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Development of Methodology for Design of Energy Efficient Compressed Air System with Case Study

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ABSTRACT

In developing country like India, energy is most important to economical of country thus energy sector plays an important role to increase in energy dependence and investment made on it. As we all know the compressed air generation consumes energy. Normally the compressed air system is an overlooked area in most of the industry but compressed air system is a costly source of energy about 7 to 10 times more expensive than electricity. Better methodology for design of energy efficient compressed air system, better maintenance practices and through energy efficiency measures can save the significant amount of energy of any industry. In this paper we have discussed the methodology for design of compressed air system for energy efficient compressed air system for industry. This paper also gives the comparative study of existing compressed air system of one industry with new optimized designed compressed air system for same industry using their specification.

Introduction

Compressed air system is the overlooked area by most of industries. Energy consumption of compressed air system is reduced by the various energy efficiency measures. Compressed air system consumes 8 to 10 % of energy of any industry. Significant amount of energy saving is possible through various methodologies of energy audit and proper maintenance. It becomes necessary to analyze compressed air system before it installation in energy consumption point of view. In order to do so design and analysis of CAS system through specific methodology is required. In this paper we have discussed the methodology for design and analysis of compressed air system for industry with case study of Choundeshwari Soot Girini. Ltd.

Literature review on design of compressed air system

The design of compressed air system for any industry is complicated issue involving design network formed by air compressors, air receiver, connecting network to all end users and major task is the air demand required. This defines the optimal solution in terms of quality assurance, technological aspects of compressed air generation, treatment and distribution. It gives the methodology of integrated and network structure design. [6]

A generation of compressed air is most expensive process in any industry. The objective of this paper is to evaluate and quantify the energy losses associated with compressed air system and there cost analysis. This discussion also shows how to reduce cost of compressed air in existing facility by making some modification with attractive payback period. [7]

Compressed air is referred to as the fourth utility. We all know the generation of compressed air consumes energy but at the same time the compressor losses and downstream components are considered, which means there are significant savings to be made. It is suggested that savings of around 33 % on average in a compressed air system are possible. It follows that cost effective compressed air production is energy efficient compressed air production, as energy is by far the biggest lifetime cost factor. Many of the different levers for cost reduction may be known, but just not applied, due to lack of knowledge about the financial savings possible. This paper shows and explains the different ways to efficient way for Compressor selection and heat losses in compressor, efficient waste heat recovery in compressor (screw compressors) and piping material selection and design of pipe line layout for reducing the pressure losses in flow.

For improvement of energy efficiency of the compressed air system the US Department of energy developed the programme known as Compressed Air Challenge. Objective of this programme is to evaluate the various energy saving measures and optimal solution for energy efficient design of compressed air system. It also gives the methodology to conduct the energy audit of compressed air systems. [9]

Introduction to textile industry

Choundeshwari Soot Girini Ltd., A textile industry located in western part of Maharashtra, India which is 20 km from the historic city Kolhapur, by driving through Sangli-Kolhapur high-way it takes half an hour's to travel from Kolhapur to industry. Choundeshwari Soot Girini Ltd. works on the cooperative basis.

The average annual usage of this industry is near about 50 lakh kWh with average energy rate of 7.6 Rs/ kWh. Compressed air system is generally consumes 3 to 5 % of total electricity consumption. There are two compressors in this industry. One of these compressors of capacity 274 m^3/hr (161 CFM) is working continuously for 24 hour and other compressor was of capacity 289 m^3/hr (170 CFM) was old one which is generally used as stand-by compressor. 24 hours load profile of first compressor as given in fig.1. Annual energy consumed by these two compressors is 1888552 kWh. Considering that first compressor is working for 6000 hrs per year (5400 hours loading) and second one is working only for 54 hours per year.

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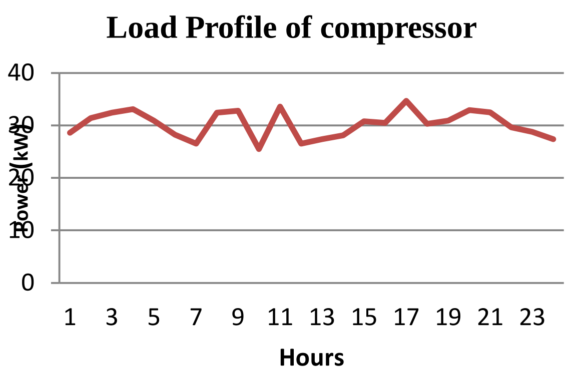


Figure 1 . Load Profile of Compressor LCC of exiting compressed air system.

