International Journal of Advance Engineering and Research Development (IJAERD)
Volume 1,Issue 5,May 2014, e-ISSN: 2348 - 4470 , print-ISSN:2348-6406

PERFORMANCE OPTIMIZATION OF SINGLE STAGE OIL FLOODED ROTARY SCREW COMPRESSOR

Jatin T Patel[1], Ashish R. Patel[2], Nilesh M. Vora[3]

[1]*M.E. student, Sardar Patel Institute of Technology, Piludara, Mehsana, jatinptl30@gmail.com*
[2]*Asst. Professor, Sardar Patel Institute of Technology, Piludara, Mehsana, ashish.rpatel@yahoo.in*
[3]*Design Engineer,Ingersoll Rand Ltd. hmedabad,nileshmanilal@yahoo.co.in*

Abstract: The performance of any equipment like pump, motor, compressor, turbine, boiler etc. are depends on numbers of parameters like design, operation, service load pattern etc. currently where day by day cost of power and maintenance is growing the focus to improve the efficiency of any machine by optimization of operating parameter has become a vital area. Present work is aimed to optimize the single stage rotary screw compressor performance for better life via optimizations of operating parameters like pressure, flow etc. Taguchi method for conducting experiment and analysis of parameter is used for optimization. Based on design of experiment we will be conducting the experimental work and same will be analyzing with help of orthogonal array in present work.

Keywords: Screw Compressor, Optimization, Taguchi Method, DOE Pro, Anova.

I. INTRODUCTION

Gas compressors are mechanical devices used for raising the pressure of gas or vapour either by lowering its volume (as in the case of positive displacement machines) or by imparting to it a high kinetic energy which is converted into pressure in a diffuser (as in the case of centrifugal machines).
The selection of compressors for different applications is a crucial issue in the process industry. It is usually the most expensive piece of equipment and has dominant influence on cycle efficiency. The common types of compressors used in industry are reciprocating, twin screw, single screw, centrifugal, scroll and rotary vane. Compressor manufacturers are used to having a large market potential. Probably all types of compressors can be improved over what is available in the market today but the potential return must justify the expense of research and development to achieve the improvement. [13]
Screw compressors have a vital role in the gas and process industry, where their power requirement is high and machine sizes are large. They are simple machines in which the movement of the parts is purely rotational. Therefore, they are typically up to five times lighter than their reciprocating counterparts of the same capacity and have a nearly ten times longer operating life between overhauls. Moreover, provided that the running clearances between the rotors and between the rotors and their housing are small, they can maintain high volumetric and adiabatic efficiencies over a wide range of operating pressures and flows.[13]

II LITERATURE REVIEW

- The compressors were often running at part- load operation, which resulted in high energy consumption per tonne of processed fish. Optimal control of the compressors was an important factor for reducing the refrigeration energy demand. K.N.Widell, T.Eikevik [3] used 5 screw compressors and ammonia as the refrigerant, with slide valves to regulate the compressors and match their refrigeration capacity with product freezing loads. Compressors in the existing system can operate simultaneously with reduced capacities, the results showed that the most electrical energy can be saved during days when not all of the tunnels were loaded. It is assumed that V 30 000–50 000 can be saved per year by optimizing the operation of the refrigeration system. [3]

