COMPRESSORS AND COMPRESSED AIR SYSTEMS

1. INTRODUCTION

Industrial plants use compressed air throughout their production operations, which is produced by compressed air units ranging from 5 horsepower (hp) to over 50,000 hp. The US Department of Energy (2003) reports that 70 to 90 percent of compressed air is lost in the form of unusable heat, friction, misuse and noise (see figure 1). For this reason, compressors and compressed air systems are important areas to improve energy efficiency at industrial plants.
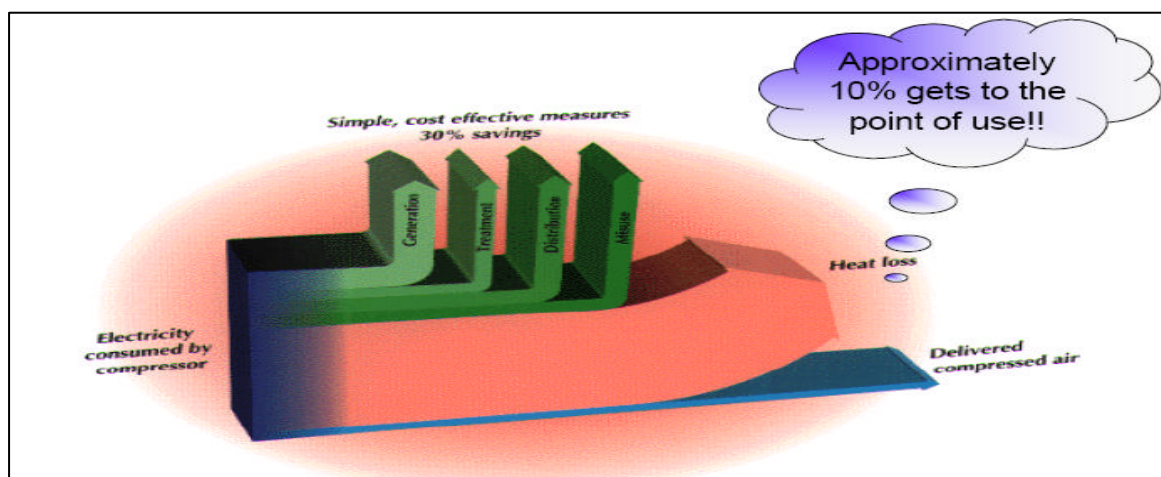

Figure 1. Shanky Diagram for Compressed Air System (McKane and Medaris, 2003)

It is worth noting that the running cost of a compressed air system is far higher than the cost of a compressor itself (see Figure 2). Energy savings from system improvements can range from 20 to 50 percent or more of electricity consumption, resulting in thousands to hundreds of thousands of dollars. A properly managed compressed air system can save energy, reduce maintenance, decrease downtime, increase production throughput, and improve product quality.
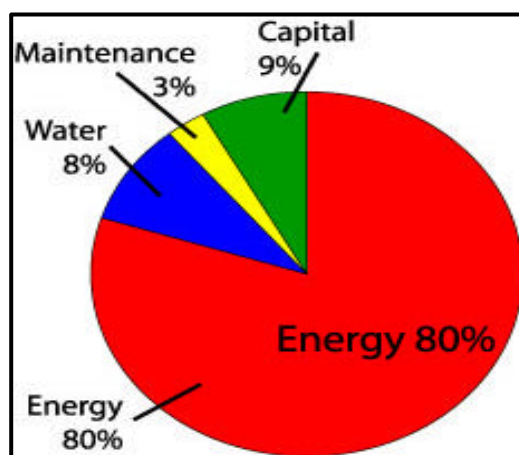

Figure 2. Cost components in a typical compressed air system (eCompressedAir)

Compressed air systems consist of a supply side, which includes compressors and air treatment, and a demand side, which includes distribution and storage systems and end-use equipment. A properly managed supply side will result in clean, dry, stable air being delivered at the appropriate pressure in a dependable, cost-effective manner. A properly managed demand side minimizes wasted air and uses compressed air for appropriate applications. Improving and maintaining peak compressed air system performance requires addressing both the supply and demand sides of the system and how the two interact.