LCC analysis considers various cost for analysis of compressed air system such as energy cost capital cost maintenance cost of system over the time spam.

1. Energy cost

As calculated above the energy consumption of the existing system is 188553 kWh. The cost of energy per kWh is 7.6 Rs. From this energy cost of exiting compressed air system is as given below.

Energy cost of exiting system = 188552 ×7.6 = 1432995.2 Rs/ year

2. Capital cost and installation cost

As per current market survey, purchase price of compressor and piping system and installation cost is approximately 3000000 Rs. To calculate yearly capital cost applying liner depreciation over 10 year with interest rate of 8 % per year.

Yearly investment cost =3000000/10 ×1.08 = 324000 Rs/year

3. Maintenance cost

Maintenance cost for compressed air includes compressor oil change, repairing leak, bearing checkup etc. annual maintenance cost for compressed air system is approximately 50000 Rs.

By analyzing all these cost, it is found that in compressed air system energy cost plays an important role. Energy cost nearly contributes 80 % of total cost.

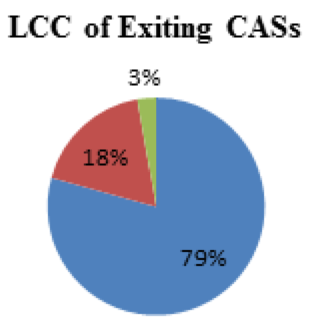
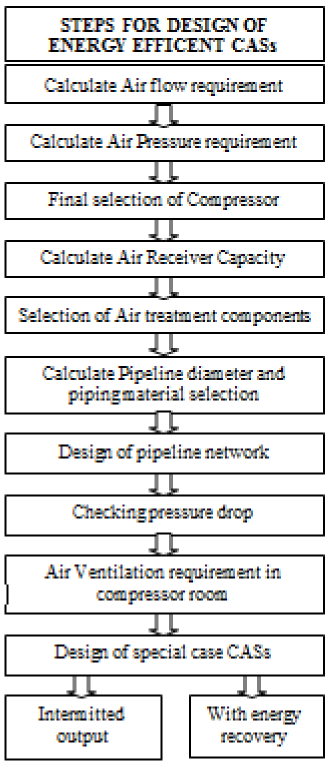


Figure 2 . LCC of Existing CASs.

Methodology for design of CASs

Steps for the design of compressed air system for energy efficient compressed air system as given in below flow chats. This methodology can save the significant amount of energy of compressed air system through various design steps as given below.



The detail design procedure for compressed air system for Choundeshwari Soot Girini Ltd. by using their specifications as given below. The areas that examined include the calculation or assessment of the air requirement and the reserve capacity and the space for future expansion. The working pressure is a critical factor, as this significantly impacts energy consumption. Sometimes it can be economical to use different compressors for different pressure ranges. The quality of the compressed air is not only a question of water content, but has increasingly become an environmental issue as well. Odor and the microorganism content are important factors that can affect the product quality, rejections, the working environment and the outdoor environment. The issue of whether the compressor installation should be centralized or decentralized may affect the floor space requirement and perhaps future expansion plans. From both a financial and ecological point of view it is becoming increasingly important to investigate the possibilities of recovering energy at an early stage for quick return on investment. It is important to analyze these types of issues with regard to current as well as future requirements. Only after doing so will it be possible to design an installation that offers sufficient flexibility.

Case Study of Choundeshwari Soot Girini Ltd

Design and analysis of energy efficient compressed air system for Choundeshwari Soot Girini Ltd. by using the new methodology as discussed below.

Air Flow Requirement

The quantity of nominal compressed air required is determined by the individual air consumers. This is calculated as sum of air consumption for all tools, machines, process that will be connected and estimating their utilization factors. In addition to this leak, wear, future changes in air requirement must be taken into consideration. The quantity of air require for individual consumer in this textile industry as given below.

Connected Equipments	Air requirement (m^3/hr)	Utilization factor	No. Of m/c	Total air require-ments
LC100 machine	2.56	1	6	15.36
LC300 machine	4.25	1	3	12.75
DO 6	3.4	1	2	6.8
Speed frame machine	2.7	1	4	10.8
Ring frame machine	4.5	1	13	58.5
Auto coner X5	40	1	1	40
Auto coner 338	40	1	1	40
Blower room	20	1	1	20
Total	205			≈ 205

Table 1. Individual compressed air requirement

Sum of the individual consumer is 205 m^3/hr. In addition to this by considering leak, wear, future changes in air requirement and safety margin approximately up to 30-40%. By recalculation we get. Flow rate required for system as follows

FAD (m3/hr) = 205 × 1.3 =267 m^3/hr

FAD (m3/hr) = 205 × 1.4 =287 m^3/hr

From compressor manufacturing catalog selecting the compressor which has having capacity in the range of 267 m^3/hr to 287 m^3/hr. it is better to have selection of compressor of high capacity for future changes.