- N. Seshaiah, Subrata Kr.Ghoshs [4] had done Performance analysis on Oil injected twin-screw compressor which are widely used in cryogenic industries for medium pressure application. A mathematical model of compressor has been constructed basing on the laws of perfect gas and standard thermodynamic relation to evaluate compressor efficiency. The complete model has been validated using experimental data. And find that volumetric efficiency increases with increases inlet temperature. And it is more fore Helium than air. [4]
- N. Seshaiah, R.K. Sahoo, S.K. Sarangi[5] has been conducted theoretical and experimental analysis on commercially available twin-screw air compressors of two different capacities using air, nitrogen, argon and helium as working gases. Inlet temperature of working gas, suction pressure and pressure ratio have been taken as operating parameters to present the variation of volumetric and adiabatic efficiencies in 5.5 kW and 37 kW air compressors. It has been observed that the volumetric and adiabatic efficiencies are better at lower injected oil temperature. Helium shows the lowest volumetric efficiency followed by argon, nitrogen and air because of light and monatomic in nature has highest leakage rate and attained highest temperature on discharge. The higher values of volumetric efficiency with nitrogen and air are due to their higher molecular weight and relatively low heat of compression. [5]
- N Stosic, I K Smith and A Kovacevic [6] design two high efficiency oil free screw compressor for delivery of dry air. Their design is based on the authors own rack generated 'N' rotor profiles. The optimum rotor size and speed, together with the shape and position of the suction and discharge ports, were determined by mathematical modelling, taking full account of the limitations imposed by bearing and seal selection required to maximize endurance and reliability. Prototype testes show that volumetric and adiabatic efficiency of these machines were higher than the published value of any equivalent compressors at that time manufactured. They develop family of two compressors based on "N" profile rotors with a 3/5 configuration for dry air delivery by Drum-International to cover air delivery in the range of 300-1000m3/min. [6]
- The volumetric efficiency of a single screw compressor is mainly dependent on its clearances. In order to improve the sealing effect, lubricating oil is usually injected to its working volumes. Theoretical researches and practical applications both showed that, leakage in the working process of this kind of compressor is always the main factor that affects the performance. Apparently, the leakage will be decreased effectively by minimizing the clearance and increasing the length of seal line, or decreasing the temperature of injecting oil and increasing the quantity of injecting oil. The volumetric efficiency is thus high up but increasing power consumption. [7]
- Tang, Y. and Fleming, J. S [8] presents a method for optimizing the geometrical parameters of a refrigeration twin-screw compressor like contact line length per lobe, blow hole area and discharge port position. Two new parameters; relative blow hole area and relative contact line length are introduced to compare the blow hole areas and contact line lengths of different rotor profiles. These new parameter directly affecting performance of the compressor so it is suitable for optimization. The highest indicated or total efficiency always is obtained when Pi is less than Pd'. A discharge port position should be chosen to make the internal pressure ratio less than the external.[8]
- Oil injection has a significant influence on performance of twin screw compressors because the injected oil serves the function of cooling, sealing and lubricating. X. Peng, Z. Xing, X. Zhang [9] obtain Large number of performance data from test on several types of oil-injected

twin screw compressor at various operating conditions, and get some performance characteristics of oil-injected twin screw compressors. Then, p- V diagrams of a prototype compressor at various operating conditions are recorded and analyzed with the aid of measuring system of dynamic pressure. Finally they observe that Performance of oil-injected twin screw compressor is characterized of smaller changes of volumetric efficiency and isentropic efficiency in a wider range of operating conditions than that of oil-free twin screw compressor, which is favorable for economic operation at variable conditions.[9]

- In India 46.67% energy used in industries which is highest with compare to other countries, we can save 39% energy by optimize system, 20% by reducing air leakage, 15% by speed control etc. Finally observed for SVRC at some pressure level (7 bar) machine is most efficient, flow rate require by machine is matched by increasing no of compressors, so ensuring the best overall energy saving additional it can be done by reducing machine speed which reduces the frictional losses.[14]
- E H Machu [15] tries to give a summary of mathematical models dealing with compressor efficiencies, volumetric as well as energetic, as well as temperature rises, considering ventilation work losses in valves and pockets, heat exchange, gas leakages and gas inertia. Find that inertia of the gas inside the cylinder may reduce the pressure difference across the discharge valve, thus reducing the gas flow rate there in, resulting in reduces volumetric efficiency. [15].

IIIMETHODOLOGY:TAGUCHI

At the core of product and process design is the concept of experimental design. How we design our experiments guides us in selecting combinations of the various factor levels that enable to determine the output characteristic and thereby calculate the performance statistic. The matrix that designates the settings of the controllable factors (design parameters) for each run, or experiment, is called an inner array by Taguchi; the matrix that designates the setting of the uncontrollable or factors is called an outer array. Each run consists of a setting of the design parameters and an associated setting of the noise factors. The inner and outer arrays are respectively designated as the design and noise matrices. 'For design factors that are quantitative, three levels are necessary to estimate the quadratic (or nonlinear) effect, if any. If only two levels of a factor are tested, then only its linear effects on the response variable can be estimated.