1.1 Main Components of Compressed Air Systems

Compressed air systems consist of following major components: Intake air filters, inter-stage coolers, after-coolers, air-dryers, moisture drain traps, receivers, piping network, filters, regulators and lubricators (see Figure 3).

- **Intake Air Filters**: Prevent dust from entering a compressor; Dust causes sticking valves, scoured cylinders, excessive wear etc.
- **Inter-stage Coolers**: Reduce the temperature of the air before it enters the next stage to reduce the work of compression and increase efficiency. They are normally water-cooled.
- **After-Coolers:** The objective is to remove the moisture in the air by reducing the temperature in a water-cooled heat exchanger.
- **Air-dryers**: The remaining traces of moisture after after-cooler are removed using air dryers, as air for instrument and pneumatic equipment has to be relatively free of any moisture. The moisture is removed by using adsorbents like silica gel /activated carbon, or refrigerant dryers, or heat of compression dryers.

- **Moisture Drain Traps:** Moisture drain traps are used for removal of moisture in the compressed air. These traps resemble steam traps. Various types of traps used are manual drain cocks, timer based / automatic drain valves etc.
- **Receivers**: Air receivers are provided as storage and smoothening pulsating air output - reducing pressure variations from the compressor
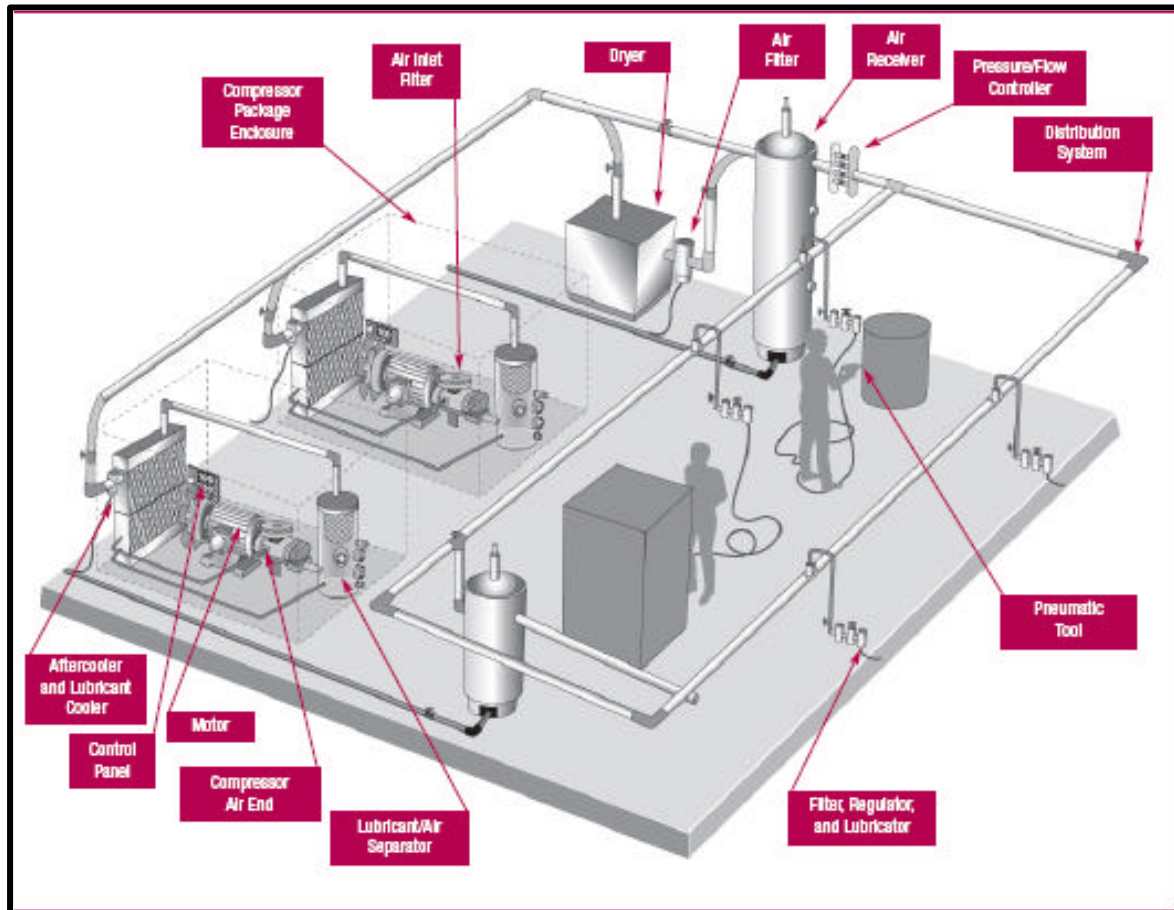