System pressure requirement

Required pressure in compressed air system is determined by the compressed air equipment in installation. The correct working pressure not only depend on compressor, but also on the design of the compressed air system and its piping, valves, compressed air dryers, filters, etc. the pressure requirement for equipment as given below

Table 2 . Individual air pressure requirement.

Connected Equipment	Working pressure(bar)
LC100 machine	5 bar
LC300 machine	6 bar
DO 6 machine	4 bar
Speed frame machine	6 bar
Ring frame machine	6 bar
Auto coner X5	5.5 bar
Auto coner 338	6 bar
Blower room	5 bar

From above table gives that different equipment requires different pressure. Normally highest require pressure is chosen as the system pressure and other equipment are operated with regulated supply.

It should also be kept in mind that the pressure drop quickly increases as flow increases. If a change in consumption can be expected, it makes economic sense to adapt the installation to these conditions. Filters and special dust filters, have a low initial pressure drop, but become clogged over time and are replaced at the recommended pressure drop. This factor will enter into the calculation. The compressor's flow regulation also causes pressure variations and therefore must also be included in the calculation. By considering various approximate pressure drop in system and compressor operating range the required system pressure in system is calculated as below.

From above calculation and by considering approximate pressure drop in system the maximum working pressure of compressor is in range of 7 bar to 7.5 bar.

Description	Pressure drop (bar)
End user	6 bar
Final filter	0.1- 0.5 bar
Pipe system	0.2 bar
Dust filter	0.1– 0.5 bar
Dryer	0.1
Compressor regulation range	0.6
Compressor max. working pressure	7- 7.5

1. Final selection of compressor

Now a day, in many industries the screw compressor is widely used for medium capacity purpose. For very high capacity centrifugal compressor are used. Form above two points i.e. calculated air flow requirement and maximum pressure required in the system final selection of compressor is made. From compressor manufacturing catalog, selecting the oil injected screw compressor having capacity of 287 m3/hr at 7.5 bar.

Oil injected screw compressor

Maximum compressor outlet pressure= 7.5 bar

FAD at 7.5 bar = 287 m^3/hr

This requirement is met by the compressor with motor shaft power =32 kW

Required Air receiver volume

To meet the fluctuating air demand and to store the compressed air calculation of air receiver volume is important. Air receiver volume required for above specification compressor is calculated as follows

$$\boldsymbol{V(m^3) = \frac{0.25 \times Q_C \times T_0}{f_{max} \times (P_U - P_L) \times T_1 \times 3600}}$$

Where,

Q_C = compressor capacity (m^3/hr)

T_0 = compressed air temperature out from selected compressor i.e. it is considered as 10 $^{\circ C}$ higher than ambient temperature = 723 +40 =313 K

$\boldsymbol{f_{max}}$= maximum cycle frequency =1cycle/30 seconds

$\boldsymbol{(P_U - P_L)}$ = pressure difference between loaded and unloaded compressor =0.6 bar

T_1= maximum inlet air temperature= 30 $^{\circ C}$ =273+ 30 =303 K

Volume of air receiver is calculated as below.

$$\boldsymbol{V = \frac{0.25 \times 287 \times 313}{\frac{1}{30} \times (7.5 - 7) \times 303 \times 3600}}$$

V = 1.235 m^3

Minimum volume of air receiver requires for given system is 1.235 m^3. But next to this value is consider as the air receiver volume i.e. 1.5 m^3 to 2 m^3 is to be installed.

Calculation for selection of air treatment components

It is vitally important to the user that the compressed air be of the right quality. If air that contains contamination comes into contact with the final product, rejection costs can quickly become unacceptably high and the cheapest solution can quickly become the most expensive. It is important that you select the compressed air quality in line with the company's quality policy and even attempt to judge future requirements.

