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Optimization of Different Control Parameters of a Cold Storage using Taguchi Methodology

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Abstract

In this project work design of experiments have been used to optimize various control factors of a cold storage so as the heat gain in the cold room or in the other words the heat flow from the outside ambience to the inside of the cold room will be minimum. Taguchi orthogonal array have been used as a design of experiments. Three control factors with three levels of each have been chosen for analysis. The control factors are insulation thickness of the side walls (TW), area of the side walls (AW), and insulation thickness of the roof (TR). Different amount of heat gains in the cold room for different set of test runs have been taken as the output parameter. The objective of this work is to find out the optimum setting of the control factors or design parameters so as the heat gain in the cold room will be minimum**.** The Taguchi S/N ratio analysis have used as an optimization technique. Smaller the better type S/N ratio have used for calculating the optimum level of control parameters, because it is a minimization problem. Analysis of variance ANOVA was also performed on the test results to find out the significant control factors. After analysis the results showed that the insulation thickness of the side walls (TW) is the most significant control factor followed by the area of the wall (AW). Insulation thickness of the roof (TR) is not statistically significant.

Key words: Design of Experiment (D.O.E); S/N ratio; ANOVA; Insulation thickness of the side walls and the roof; area of the side walls.

1. 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 $L_{27}(9^3)$ 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. Dr.M.Chourasia (2009) [4] deals with different aspects cold storage design to improve its performance. He studied air flow pattern inside the cold room. Some researchers [5] also proposed some mathematical model of heat gain in the cold room. By studying those models one can get the idea about optimum values of the various control factors.

D.O.E [5] 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. A D.O.E technique not only save the time but also saves the money for conducting the experiments.

There are several D.O.E methods available like factorial design, response surface methodology (RSM), Taguchi methodology. Taguchi method[6] is based on performing evaluation or experiments to test the sensitivity of a set of response variables to a set of control parameters (or independent variables) by considering experiments in "orthogonal array" with an aim to attain the optimum setting of the control parameters. It was developed Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan. Orthogonal arrays provide a best set of well balanced (minimum) experiments. As the name suggest, the columns of this array are mutually orthogonal. Here, orthogonality [7] is interpreted in the combination based sense i.e. for any pair of columns; all combinations of factor levels would occur and appear in the design matrix an equal number of times. This is called the balancing property and it implies orthogonality. 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.

In this present study Taguchi L_9 orthogonal array [8] has been used as design of experiments (D.O.E) method. Taguchi S/N ratio employed as an optimization tool to determine the best combination of control parameters such as insulation thickness of the side walls(TW), area of the side walls(AW),insulation thickness of the roof(TR) to attain minimum heat gain(Q) in the cold room. ANOVA has been employed and compared with Taguchi method. By analysis of variance (ANOVA) mostly influential input parameters have been identified.

The purpose of analysis of variance is to determine the relative effect of each factor and to indentify the factors significantly affecting the response under consideration.

2. 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 control parameters and heat flow(Q) from outside to inside of the cold room taken as output variable. Three levels of each control factor are chosen for analysis. It is a three level three factor problem; the appropriate Taguchi orthogonal array (OA) for this problem is L_9. The number 9 indicates only nine test runs have to be conducted. Taguchi orthogonal arrays are specially designed matrix which obeys the orthogonal property among the various combinations. Here orthogonal property means that each combination will appear in the design matrix equally. The selection of the appropriate design matrix depends on number of control factors and their respective levels. According to this problem available design matrix are L_9 & L_{27}. In order to avoid large computation difficulties L_9 OA has been chosen.

Insulating material taken as PUF (Polly urethane foam) Panel for analysis. The available Panel Thicknesses are [9]- 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 India. The overall dimensions of cold storage plant are 17m x 22m x 12m [9]. It consist four cold chambers. They are called cold rooms. The dimension of the cold rooms is 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=(K*A*TD)/x[10] (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℃ and assumed that it is constant throughout the cold room. With the help of equation (1) Q values are computed. In the above equation only fixed quantity is the thermal conductivity of the insulating material. But thermal conductivity changes with temperature. But in this analysis temperature of the cold room is assumed to be constant. The average cold room temperature has been taken as 2℃ and the outside ambient temperature has been taken as 26℃. Therefore the temperature difference value becomes 24℃ which is kept constant during entire analysis. Only area value of the room & insulation thickness varied during analysis. In this way heat transfer values are calculated.

Table 2 shows the L_9 OA combinations among various control factors.