3.1 Design of Experiment

First of all for carry out, we want to define the problem. Here the problem is to find out the effect of three input parameters:

- Ambient Temp
- Frequency
- Pressure

On Two output parameters:

- Power consumption KW
- Compressed Air flow in CFM

There is 3-level parameter design considered here. So there are three different value of every input parameter is taken into account for investigating its effect on output parameters.
So there are two different combination of design of experiment is carried out.

With the help of TAGUCHI METHOD of design of experiment, we have designed L9 type orthogonal array, which manage various input parameter in a tabular form. Here

3.2 Test Setup

The set up for compressor performance measurement is carried out as per industrial accepted standard. The screw compressor performance can be measured as per CAGI as well as ISO 1217 – Annexure C. Looking to Indian customer and consultant the CAGI is not acceptable with respect to ISO: 1217 Annexure C. We have carried the testing of compressor as per manufacturer's set up which confirms to ISO 1217 –Annexure C.

3.3 Procedure

Run unit at rated load until stability is reached. Record the total electric power input to the package, including volts, amps, kilowatts and power factor. This should include main drive motor, fan motor and instrument panel (also and system variable speed drives that are utilized within the package). Include in the data package inlet temperature, motor shaft speed and package discharge pressure. Run unit, with air through the metering section until the nozzle inlet temperature stabilizes to within +/- 2°C in 15 minutes. If the data is logged manually, record data after stability. Measure parameters as identified on the Power and Capacity Lab Form as specified by the Test Request. The Power and Capacity Lab Form is only applicable when using CAVs.

3.4 Actual Test Setup

Figure 1 Test Setup

Figure 2 Nozzles for Flow Measurement

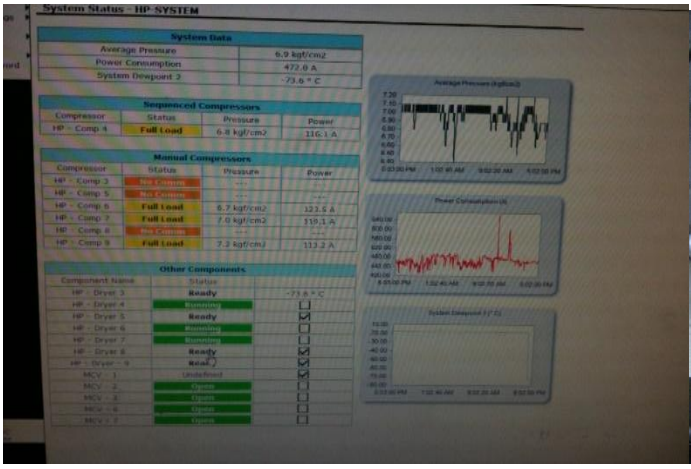


Figure 2 Scada Software

Electric Control Penal

3.5 Level Factor Selection

Factor	unit	Level 1	Level 2	Level 3
Discharge Pressure	Bar	7	8.5	10
Ambient Temperature	^{o}c	16	23	30
Frequency	Hz	49.80	50	50.20

As discussed we have conducted set of experiment for single stage Oil flooded Screw Compressor as per ISO: 1217 – Annexure C. There are 3 Variable taken as per input and based on this variable we have measured Power consumption and Discharge flow as a set of output. Below table shows the details of input and output based on experimental setup.

IV RESULT AND DISCUSSION

4.1 Set of Result

INPUT			OUT PUT					
Amb Temp	Frequency	Pressure	POWER			FLOW		
			SET1	SET2	SET3	SET1	SET2	SET3
16.00	49.80	7.00	13.60	13.80	13.70	54.00	52.00	53.00
16.00	50.00	8.50	14.00	41.20	27.60	52.00	54.20	53.10
16.00	50.20	10.00	12.55	12.56	12.56	50.40	50.30	50.35
23.00	49.80	8.50	13.70	13.90	13.80	51.00	50.80	50.90
23.00	50.00	10.00	13.45	13.80	13.63	50.80	51.08	50.94
23.00	50.20	7.00	14.30	14.23	14.27	52.00	52.34	52.17
30.00	49.80	10.00	12.30	12.54	12.42	50.10	52.45	51.28
30.00	50.00	7.00	13.55	14.23	13.89	53.90	54.21	54.06
30.00	50.20	8.50	13.99	14.63	14.31	51.30	52.40	51.85