Air dryer selection

The required dew point in this case is 5 $^{\circ C}$. When selecting the size of the refrigerant dryer a number of factors must be taken into consideration by correcting the refrigerant dryer's capacity using correction factors. These correction factors are unique for each refrigerant dryer model. The four correction factors are:

1. Refrigerant dryer's intake temperature and pressure dew point.

As the compressed air temperature out of the selected compressor is 10°C higher than the ambient temperature, the refrigerant dryer's intake temperature will be maximum 30 + 10 = 40°C. In addition, the desired pressure dew point is +5°C.

The correction factor 0.95.

2. Working pressure

The actual working pressure in the compressor central is approx. 7.3 bar, which represents a correction factor of 1.0.

3. Ambient temperature

With a maximum ambient temperature of 30°C a correction value of 0.95 is obtained.

Accordingly the refrigerant dryer should be able to handle the compressor's fully capacity 287 m3/hr multiplied by the correction factors above.

287×0.95×1×0.95= 259.07 m^3/hr

Selecting dryer which should able to handle flow rate of 259.07 m^3/hr

Selecting dryer with specification as follows

Capacity at 7.3 bar =259.07 m3/hr

Total power consumption =2.6 kW

Pressure drop across the dryer = 0.09 bar

Air filter selection

If oil lubricated compressor is selected, after drying the air through the air dryer oil in the compressed air is remain as it to remove the oil from air correct filter should be selected. Selection of air filter depend on the amount of oil remain in compressed air after drying. Amount of condensate in air is calculated as follows.

The total flow of water in the air taken in is obtained from the relation:

$\mathbf{f_1}$ = relative humidity x the amount of water (g/litre) the air can carry at the maximum ambient temperature 30°C x air flow(liter/sec)

$$f_1 = 0.366 \times 0.030078 \times 75.56$$

$$f_1 = 0.83\ g/sec$$

Amount of condensate remained in compressed air after drying

$$f_2 = \frac{1 \times 0.007246 \times 75.56}{8}$$

$$f_2 = 0.068\ g/sec$$

Amount of oil remain in compressed air is

$$f_3 = f_1 - f_2$$

$f_3 = 0.83 - 0.068$

$$f_3 = 0.762\ g/sec$$

$$f_3 = 2.7\ kg/hrs$$

With help of the calculated condensation flow the right oil separator can be chosen

Sizing of pipeline and material selection

1. Pipe sizing

Selection of correct size of pipe for compressed air system is the important task. Pipe that is sized too small create big pressure loss and reduces operating efficiency. Replacing the pipe is costly. While designing the pipe size the many people will not consider the equivalent length of fitting in the piping. Detail procedure for pipe sizing as given below.

Every pipe fitting creates a certain amount of increased frictional air loss that is equal to a specified length of pipe. Any turns in the pipe at fittings, ells, tees, and valves increase pressure drops even more. That's why the equivalent length of pipe (ft.) for pipe fittings chart was developed to help you determine the best pipe size for your system. If you are planning to add more equipment in the next year, then plan for larger piping now. Since the material costs in piping are low compared to installation or replacement cost, it's wise to select pipe of an adequate size. If there is any doubt that a pipe size may create a pressure drop, use the next largest size. Remember that an oversize pipe compensates for possible scale build-up and provides for future expansion of the overall air system.

Steps to Determine Pipe Size

1. From above maximum compressor capacity is 287 m^3/hr (approx. 170 cfm).
2. Total length of straight pipeline at this soot girini is found to be 61 meters (200 feet).
3. By using table no. 3, finding the compressor capacity of 170 cfm in the left column, then going to right we will found the length of pipe in upper header column where the total length and compressor cfm intersects on the chart. This will recommended you the pipe size for required length. i.e 50.8 mm (2'')
4. Equivalent length for all pipe fitting as below

The pipe system consists of the 16 elbows, 20 reduced elbows, 5 gate valve. From table no.4, by selecting the pipe size of 2'' diameter as calculated above.

Recalculating the equivalent length for fitting

Equivalent length for fitting = 16 ×2.07 +20×5.17 +5×1.17 = 142.37 feet

Total length= 200+ 142.37 = 342.37 feet

5. Going back to table no.4 check the pipe size for new length 342.37 feet which is 2 ½ ''(65 mm)

Select the pipe size of 2 ½'' (65mm) diameters will best for minimum friction as well as pressure loss.

