International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-5, January 2020

Optimization of Heat Gain by Air Exchange through the Cold Storage Window

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Abstract*: *Energy is the one which is playing a vital role in today's lives. In cold storage, if most of the heat is captivated by the evaporator inside the cold room due to convection, condensation and due to air exchange through the windows, more quantity of energy will be needed to maintain the desired temperature range inside the evaporator space. In this paper, author tried to optimize the heat gain by the air exchange through the windows of cold storage in the evaporator space using the Taguchi S-N ratio analysis. Temperature difference, Height of cold store window and Relative Humidity are the primary variables taken for optimization of heat transfer and for each parameter three ranges are chosen for the model development. Graphical elucidations justify the model proposed with the Taguchi S-N ratio analysis. The study shows that the model is good for cold storage application saving the heat energy.

Keywords* : *Optimization, Taguchi analysis, Cold storage, Air exchange.

I. INTRODUCTION

India is an agro-based country that produces lots of different types of agro-based products, but these products have less span life, which restricts its availability throughout the year. Here the cold storages play a vital role that helps us to increase the availability period of the agro products as well as marine products. The cold storage amenities are one of the prime infrastructural requirements which play a keen role in availability of a product throughout a year. Besides stabilizing market prices and demand distribution, the cold storage industry provides other benefits like an excellent return to the farmers and products at cheaper rate to the consumer. One of the most critical issues faced by the world is energy depletion. With the increase in electric cost, the cold storage operation cost is rising which further increases the rate of goods. Conventionally, the refrigerant absorbs the maximum heat to maintain uniform cooling throughout the evaporator space. If it is not so, then the quality of stored products, as well as the enactment of the plant, diminishes. The heat can infiltrate the cold storage through doors and windows. Fresh air charge is required for the commodities kept in the cold storage, but whenever this fresh air enters the cold store room it increases the temperature of the cold storage room, which creates a load on the cooling device and extra consumption of energy takes place.

The authors worked on increasing the cooling performance of different thermal systems [1-3]. They used various modes of cooling and also used nanoparticles to enhance the performance of systems. Some authors used twisted inserts to enhance the heat transfer behavior of the heat exchangers [4-5]. The use of nanoparticles and twisted inserts increase the cost, so optimization is needed. Therefore, designing and optimization are required by using different techniques like RSM, Taguchi method, ANOVA method, to improve the heat transfer performance [6-13]. Bhattad et al. [14-16] performed review on the performance enhancement of refrigeration systems and conducted some theoretical analysis on food processing units. Theoretical analysis has been carried out by Mukhopadhyay and Debnath [17]; and Mukhopadhyay and Mondal [18] to optimize the heat transfer through cold storage by Taguchi S/N ratio and regression analysis.

Few studies have been reported on the performance augmentation of cold storage. Hence, in present paper, author attempted to propose a modified model to optimize heat transfer in the cold storage due to access through windows by Taguchi L9 array method. Relative humidity (RH), temperature difference (dT) and height of cold storage window (H) are the underlying variables considered for the analysis and three ranges have been considered for each of them during the model development. Model is justified with the graphical representation.

II. MATHEMATICAL MODELLING

A. Methodology

In present work, heat transfer through the evaporator space and due to infiltration through windows were considered. The heat transfer rate is calculated in terms of relative humidity (RH), temperature difference (dT) and cold storage window height (H).

Manuscript published on January 30, 2020.
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The heat transfer mainly takes due to convection. Inside the cold storage there are many numbers of windows. Eight number of windows have been considered. With the help of Taguchi array, the design matrix has been developed. The expression of total heat transfer rate/ Rate of heat absorbed into refrigerant (QT) is given below as:

$Q_T = Q_{conv} + Q_{cond}$ (1)

Q_T = Rate of heat absorbed into refrigerant (in W)

Heat transfer rate due to convection mode is given by,

$Q_{conv} = A.h_c.dT$ (2)

hc = Convective heat transfer coefficient (in $W/m^2.K$)

= Nu.L/k

Where, Nu = Nusselt number

L = Length (in m)

k = Thermal conductivity (in W/m.K)

A = Area of evaporator (in m^2)

Q_{conv} = Convective heat transfer rate (in W)

Heat transfer rate due to conduction mode includes relative humidity and latenet heat, and is given by,

$Q_{cond} = A.h_m.RH.h_{fg}$ (3)

Where Q_{cond} = Condensation heat transfer (in W)

RH= Relative humidity (%).