4.2 Regression Analysis

Factor	Name	Low	High	Exper
A	Amb Temp	16	30	30
B	Frequency	49.8	50.2	49.8
C	Pressure	7	10	7

Exper Value

Multiple Response Prediction			99% Confidence Interval	
	Y-hat	S-hat	Lower Bound	Upper Bound
POWER	15.0028	0.3568	13.932	16.073
FLOW	53.4315	0.3975	52.239	54.624

Multiple Response Prediction

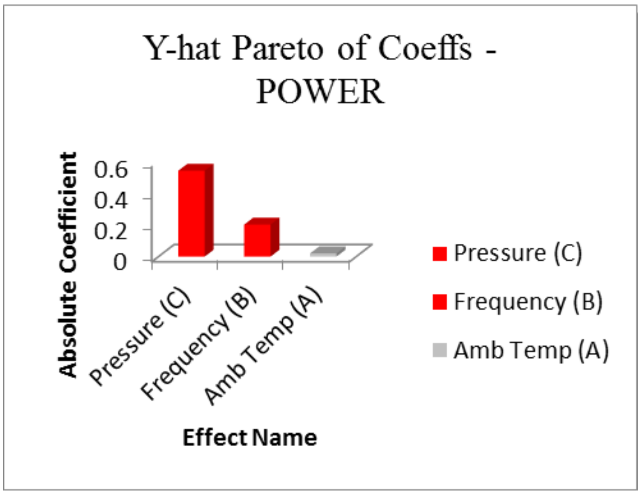
4.3 Anova Technique for Power and Flow

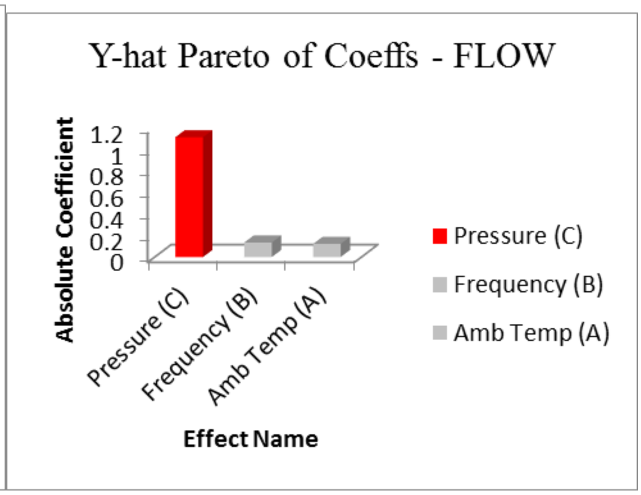
POWER						
Source	SS	df	MS	F	P	% Contrib.
Amb Temp	0.8664	2	0.4332	5.181	0.015	6.89%
Frequency	1.7447	2	0.8723	10.432	0.001	13.88%
Pressure	8.2884	2	4.1442	49.560	0.000	65.93%
Error	1.672	20	0.084			13.30%
Total	12.572	26				

FLOW						
Source	SS	df	MS	F	P	% Contrib.
Amb Temp	5.5205	2	2.7602	6.318	0.007	12.51%
Frequency	7.6884	2	3.8442	8.799	0.002	17.42%
Pressure	22.2	2	11.1	25.384	0.000	50.26%
Error	8.738	20	0.437			19.80%
Total	44.126	26				

Based on this ANOVAs table we can see that the Discharge pressure is having highest impact on Power and flow, it is 65.93 % and 50.26% respectively on power and flow. The frequency is having 13.88 % on Power and 17.42% on flow. The least impact is of Ambient temp which shows 12.51 % and 6.89 % of contribution on flow and power respectively. Which is also indicated with help of Pareto chart