Table 3 Equivalent length of pipeline

Flow Rate		Length					
m3/hr.	CFM	25 feet	50 feet	75 feet	100 feet	150 feet	200 feet
1.7	1	1/2	1/2	1/2	½	1/2	1/2
3.4	2	1/2	1/2	1/2	½	1/2	1/2
5.1	3	1/2	1/2	1/2	½	1/2	1/2
8.5	5	1/2	1/2	1/2	½	1/2	1/2
17.0	10	1/2	1/2	1/2	¾	3/4	3/4
25.5	15	1/2	3/4	3/4	¾	3/4	3/4
34.0	20	3/4	3/4	3/4	¾	3/4	3/4
42.5	25	3/4	3/4	3/4	¾	3/4	1
51.0	30	3/4	3/4	3/4	¾	1	1
59.5	35	3/4	3/4	1	1	1	1
68.0	40	3/4	1	1	1	1	1
85.0	50	1	1	1	1	1	1
101.9	60	1	1	1	1	1-1/4	1-1/4
118.9	70	1	1	1	1	1-1/4	1-1/4
135.9	80	1-1/4	1-1/4	1-1/4	1-1/4	1-1/4	1-1/2
169.9	100	1-1/4	1-1/4	1-1/4	1-1/4	1-1/2	1-1/2
212.4	125	1-1/4	1-1/4	1-1/4	1-1/4	1-1/2	1-1/2
254.9	150	1-	1-	1-	1-	1-	1-

		1/4	1/4	1/4	1/4	1/2	1/2
297.3	175	1-1/2	1-1/2	1-1/2	1-1/2	2	2
339.8	200	1-1/2	1-1/2	1-1/2	1-1/2	2	2
382.3	225	1-1/2	1-1/2	1-1/2	1-1/2	2	2
424.8	250	2	2	2	2	2	2
467.2	275	2	2	2	2	2	2
509.7	300	2	2	2	2	2	2
594.7	350	2	2	2	2	2-1/2	2-1/2
679.6	400	2	2	2	2	2-1/2	2-1/2

Table 4 Equivalent length of pipe fitting

Pipe size (inch)	Long rad Ell or Run of TEE	Std Ell or Run of reduced TEE	TEE through side outlet	Globe Valve	Gate Valve
1/2	0.62	1.55	3.1	17.3	0.36
3/4	0.82	2.06	4.12	22.9	0.48
1	1.05	2.62	5.24	29.1	0.61
1-1/4	1.38	3 4/9	6.9	38.3	0.81
1-1/2	1.61	4.02	8.04	44.7	0.94
2	2.07	5.17	10.3	57.4	1.12
2-1/2	2.47	6.16	12.3	68.5	1.44
3	3.07	6.16	15.3	85.2	1.79
4	4.03	7.67	20.2	112	2.35

6.2 Material selection for pipeline

The cost of piping and pressure loss through piping is greatly depending on the material selection. Material selection for compressed air system is depending on the type of industries. Example aluminum pipe should not be used in industry having fire hazards. Material should be selected as given below table

Table 5 . Pipe Material Selection.

Pipe material	Advantage	disadvantage
Galvanized steel	Known technology, widely available	Heavy, prone to rusting, threaded joints require careful preparation, inner surfaces are not smooth and as a result promotes energy loss (pressure drop)
Aluminum	Lightweight, easy to install, Does not rust.	Not suitable for applications where there is a fire risk, e.g. mines, offshore and hospitals
High performance plastic e.g. ABS, polyethylene PVC	Lightweight, non-corrodible, nontoxic	Use only piping specified as suitable for compressed air. temperatures increase check suppliers data for suitability Subject to ultra-violet Degradation
Stainless steel	High rigidity, corrosion and rust resistant.	Applications tend to be limited to high specification, critical processes (e.g. food processing) due to the higher initial cost
Copper	High purity copper inhibits Microbial growth useful for medical applications	Maximum diameter is 40mm Cost is very high

By analyzing all these materials for pipeline selecting the pipe of high performance plastic for Choundeshwari soot girini ltd

Cost of various piping

Cost of the piping depends on the material you have selected for installation. As comparing, the cost of the three materials which can be useful for Choundeshawari soot Girini. In installation of new piping system on average 70 % of installation cost includes labor cost and remaining 30 % is material cost.

As per current market survey, Cost of galvanized steel pipe is near about Rs 200000 including all material cost plus labor cost. As Galvanized steel piping system suffers high pressure drop, corrosion problem, leak problem, lower payback period. In the steel piping the joint are of threaded joint will cause the more leak at joint. As comparing cost and these entire problem it not suitable for Choundeshawari Soot Girini.

As we see the cost of aluminum piping for Choundeshawari soot girini it is significantly higher than the other piping system. Best advantages of aluminum piping are that have less pressure drop, less chances of leakages and longer payback period. Material and labor cost for aluminum piping is nearly 500000 to 600000 Rs.

