A Study on Expansion Process of a Cold Storage using ANOVA & S/N Ratio Analysis

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Abstract

In this paper we have done a theoretical experimentation on expansion process of a cold storage, which operates on vapour compression refrigeration system and then obtained results are compared using S/N Ratio and ANOVA analysis. We have chosen three control parameters as Inlet Temperature of expansion process (T1), Outlet Temperature of expansion Process (T2) and Pressure ratio (Pr) of expansion process for the theoretical experiment and change in entropy (ΔS) is taken as the response variable of the experiment. Main objective of this study is to show how change in entropy (ΔS) in expansion process in a refrigeration system of a cold storage by several control parameters

Index Terms— *ANOVA, Change in Entropy (ΔS), Cold Storage, S/N Ratio*

I. INTRODUCTION

Now-a-days cold storage is widely used for preserving food commodities so that food can be supplied throughout the year. It is also used to preventing fruits & vegetables from perishing and for this; we have to maintain proper environment & temperature inside the cold storage. Cold Storage is prime infrastructural component for preserving food commodities. It stabilizes the market price by distributing food commodities both on demand and time basis need. A theoretical study on expansion process of a cold storage is being reported in this paper in order to optimize the performance of a cold storage.

At the other end, energy crisis become a headache now-a-days to us. A cold storage requires bulk amount of electrical energy to operate its refrigeration system. As the demand of cold storage is increasing day by day so the demand of energy is also increased rapidly. So it is very necessary to make cold storage energy efficient so that energy consumption of the cold storage can be reduced.

In expansion process of a vapour compression refrigeration system, high pressure refrigerant is expanded to low pressure. It is an isenthalpic process in which enthalpies of the refrigerant before and after the process remain same i.e. there is no change in enthalpy ($\Delta h=0$).

In this project, we have proposed a mathematical model of change in entropy (ΔS) considering three control parameters i.e.- Inlet & Outlet temperature of expansion process (T1 & T2) and Pressure ratio of the expansion process(Pr) by using Taguchi L9 orthogonal Array. Results obtained from the experimentation then analyzed by S/N Ratio & ANOVA Analysis.

II. MODEL DEVELOPMENT

In this study, we assumed that working fluid of the refrigeration system or refrigerant acts like an ideal gas. Then as we know that change in entropy(ΔS) of an ideal gas during expansion process is given by –

$$\Delta S = C_p \log\left(\frac{T2}{T1}\right) - R_c \log(Pr) \quad [1]$$

where, ΔS= Change in Entropy in KJ/Kg-K; T1= Inlet Temperature of Expansion process in K; T2= Outlet temperature of Expansion Process in K; Pr= Pressure Ratio of Expansion Process; C_P= Specific heat at constant pressure in KJ/Kg-K; R_C= Characteristic Gas constant in KJ/Kg-K = (R/n); where R= Universal gas constant in KJ/mol-K & n= Molar mass in Kg/mol; Pr= Pressure ratio of expansion process = (P2/P1); where, P1= Pressure of refrigerant entering into the expansion process in N/m^2 & P2= Pressure of refrigerant leaving from the expansion process in N/m^2.

We constructed our design matrix of theoretical experimentation with the help of Taguchi L9 orthogonal array methodology in which change in entropy (ΔS) in our response variable and Inlet & Outlet Temperature (T1 & T2) and Pressure Ratio(Pr) are three predictor variables.

Generally, orthogonal arrays (OA) are used to obtain well balanced minimum sets of experiments. In this theoretical study, we used full set design matrix of Taguchi L9 orthogonal arrays(OA) for the experimentation.

III. CONTROL FACTORS & RANGES

Table-I: Three Control factors and ranges or level are shown in below table-

Three control factors with three different level i.e. LOW, MEDIUM & HIGH are taken as shown in above table to carry out the experiment in Taguchi L9 Orthogonal Array design matrix of experiment.

IV. THEORETICAL EXPERIMENTATION

For the experiment, design matrix of experiment of Taguchi L9 Orthogonal Arrays was used-

Table-II: L9 Orthogonal Array (OA) combination table-

EXPERIMENT 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

CONTROL FACTORS	LEVEL		
	LOW(1)	MEDIUM(2)	HIGH(3)
Inlet Temperature(T1) in 'K'	301	303	305
Outlet Temperature(T2) in 'K'	255	257	259
Pressure Ratio(Pr)	0.18	0.19	0.20

We used above L9 Orthogonal Array (OA) table for theoretical experiment and we got following result table-

Table-III: Theoretical Experimentation table-

EXP. NO	CONTROL FACTORS			RESPONSE (ΔS) (KJ/Kg-K)
	Inlet Temp.(T1) (K)	Outlet Temp.(T2) (K)	Pressure Ratio(Pr)	
1	301	255	0.18	0.21549
2	301	257	0.19	0.21100
3	301	259	0.20	0.20705
4	303	255	0.19	0.19811
5	303	257	0.20	0.19421
6	303	259	0.18	0.22347
7	305	255	0.20	0.18136
8	305	257	0.18	0.21068
9	305	259	0.19	0.20614