Then the final equation of heat transfer is given by:

$Q_T = (0.322.H.dT) + (352.39.RH)$ (4)

Where, H= Height of the window (in m)

dT= Temperature difference (in °C)

B. Taguchi Analysis

The Taguchi method has been used as an optimizing tool. Different controlling parameters and their levels are given in Table I and various combinations of controlling parameters have been mentioned in Table II. Here 1, 2 and 3 represent the level of control factors.

Table- I: Control parameters with respective levels

Factors	Levels of experimental data		
	1	*2*	*3*
Height of window H, m	1	1.25	1.5
Temperature difference dT, °C	2	4	6
Relative humidity RH, %	85	90	95

Table- II: Combinations of controlling parameters

Test Runs	*H*	*dT*	*RH*
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

C. Signal-to-noise ratio (S/N RATIO)

Taguchi method applies the loss function for measuring the deviation in the performance characteristic, which is further converted to S/N ratio. Generally, there three classes of the S/N ratio analysis are in use, the lower-the-better, the nominal-the better and the higher-the-better. The higher S/N ratio means a better heat transfer rate for efficient cooling effect. Hence, the optimal process parameter level corresponds to the level of the highest S/N ratio. S/N ratio was determined to see the impact of the control variables (shown in Table III). S/N ratio for maximum heat transfer is calculated by,

$S_i = -10 \log[\Sigma(1/(Q_i)^2)/n]$ (5)

Where n= Number of trials

Q_i= Calculated value in the test run.

i = Trial number

S_i = S/N ratio for respective result

The overall mean is calculated as follows: -

$H_{11}= (S_1+S_2+S_3)/3 = 50.04$, $H_{21}= (S_4+S_5+S_6)/3 = 50.05$ and $H_{31}= (S_7+S_8+S_9)/3 = 50.06$;

$dT_{12}= (S_1+S_4+S_7)/3 = 50.03$, $dT_{22}= (S_2+ S_5+ S_8)/3 =50.05$ and $dT_{32}= (S_3+ S_6+ S_9)/3 = 50.06$;

$RH_{13}= (S_1+S_6+S_8)/3 = 50.03$, $RH_{23}= (S_2+S_4+S_9)/3 = 50.06$ and $RH_{33}= (S_3+S_5+S_7)/3 = 50.22$

Using the following data, we determined the overall mean of S/N ratio through Eq. 6 and its data is given in Table IV.

$$\text{Overall Mean} = \frac{1}{9}\left(\sum_{i=1}^{9} mean\right) = 318.761 \quad (6)$$

$$\text{Sum of squares (SOS)} = \sum_{i=1}^{9}(mean(i) - mean)^2 = 1850.268 \quad (7)$$

$$(SOS)_H = 3\sum_{i=1}^{3}(\Delta mean(H_i))^2 = 3\sum_{i=1}^{3}(mean(H_i) - mean(\min))^2 \quad (8)$$

Likewise, $(SOS)_{dT}$ and $(SOS)_{RH}$ can be calculated.

Hence, percentage change in different parameters are discussed below. Percentage change in the Window Height is calculated as,

$\%CH=100*((SOS)_H/(SOS)_T) = 0.033.$

Where, $(SOS)_T = (SOS)_{dT} +(SOS)_H +(SOS)_R$

Similarly, percentage change in Temperature Difference and Relative Humidity are given as

%CdT=100*((SOS)$_{dT}$/(SOS)$_{T}$) = 0.210 and

%CRH=100*((SOS)$_{RH}$/(SOS)$_{T}$) = 99.753, respectively.

III. RESULTS AND DISCUSSION

Figs. 1-3 shows the variation of different parameters with mean of S/N ratio. Larger the better criteria have been used for increasing the heat transfer rate through evaporator.

