513.7434
0.2	508.48

With the help of the above data set the variation of Q with TW can be represented as-

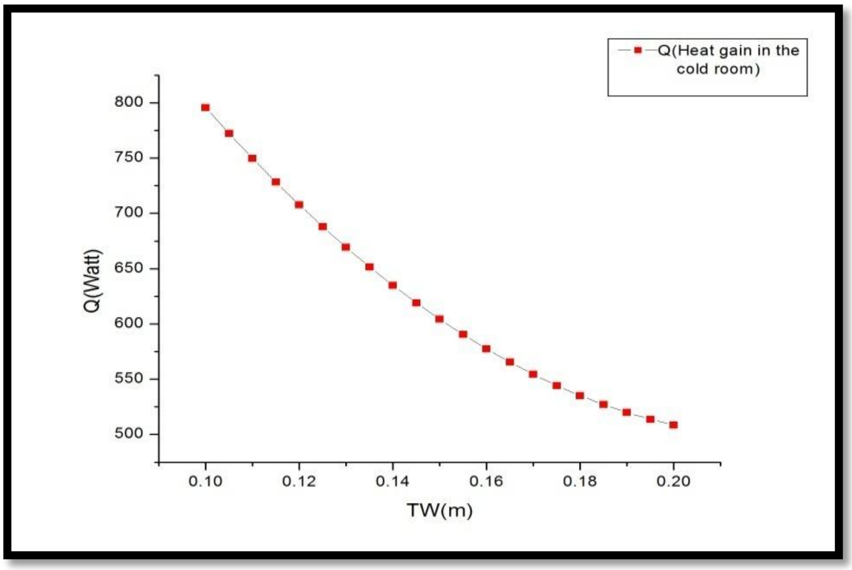

Fig 1 variation of insulation thickness of the side walls (TW) with heat gain (Q) in the cold room
From the

Fig 1 it can be seen that for TW=.200m the heat gain in the cold room (Q) becomes minimum. Similarly the variation of AW with Q can be represented as-

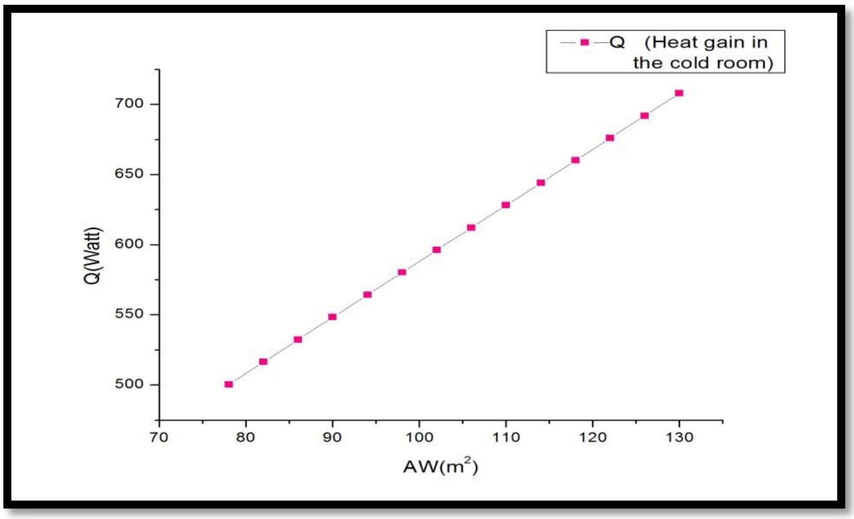

Fig 2 variation of area of the side walls (AW) with heat gain (Q) in the cold room

From Fig 2 it can be seen that for AW=78m^2 the heat in the cold room (Q) will be minimum. And the variation of TR with Q can be represented as-

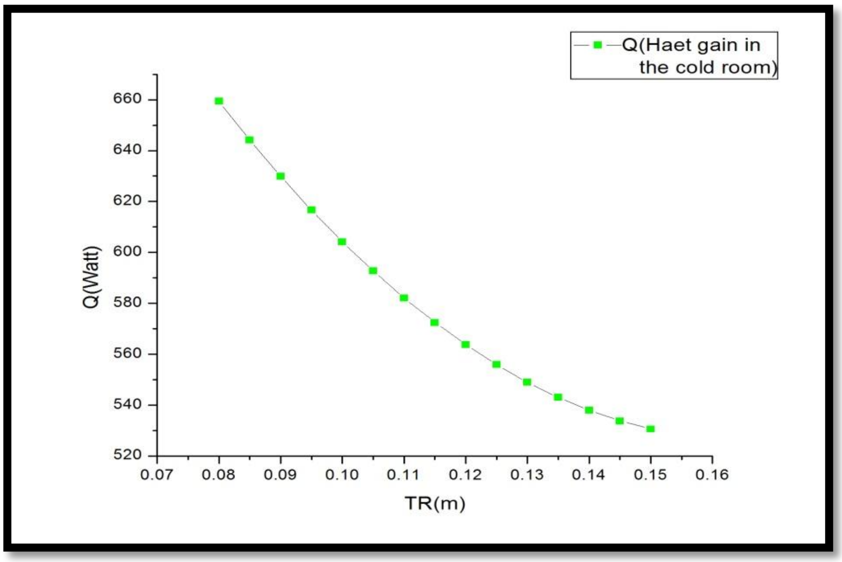

Fig 2 variation of insulation thickness of the roof (TR) with heat gain (Q) in the cold room

From Fig 2 it can be seen that for the value of TR=.150m the heat transfer will be minimum.

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-

- From the graphical analysis the optimal settings of the cold storage are insulation thickness of the side wall (TW) -.200m; area of the side wall (AW)-78m^2 and insulation thickness of the roof (TR)-.150m. This optimality has been proposed out of the range of [TW (.100, .150, .200), AW (78,104,130), TR (.080, .100, .150)].
- For TW=TW_3, AW=AW_1,TR=TR_3 the heat flow into the cold room (Q) will be minimum.
- L_{27} orthogonal array has been used as design of experiments. The findings obtained from the graphical analysis are in close agreement with the other research work[9].

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