As comparing with both aluminum and steel piping for Choundeshawari Soot Girini. Piping of higher performance plastic is best suitable for this. The advantages of the plastic piping are the less pressure drop, minimum leak rate, higher payback period and less cost. The cost of plastic piping as per current market survey is 250000 Rs. As the joint of the piping are made by the thermal joint there is less chance of leak at the joint

Piping system should be test under EN ISO 13845:2000, Plastics Piping system – Test method for leak-tightness under internal pressure

As comparing the all these materials the high performance pipe is best suitable

Pipe Line Layout Design

Properly designed layout of compressed air system can reduces the pressure drop in the pipeline which also helps to maintain the constant pressure throughout the system. Layout of compressed air system for this industry was open loop. The open loop layout causes the pressure drop.

The newly designed closed loop system in 3D for Choudeshwari soot girini as shown below

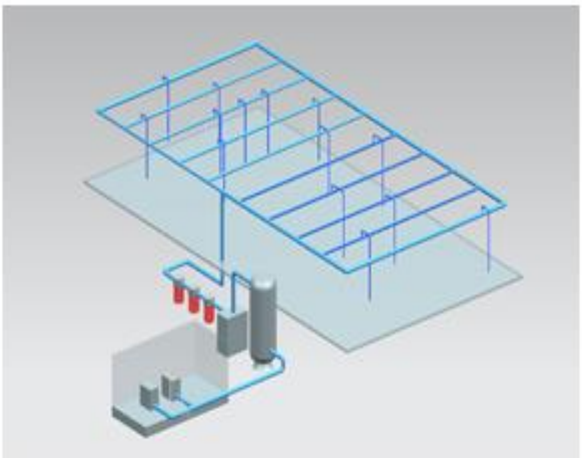


Figure 3 . Close loop CAS pipeline layout for Choundeshawari Soot Girini.

7. Pressure drop calculation

Pressure drop for newly design is calculated and discussed below table pressure drop is calculated by means of software called as SF pressure drop calculator

Once, all compressor installation components are selected. Calculate pressure drop through the system. It should not be too high. All compressor installation should be schematically drawn on network diagram. Pressure drop for the optimized system as calculated from the From result of software output the minimum pressure drop throughout the system that can be maintain through above design methodology is 1.711 bar. Whereas discussed above result of exiting system pressure drop was 2.7662 bar. It means that nearly 1 bar pressure drop can be reduced by this design methodology. As many studies stated that 1 bar pressure drop can save the significant energy.

Air ventilation and minimum temperature in compressor room

Air ventilation in compressor room

Air flow rate and air temperature in compressor room will directly affects the compressor power consumption. The compressor room air flow for this textile industry is calculated as by follow.

Ventilation required in compressor room as follows

$$m = \frac{P}{C_p \times \nabla T}$$

P= roughly 94 % of the supplied shaft power to compressor + difference between supplied total power for compressor package and the supplied shaft power to compressor

∇T =maximum allowed ventilation air temperature difference in compressor room (10 °C)

P = 0.94 ×32 + (36 -32)

$$P \approx 38\ kW$$

$$m = \frac{38}{1.006 \times 10}$$

m =3.7 Kg/sec

m =3.7 ×1.2 =3.08 m^3/sec

Room should be design in such way that there should be air flow rate of 3.08 m^3/sec to increase the performance of compressor.

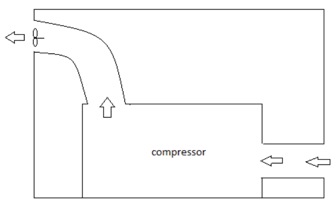
Minimum temperature in compressor room

As a thumb rule, "Every 4°C rise in inlet air temperature results in a higher energy consumption by 1 % to achieve equivalent output". Hence, cool air intake leads to a more efficient compression. During visit to the industry it was found that average temperature in compressor room was 37 ℃, whereas the average surrounding temperature was 30 ℃.