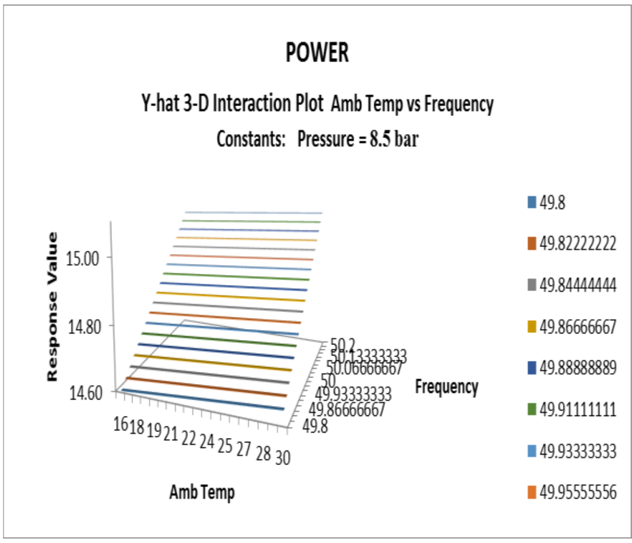
4.4 Y-hat Pareto co efficient for Power and Flow

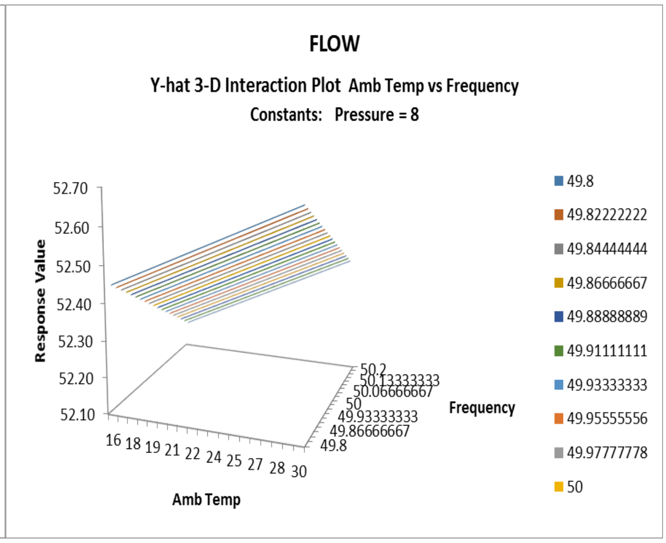




The impact of ambient temp, pressure and frequency on power are shown with help of Pareto chart in above figure, the pressure has most signification impact on power with respect to ambient temperature and frequency