Table 2 L_9 orthogonal array combinational table

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	TW	AW	TR	Q
1	0.100	78	0.080	706.56
2	0.100	104	0.100	794.88
3	0.100	130	0.150	864.80
4	0.150	78	0.100	507.84
5	0.150	104	0.150	529.92
6	0.150	130	0.080	754.40
7	0.200	78	0.150	362.48
8	0.200	104	0.080	563.04
9	0.200	130	0.100	579.60

To find out best set of combinations of control variables to attain the minimum heat gain (Q) in the cold room, Taguchi S/N ratio has been used. ‘Smaller-the-better’ type S/N ratio has been chosen for the analysis. MINITAB 15software has been used for data analysis.

2.1 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. This is a minimization problem so smaller-the-better S/N ratio has been chosen.

2.2 Smaller-the-better

This is expressed as- (S/N)= ─10Log10 (mean of sum of squares of measured data).
This is usually the chosen S/N ratio for all the undesirable characteristics like "defects" for which the ideal value is zero. When an ideal value is finite and its maximum or minimum value is defined (like the maximum purity is 100% or the maximum temperature is 92 K or the minimum time for making a telephone connection is 1 sec) then the difference between the measured data and the ideal value is expected to be as small as possible. Thus, the generic form of S/N ratio becomes-

(S/N)= ─ 10Log10 {mean of sum of squares of (measured-ideal) data}

3. Result and discussion

TABLE 4 shows S/N ratios for each test run.

Table 4 (S/N) ratio table smaller the better type

Test Runs	TW	AW	TR	Q	S/N ratio
1	0.100	78	0.080	706.56	-57.1105
2	0.100	104	0.100	794.88	-58.1289
3	0.100	130	0.150	864.80	-58.4879
4	0.150	78	0.100	507.84	-53.8641
5	0.150	104	0.150	529.92	-54.6117
6	0.150	130	0.080	754.40	-57.6749
7	0.200	78	0.150	362.48	-51.3086
8	0.200	104	0.080	563.04	-54.7604
9	0.200	130	0.100	579.60	-55.3901

3.1Analysis of the S/N ratio

Table 5 shows average Signal to Noise ratios of smaller the better type for different control factor levels.

Table 5 Average S/N ratios of each control factor levels

Level	Control Factors		
	TW	AW	TR
1	-57.91	-54.09	-56.52
2	-55.38	-55.83	-55.79
3	-53.82	-57.18	-54.8
Delta	4.09	3.09	1.71
Rank	1	2	3

Here Delta means the absolute difference between maximum S/N and minimum S/N ratio. Rank denotes the relative significance of each control factor. Based on Taguchi methodology greater S/N ratio value is always considered. Bigger the difference of values more will be the significance or give more effect.

TABLE 5 shows that insulation thickness of the side walls (TW) is the most significant control parameter as the delta value is highest about 4.09, followed by AW about 3.09 and TR about 1.71.

Fig 1 shows the main effect plot for S/N ratio for heat gain in the cold room (Q)