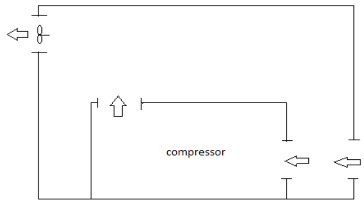
It means that with proper exhaust air duct design can reduces the temperature in the compressor room. Air duct design for compressor as shown below

By design the duct in this way can save the $\mathbf{4813.02}\ ^{Kwh}/_{year}$ by maintaining the compressor room temperature up to 30 ℃ and air flow rate 3.08 m^3/sec

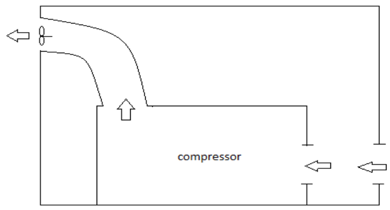
Various options for Air duct for maintaining minimum temperature



Option 1



Option 2



Option 3

Figure 4. Air ventilation in compressor room

Out of all three options given above 3 option for air ventilation is best for the Choundeshawari Soot Girini.

Energy saving though maintaining air ventilation

Average temperature of compressor room was found 37 ^{0}C whereas average temperature of surrounding in the plant area is 29 °C

Fraction of compressor work reduction by reducing intake air temperature

$$W_R = \frac{[37-29]}{37+273}$$

$$W_R = 0.0258$$

Monthly demand saving, at unload condition,

$$DS_1 = (11.11\ kw) \times 0.95 \times 0.0258 / 0.89$$

$$DS_1 = 0.3059 \frac{Kw}{month}$$

At load condition,

$$DS_2 = 33.34 \times 0.95 \times 0.0258 / 0.92$$

$$DS_2 = 0.888 \frac{Kw}{month}$$

Total demand saving per month,

$$DS = DS_1 + DS_2$$

$$DS = 0.3059 + 0.888$$

$$DS = 1.194 \quad \frac{Kw}{month}$$

Annual energy usage saving,

At unload condition,

$$US_1 = 0.3059 \times 6000 \times 0.3$$

$$US_1 = 550.62\ ^{Kwh}/_{year}$$

At load condition,

$$US_1 = 0.888 \times 6000 \times 0.8$$

$$US_1 = 4262.4\ ^{Kwh}/_{year}$$

Total annual energy saving

$$US = 550.62 + 4262.4\ ^{Kwh}/_{year}$$

$$US_1 = 4813.02\ ^{Kwh}/_{year}$$

Annual Cost of energy saving

=4813.02 × 7.6

= 36578.75 Rs/year

Design of special case CASs

Intermitted output

If one of consumer of compressed air system say blower room require further 35 m3/ hrs for 60 seconds of every hour. In such case the air receiver we have design will become

insufficient. Therefore it is require adding the extra receiver. The volume of this extra air receiver is calculated as follows.
Air flow required (Q) = 35 m^3/hrs =9.72 m^3/sec

$$V = \frac{Q \times T}{P_1 - P_2}$$

$$V = \frac{9.72 \times 60}{7.3 - 6.69}$$

$$V = 956.06\ liters$$

$$V = 0.956\ m^3 \approx 1\ m^3$$

Hence for the extra intermitted output the 1 m3 volume extra receiver is required

Waste heat recovery from compressor

During compression of air lot of heat is generated which can be utilized for different purposes as per need of industry. The amount of heat generated from compressor and amount of energy recover from compressor can be calculated as follow;
Assuming that compressor is working at full load for 4000 hrs of year. As per many studies it was found that 50 % of total energy can be recovered by waste heat recovery.
Heat can be recovered =0.5×32 =16 kW
Amount of energy recovered annually
Energy can be recovered=16×4000
= 64000 kWh/ year
Cost of energy =7.6 ×64000
=486400 Rs/ year
Recover heat from the compressor can be used for heating the room/ water, which can save energy of heating air or water.

Life cycle cost analysis

Calculating energy cost, capital cost maintenance cost for CAS and analyzing a cost is important can play important role in design of compressed air system. This can be done by life cycle cost analysis.

Energy cost

For calculating energy cost of optimized CA system firstly we have to calculate energy consumption of this system. Consider that compressors are running for 6000 hrs/year. Out of 6000 hrs, 5400 hrs are compressor loading hours and 600 hrs are compressor unload hours
Power consumed during load hours =35.6 kW
Power consumed during unload hours = 11.87 kW
Annual energy consumption during load hours = 35.6 ×5400 =192240 kWh
Annual energy consumption during unload hours = 11.87× 600 =7122 kWh
Total annual energy consumed by compressor = 1192240 + 7122 =199363 kWh
Energy saving through optimized design