4.5 Various Graphs for Power and Flow

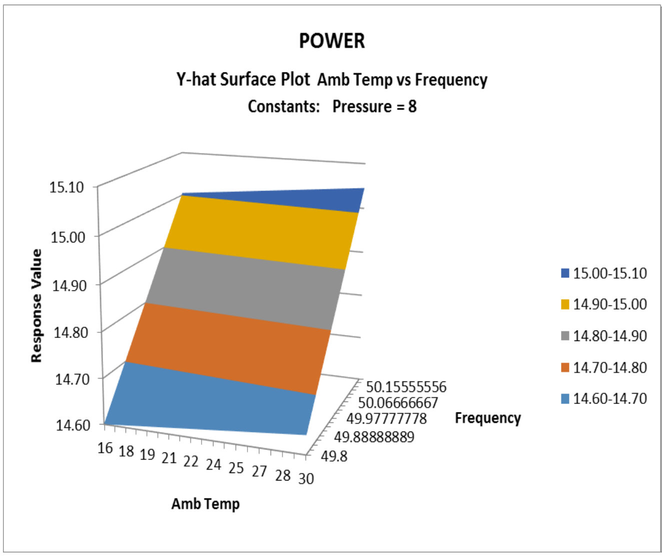




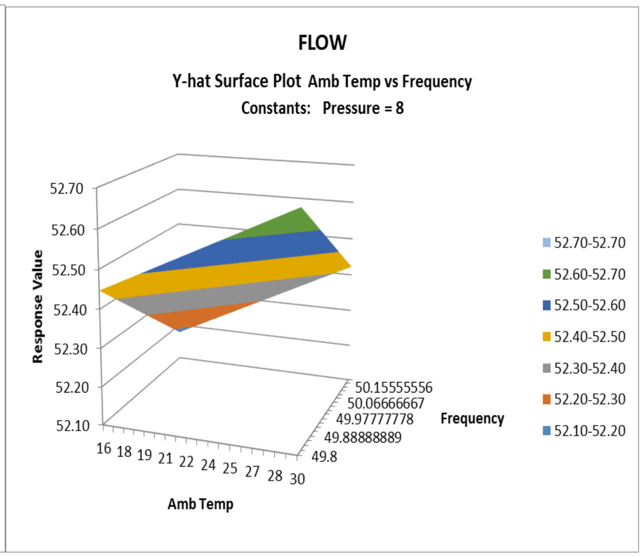
Y-hat 3D Interact Plot Amb Temp vs. Frequency

Y-hat 3D Interact Plot Amb Temp vs. Frequency

Above 3D graphs shows interactive relation between Amb Temp and Frequency and Power as a response value for Power and Flow Respectively as Temp range of 16 to 30 o C and frequency of 49.8 Hz to 50.2 Hz at Pressure of 8.5 bar. Same readings are shown as a surface plot.



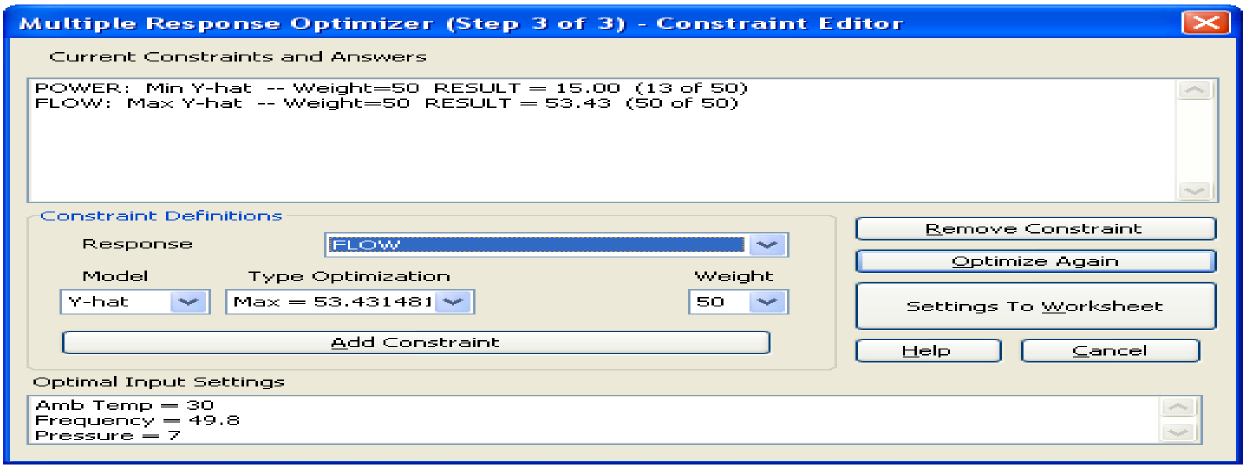
Y-hat surface Plot Amb Temp vs. Frequency



Y-hat surface Plot Amb Temp vs. Frequency

4.6 Optimum Value

With constrain of Min Power from Y hat Model and Max Flow the optimum input parameters are Ambient Temp =30 Frequency = 49.8 Hz Pressure = 07 Bar with this desirable output are
Power = 15.00 KW and Flow = 53.43CFM.



After doing an optimization we have carried the same testing at industry with help of standard test set up in compressor room where we have control on all parameter. With the help of it we simulated inlet condition as Amb temp = 30°C Frequency = 49.8 Hz and Discharge pressure as 7 Bar constant. The output performance of machine was measured against flow and power value. The flow was measured as flow = 55.06 cfm power = 13.13KW.