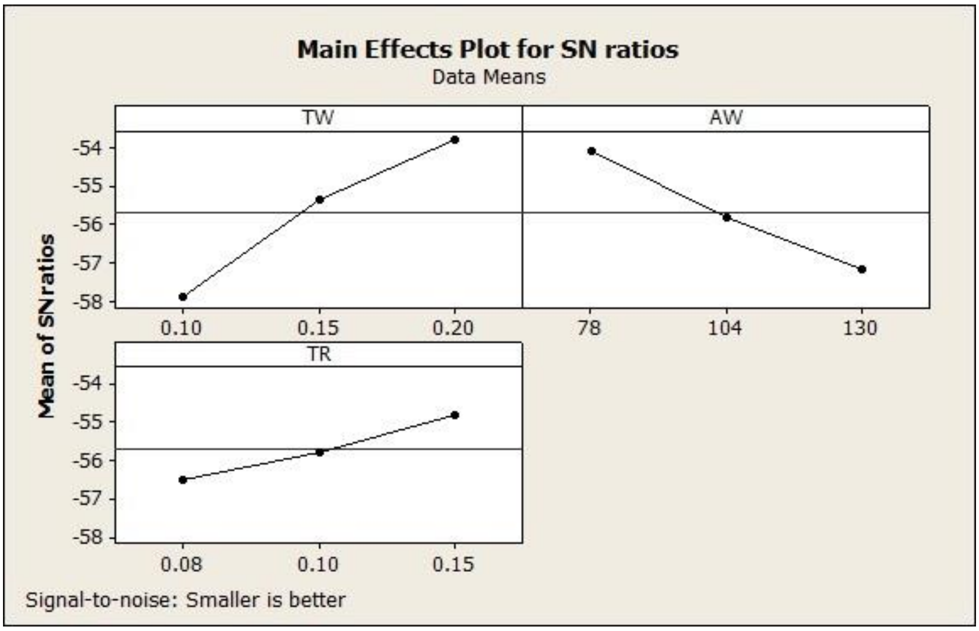

Fig 1 Main effect plots for S/N ratios of control factors on heat gain (Q) in the cold room

In this figure abscissa is the level values of the three control parameters & ordinate represents the mean value of the S/N ratios. It is clear from the Fig 1 that for the value of TW=.200m the S/N ratio is maximum. Since the S/N ratio is a monotonic decreasing function the maximum value of S/N ratio is desired. Hence the optimum level for a factor is the level that gives the highest value of S/N ratio. From Fig 1 it is observed the optimum settings of the control factors are TW_3, AW_1, TR_3.

3.2 Analysis of variance

The tests run data in TABLE 3 were again analyzed using ANOVA at 95% confidence level (α=.05) for identifying the significant factors and their relative contribution on the output variable.
TABLE 6 shows ANOVA for the output variable Q.

Table 6 ANOVA result for Q (at 95% confidence level)

Source	Notation	Degrees of freedom	Sum of squares	Mean squares	F ratio	% contribution
Insulation thickness of the wall (m)	TW	2	128165	64083	48	62
Area of the side wall (m)	AW	2	64464	32232	24.14	31
Insulation thickness of the roof (m)	TR	2	11879	5939	4.45	6
Error		2	2670	1335		1
Total		8	207178			100

The ANOVA table shows F-test values of each source. The last column of TABLE 5 shows the percent contribution of significant source to the total variation indicating the degree of influence on the result. The F test values for the control factor TW is 48, for AW it is 24.14 & for TR it is 4.45. In statistical analysis of Taguchi method higher the F test value gives more significant effect on the output for a given degrees of freedom. So from TABLE 6 it is clear that TW has the highest influence followed by AW & TR. The percentage contribution of the control variables influencing the heat gain (Q) in the cold room are insulation thickness of the side walls (TW) 62%, area of the side walls (AW) 31% and insulation thickness of the side walls (TR) 6%.

Conclusion

The present study discusses about the application of Taguchi method and ANOVA to investigate the effect of control parameters on heat gain (Q) in the cold room. From the analysis of the results obtained following conclusion can be drawn-

- From the Taguchi S/N ratio graph analysis the optimal settings of the cold storage are insulation thickness of the side wall (TW) -.200m; area of the side wall (AW)-78m2 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)].
- ANOVA indicates that TW is the most influencing control factor on Q and it is near about 62%.
- L_9 orthogonal array has been used as design of experiments. The findings obtained from the S/N ratio analysis and ANOVA are in close agreement. Both have identified insulation thickness of the side walls (TW) is the most significant control parameter followed by area of the side walls (AW), and insulation thickness of the roof (TR).

References

[1] M.S.Soylemez, M.Unsal(1997), “Optimum Insulation Thickness for Refrigerant applications”, Energy Conservation and Management, 40(1999) 13-21.

[2] N.Yusoff and M.Ramasamy(2010), “Selection of RGP Optimization variables using Taguchi Method”, Journal of Applied Science 10(24) 3313-3318,2010 ISSN 1812-5654

[3] 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.

[4] Chourasia, Goswami, “Efficient design, operation, maintenance and management of cold storage” (e Journal of Biological Sciences), Volume: 1, Issue 1 (December 2009) ISSN: 2076-9946

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

[6]D. C. Montgomery, “Design and analysis of experiments”(3rd edition, John wiley and sons, 1991)

[7] Module 5 Design for Reliability and Quality - nptel, IIT Bombey

[8] M. S. Phadke, “Quality engineering using robust design” (2nd edition, Pearson, 2009).

[9] Ashish S. Utage, K. V. Mali, a. D. Kadam, Performance Simulation of cold storage using energyplus, International Journal of Engineering Science and Technology, Vol. 5 No.02, February 2013 ISSN : 0975-5462

[10] Holman, J. P,. “Heat Transfer”, (4th reprint, Tata McGraw–Hill Publishing Company, New Delhi, 2002).