In this experiment, values of control parameters or factors i.e.- T1,T2 & Pr were taken from SRIRAM COLD STORAGE, Jalpaiguri, West Bengal- 735102 and corresponding ΔS was calculated at combination of different level of control factors as per L9 Orthogonal Array Table from the equation –

$\Delta S = C_p \log\left(\frac{T2}{T1}\right) - R_c \log(Pr)$ where, R_C= Characteristic gas constant of Ammonia= 0.4882 KJ/Kg-K & C_P= Specific heat at constant pressure of Ammonia= 2.056 KJ/Kg-K.

V. S/N RATIO ANALYSIS

The signal to noise (S/N) ratio generally helps to predict the optimum results and also help in data analysis. Signal to noise ratios are log functions of desired output and it serve as the objective function for optimization.

There are three types of signal to noise ratios-

a. Nominal the Better
b. Larger the better
c. Smaller the better

In this project we used smaller the better because as we know that TdS= dQ so in order to maximize the expansion process, we have to minimize the change in entropy (*ΔS or dS)*. If we can minimize the change in entropy(ΔS) then heat transfer (dQ) will be minimum thus we can optimize the expansion process.

The equation for calculating S/N Ratio smaller the better for change in entropy(ΔS) is given by –

$SNi = -10\times\log10(\sum Y_i^2/n)$

Where, Y_i= Result or experimental value of the test run or row .

i= Trial or experiment no.

n= no of trials or experiments done in a test or row. In our case, we have taken the value of n=1.

SNi= S/N Ratio for respective result.