V CONCLUSION

We can conclude from the above results that the Discharge pressure is having highest impact of Power and flow and same was also derived from the optimization. Secondly the Frequency can play important role in overall performance of machine. Due to constant fluctuation in incoming
Power frequency is not a constant but with help of frequency controller like Variable frequency drive we can manage a constant required value of frequency which has an impact of 14 % on Power and 17 % on flow, so by installing the frequency controller we can save power and enhance the flow of compressor. The ambient temperature has least impact among these three parameter but that can be also controlled with help of compressor room but looking to impact factor the investment may be not justified against saving. So first two parameter like pressure and frequency control can offer better performance of machine with same specification. If required application is having high pressure then optimum value then same can be achieve by reducing the downstream line from the receiver to an application point which may increase slight pressure to required level of application.
Here we can see from below table that the at Ambient of 30 C and 7 bar discharge pressure with frequency of 50 Hz the average output of power is 13.89 KW and flow is 54.05 CFM While same is at 10 bar pressure and 49.80 Hz frequency are 1.42 KW and 51.27 CFM but with controlled value of frequency of 49.8 Hz we can get 55.06 CFM and power is 13.13 KW Which shows with respect to 7 bar pressure the increased in flow is 1.86864 % and reduction in power is 5.47156 % So by selecting an optimum parameter we could save power near about 5 % and flow can be increase by 1.85 % which is justified for installment cost of frequency controller as life of compressor is considered as 8 – 10 years based on application and utilization.

INPUT			OUT PUT					
Amb Temp	Freq uency	Pressure	POWER			FLOW		
			SET1	SET2	SET3	SET1	SET2	SET3
30.00	49.80	10.00	12.30	12.54	12.42	50.10	52.45	51.28
30.00	50.00	7.00	13.55	14.23	13.89	53.90	54.21	54.06

REFERENCES

Books

1. Compressor hand book by Paul C. Hanlon, McGraw-Hill publication
2. Screw compressor Mathematical Modelling and Performance Calculation By N. Stosic I. Smith A. Kovacevic

Research Papers

3. K.N.Widell, T.Eikevik "Reducing power consumption in multi-compressor refrigeration systems" international journal of refrigeration 3 3 (2010) 88–94
4. N. Seshaiah, Subrata Kr.Ghoshs "Performance analysis of oil injected twin screw compressor" 18th National and 7th ISHMT-ASME, HMT conference, January 4-6, 2006.IIT Guwahati, India.
5. N. Seshaiah, R.K. Sahoo, S.K. Sarangi, "Theoretical and experimental studies on oil injected twin-screw air compressor when compressing different light and heavy gases" Applied Thermal Engineering 30 (2010) 327–339
6. N Stosic, I K Smith and A Kovacevic, "Design of efficient screw compressor for delivery of dry air" Centre for Positive Displacement Compressor Technology City University
7. N Stosic, I K Smith and A Kovacevic, "Optimization of screw compressor" Applied Thermal Engineering 23 (2003) 1177–1195
8. Li, Hong Qi and Jin, Li Wen, "Design Optimization of an Oil-Flooded Refrigeration Single Screw Compressor" International Compressor Engineering Conference,2004 Paper 1715.
9. Tang, Y. and Fleming, J. S , "Obtaining the Optimum Geometrical Parameters of a Refrigeration Helical Screw

Compressor" (1992).International Compressor Engineering Conference. Paper 811.

10. X. Peng, Z. Xing, X. Zhang, "Experimental Study of Oil Injection and Its Effect On Performance of Twin Screw Compressors." , Fifteenth International Compressor Engineering Conference at Purdue University, West Lafayette, IN, USA - July 25-28, 2000

11. Wu, Weifeng and Feng, Quanke, "Leakage Paths Two Type of Meshing Pairs in Single Screw Compressors" International Compressor Engineering Conference at Purdue, July 14-17, 2008

12. N.Stosic, I.K. Smith, A. Kovacevic. "Optimization of Screw Compressor Design" International Compressor Engineering Conference. Paper 1592

13. G. Chanukya Reddy, "cfd studies on flow through screw compressor" ethesis.nitrkl.ac.in/4334

14. R Cipollone "Sliding vane rotary compressor technology and energy saving" 8th International conference compressor and their system,(27-54)

15. E H Machu "Survey of factors influencing reciprocating compressor efficiencies and discharge gas temperatures"8th International conference compressor and their system,(348-357)