Table- III: S/N ratio data

Exp. No.	Parameter						Heat transfer rate	S/N ratio
	Combination of control parameters			Control parameters				
	H	dT	RH	H	dT	RH		
1	1	1	1	1	2	0.85	300.175	49.54
2	1	2	2	1	4	0.90	318.448	50.06
3	1	3	3	1	6	0.95	336.702	50.54
4	2	1	2	1.25	2	0.90	317.956	50.04
5	2	2	3	1.25	4	0.95	336.380	50.53
6	2	3	1	1.25	6	0.85	301.946	49.59
7	3	1	3	1.5	2	0.95	335.756	50.51
8	3	2	1	1.5	4	0.85	301.463	49.58
9	3	3	2	1.5	6	0.90	320.049	50.10

Table- IV: Overall mean of S/N ratio

Level	H	dT	RH	Overall mean of S/N
Low	50.04	50.03	49.57	50.04
Medium	50.05	50.05	50.06	
High	50.06	50.07	50.52	
Delta = Large - Small	0.02	0.04	0.95	
Rank	3	2	1	

In Fig 1, variation of window height with Mean of S/N has been shown. The height of the window is varied from 1m to 1.5m. It can be seen that proposed analytical model is in good agreement with existing theoretical model.

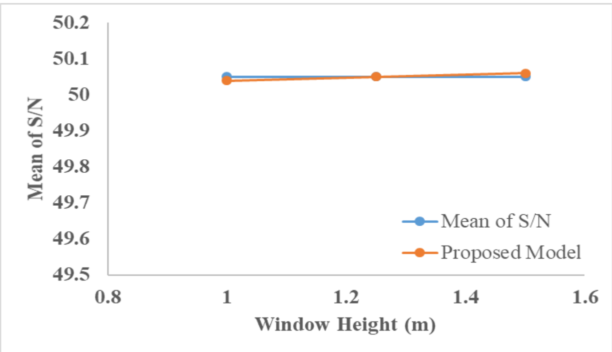

Fig. 1: Window height Vs. Mean of S/N

In Fig 2, the variation of temperature difference with the Mean of S/N is shown. Here temperature difference in cold storage is varied from 2°C to 4°C. It can be seen that proposed analytical model is in good agreement with existing theoretical model. Similarly, the variation of relative humidity with the mean S/N ratio is shown by Fig 3. Very small deviation has been observed between existing and proposed model using Taguchi approach. It has been observed that for the Taguchi approach (Signal to Noise ratio), Larger is better method is most suitable.

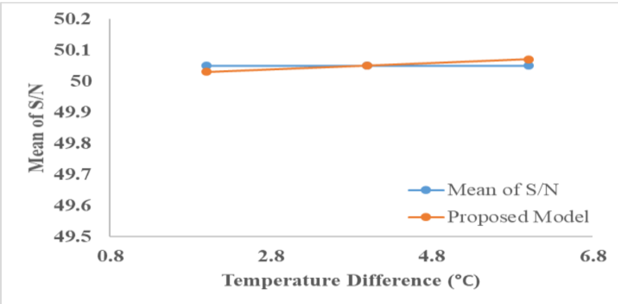

Fig. 2: Temperature difference Vs. Mean of S/N

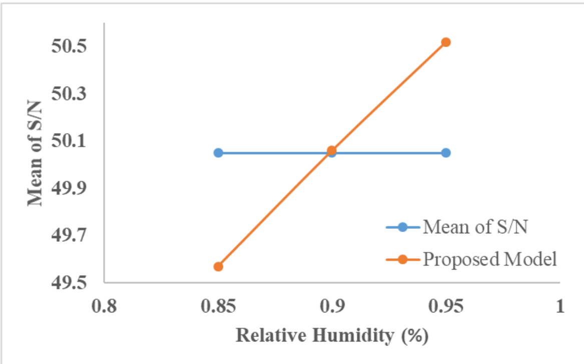

Fig. 3: Relative humidity Vs. Mean of S/N

IV. CONCLUSIONS

In the present work, the Taguchi method has been applied for designing the experiments to optimize the controlling factors to augment the heat transfer rate of evaporating space.

From the obtained results, the conclusions drawn are as follows-

1) From the analysis, the optimal values of the height of window (H) is 1.5m, change in temperature is 2°C, and relative humidity is 0.95. So, an increase in window height is the most important factor.

2) Analysis indicates the Height of the Window (H) is the most effective factor for controlling Q contributing around 97.78%. Relative Humidity (RH) with 2.1% contribution.
3) The results identified that the Height of the Window (H) is the most influencing controlling parameter trailed by other two factors (RH and dT).
4) The model saves the heat energy and is suitable for modeling heat transfer in cold storage application.

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