CALCULATION OF S/N RATIO-

For Experiment No.-1

$SN1= -10\times\log10(0.21549^2/1) = 13.331$

For Experiment No.-2

$SN2= -10\times\log10(0.21100^2/1) = 13.514$

For Experiment No.-3

$SN3= -10\times\log10(0.20705^2/1) = 13.678$

For Experiment No.-4

$SN4= -10\times\log10(0.19811^2/1) = 14.062$

For Experiment No.-5

$SN5= -10\times\log10(0.19421^2/1) = 14.235$

For Experiment No.-6

$SN6= -10\times\log10(0.22347^2/1) = 13.015$

For Experiment No.-7

$SN7= -10\times\log10(0.18136^2/1) = 14.829$

For Experiment No.-8

$SN8= -10\times\log10(0.21068^2/1) = 13.527$

For Experiment No.-9

$SN9= -10\times\log10(0.20614^2/1) = 13.716$

OVERALL MEAN OF S/N RATIO-

The calculation of overall mean of S/N ratio is done by following method-

T11= Mean of low level values of S/N ratio of Inlet Temperature

T11= (SN1+SN2+SN3)/3

= (13.331+13.514+13.678)/3 = 13.507

T12= Mean of medium level values of S/N ratio of Inlet Temperature

T12= (SN4+SN5+SN6)/3

= (14.062+14.235+13.015)/3 = 13.770

T13= Mean of high level values of S/N ratio of Inlet Temperature

T13= (SN7+SN8+SN9)/3

= (14.829+13.527+13.716)/3 = 14.024

T21= Mean of low level values of S/N ratio of Outlet Temperature

T21= (SN1+SN4+SN7)/3

= (13.331+14.032+14.829)/3 = 14.074

T22= Mean of medium level values of S/N ratio of Outlet Temperature

T22= (SN2+SN5+SN8)/3

= (13.514+14.235+13.527)/3 = 13.758

T23= Mean of high level values of S/N ratio of Outlet Temperature

T11= (SN3+SN6+SN9)/3

= (13.678+13.015+13.716)/3 = 13.469

Pr1= Mean of low level values of S/N ratio of Pressure ratio

Pr1= (SN1+SN6+SN8)/3

= (13.331+13.015+13.527)/3 = 13.291

Pr2= Mean of medium level values of S/N ratio of Pressure ratio

Pr2= (SN2+SN4+SN9)/3

= (13.514+14.062+13.716)/3 = 13.764

Pr3= Mean of high level values of S/N ratio of pressure ratio

Pr3= (SN3+SN5+SN7)/3

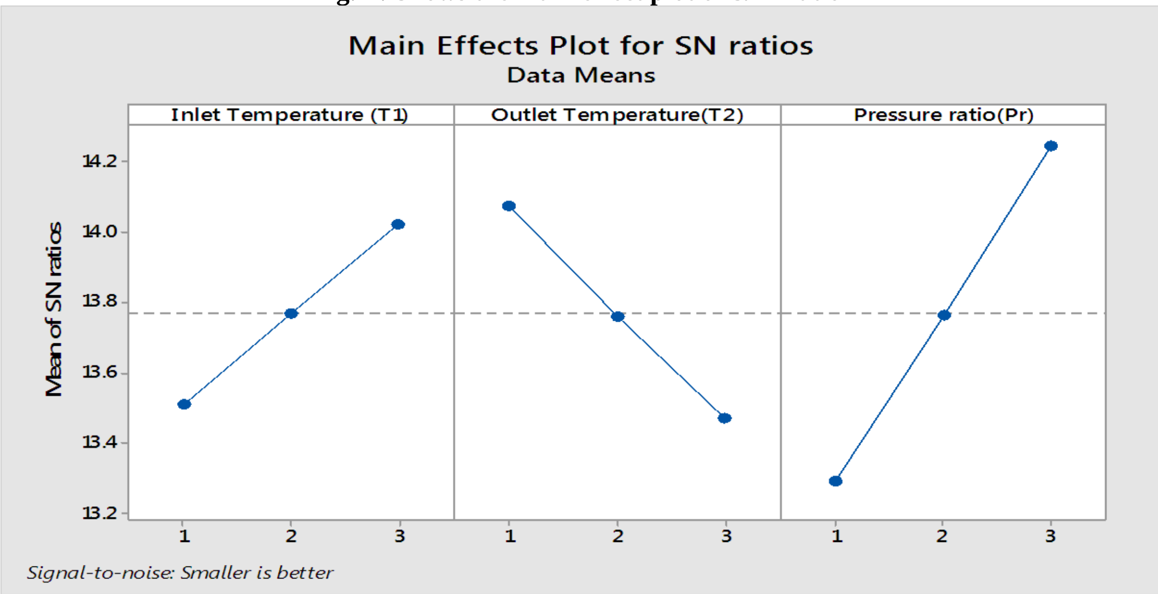
= (13.678+14.235+14.829)/3 = 14.247

Table-IV: Overall mean of S/N ratio (Response table for Signal to Noise ratio for Smaller the Better)

Level	Mean of S/N Ratio at Factor Level			Overall Mean Of S/N Ratio
	Inlet Temperature(T1)	Outlet Temperature(T2)	Pressure Ratio(Pr)	
LOW	13.507	14.074	13.291	13.767
MEDIUM	13.770	13.758	13.764	
HIGH	14.024	13.469	14.247	
Delta= Larger-Smaller	0.517	0.605	0.956	
Rank	3	2	1	

VI. RESULTS & DISCUSSION-

Fig.-1: Shows the main effect plot of S/N Ratio-



In the above figure it is clear that Pressure ratio(Pr) has the higher S/N Ratio at level '3' followed by Outlet temperature(T2) at level '1' & Inlet temperature at level '3'.

A. Analysis Of Variance (Anova)-

Obtained results from the theoretical experiment were again analyzed using ANOVA for indentifying the significant control factors and their contribution on the response variable. Taguchi method generally is not suitable for determining effect of individual control parameter on entire process, while percentage of contribution. The experimental data were analyzed using ANOVA at 95% of confidence level (α=0.05) in *Minitab Software* for indentifying the significant control factor and their relative contribution on response variable.

Table-V: ANOVA result table for 'ΔS'(at 95% confidence level)

Control Factors	Notation	Degree of Freedom	Sum of Squares	Mean Squares	F Ratio	% of Contribution
T1	Inlet Temperature	2	0.000208	0.000104	0.60	16.35
T2	Outlet Temperature	2	0.000290	0.000145	0.91	22.70
Pr	Pressure Ratio	2	0.000749	0.000374	4.51	58.90
Error		2	0.00002494	0.000416		2.05
Total		8	0.00127194			

In the above ANOVA analysis table it is clear that Pressure ratio has the largest influence on change in entropy with a contribution of 58.90%, followed by Outlet temperature with a contribution of 22.70% and Inlet temperature with a contribution of 16.35%.

VII. CONCLUSION

In this study, Taguchi method of experiment has been applied for optimizing the control parameters so as to optimize the expansion process. From the ANOVA and S/N ratio analysis, following conclusion can be made

1. From the S/N ratio analysis graph, Pressure ratio(Pr) at level'3' has the highest S/N ratio of 14.2474,

followed by Outlet temperature(T2) with S/N ratio of 14.0742 at level '1' and Inlet temperature(T1) with S/N ratio of 14.0245 at level '3'.

2. From the ANOVA analysis table(Table-V), Pressure ratio(Pr) has the highest contribution of 58.90% on Change in entropy(ΔS) followed by Outlet temperature(T2) with contribution of 22.70% and Inlet temperature(T1) with a contribution of 16.35%.
3. From the both ANOVA & S/N ratio analysis, it is clear that Pressure ratio(Pr) has the highest influence on Change in Entropy(ΔS) in expansion process of a cold storage.

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