As discussed in above chapter the energy saving can be possible though optimized design through maintaining air ventilation in compressor room and through waste heat recovery. As calculated above the possible energy saving through optimized design as follow,
Saving through air ventilation =4814 kWh/ year
Saving through waste heat recovery = 64000 kWh/year
Total saving = 4814 + 64000 = 68814 kWh/year
Total energy consumption of optimized system is 199363 – 68814 = 130549 kWh/year
As calculated above energy consumption of optimized system is 130549 kWh. Energy cost per kWh is 7.6 Rs.
Energy cost for optimized system =130549 ×7.6 = 992172.4 Rs/year

Capital cost and installation cost

Purchase price of compressor is estimated at Rs 3000000 over liner depreciation of 10 years with interest rate of 8%. Yearly cost for investment is calculated as
3000000/10 ×1.08 =324000 /year

Maintenance cost

Compressor runs for 6000 hours. Maintenance cost for CAS per year is 50000/year

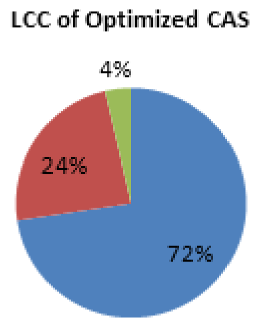
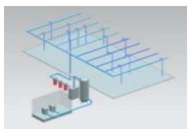
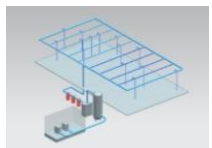
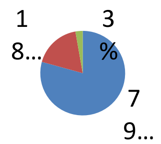
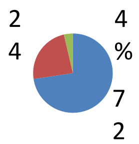


Figure 5. LCC of Optimized CAS.

Comparison

Table 6 . Comparison between two CASs.

	Exiting system	**Optimized system**
Compressor specification		
Compressor type:	single stage screw compressor	single stage screw compressor
Capacity:	272 m^3/hr	287 m^3/hr
Motor rating :	30 kW	32 kW
System Discharge Control Range	7- 7.5 bar	7- 7.5 bar
Air receiver capacity (m^3)	2 m^3	2 m^3 + 1 m^3(special case)
Energy consumption	188552 kWh/year	130549 kWh/year
LCC analysis	Energy cost = 1432995.2 Rs/ year	Energy cost = 992172.4 Rs/year
Piping system		
Main header diameter	65 mm	65 mm
Pipe material	Galvanized steel	High performance plastic
Cost of piping	Rs 200000	Rs 250000
Layout	Open loop system	Close loop system
Pressure drop in pipe	Pressure drop = 2.7662 bar Higher due to friction, leak etc	Pressure drop = 1.7112 bar Lower due to less friction ,minimum leakages etc
Layout network		
LCC		

Results

From above discussion, it has been observed that the significant energy saving can be possible through designing the system by this methodology. As study carry out using the same specification of Choundeshwari Soot Girini compressed air system following results are found which can save the considerable energy in industry.

In optimized compressed air system although the system capacity is more than exiting system the energy saving can possible through the air ventilation in compressor room, by reducing pressure drop and by heat recovery from compressor.

Through optimized system possible Energy saving with heat recovery is 58003 kWh/year this can save the 440822.8 Rs/year. Hence near about 30 % energy saving can be possible through optimized CAS with heat recovery.

Many of industry will not able to get waste heat recovery through the compressor due the high investment cost and lack of recoverable heat application. For this industry energy saving possible without waste heat recovery is 4814 kWh/year which can save 36586 Rs/year.

Also in the newly designed optimized system will maintain the constant pressure throughout the system and near about 1 bar pressure drop can be reduce through effective pipe diameter calculation and piping material selection and closed loop piping system.

Conclusion

During project work study of compressed air system carried out at textile industry Choundeshawari Soot Girini Ltd Jaysingpur, it was found that significant energy saving can be possible through energy analysis and various energy efficiency measures and through energy efficient design methodology.

Energy cost plays an important role in compressed air LCC. If the compressed air system designed by using this methodology can save 10 to 30 % of energy of compressed air system. In the energy efficient design of system key factor which can reduces the energy consumption are pipe layout, air ventilation in compressed room selection of compressor and air receiver volume.

In this textile industry, system designed layout was open loop which causes significant pressure drop in this system. This 1bar pressure drop can be reducing by closed loop system layout which can also able to maintain constant pressure throughout system.

Compressor room temperature and relative humidity and Compressor room air ventilation can cause direct impact on compressor power consumption. The compressor room air velocity was found to be more than 4 m/s. This air velocity can be reducing to 3 to 3.5 m/s through effective air duct design as discussed above.

The significant energy recovery can possible through effective waste heat recovery method as per requirement of industry. Nearly 50% of heat generated can be possible through this as discussed above

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