Figure 3. Types of Compressor Components (US DOE, 2003)

2. TYPES OF COMPRESSORS

As shown in Figure 4, there are two basic compressor types: positive-displacement and dynamic.

In the positive-displacement type, a given quantity of air or gas is trapped in a compression chamber and the volume it occupies is mechanically reduced, causing a corresponding rise in pressure prior to discharge. At constant speed, the air flow remains essentially constant with variations in discharge pressure.

Dynamic compressors impart velocity energy to continuously flowing air or gas by means of impellers rotating at very high speeds. The velocity energy is changed into pressure energy both by the impellers and the discharge volutes or diffusers. In the centrifugal-type dynamic

compressors, the shape of the impeller blades determines the relationship between air flow and the pressure (or head) generated.
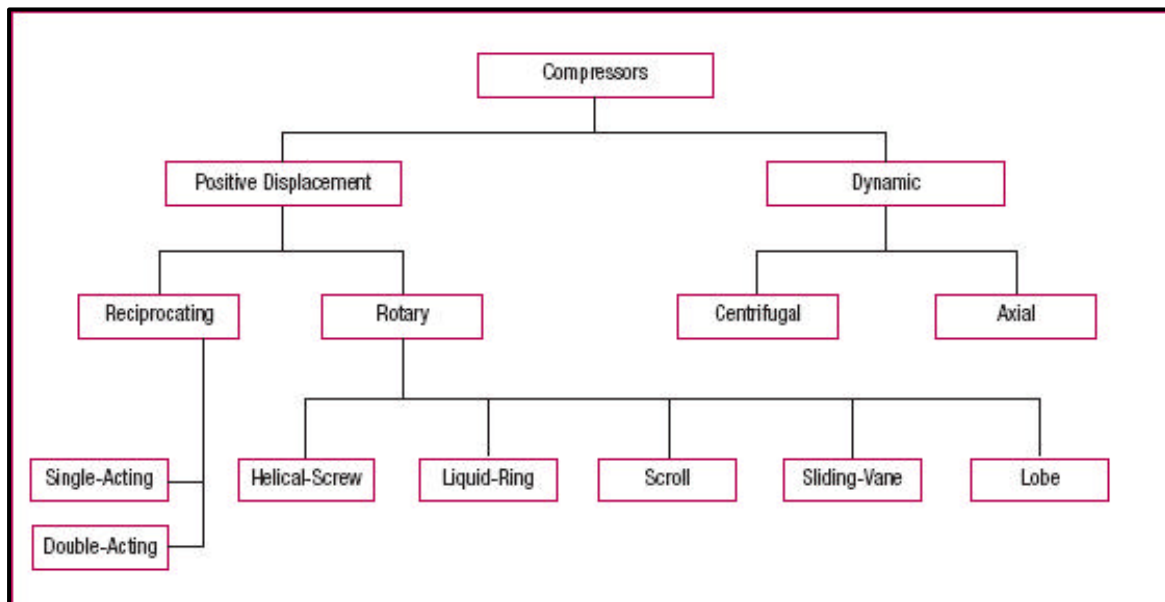
Figure 4. Types of Compressors (US DOE, 2003)

2.1 Positive Displacement Compressor

These compressors are available in two types: reciprocating and rotary.

2.1.1 Reciprocating compressor

In industry, reciprocating compressors are the most widely used type for both air and refrigerant compression (see Figure 5). They work on the principles of a bicycle pump and are characterized by a flow output that remains nearly constant over a range of discharge pressures. Also, the compressor capacity is directly proportional to the speed. The output, however, is a pulsating one.

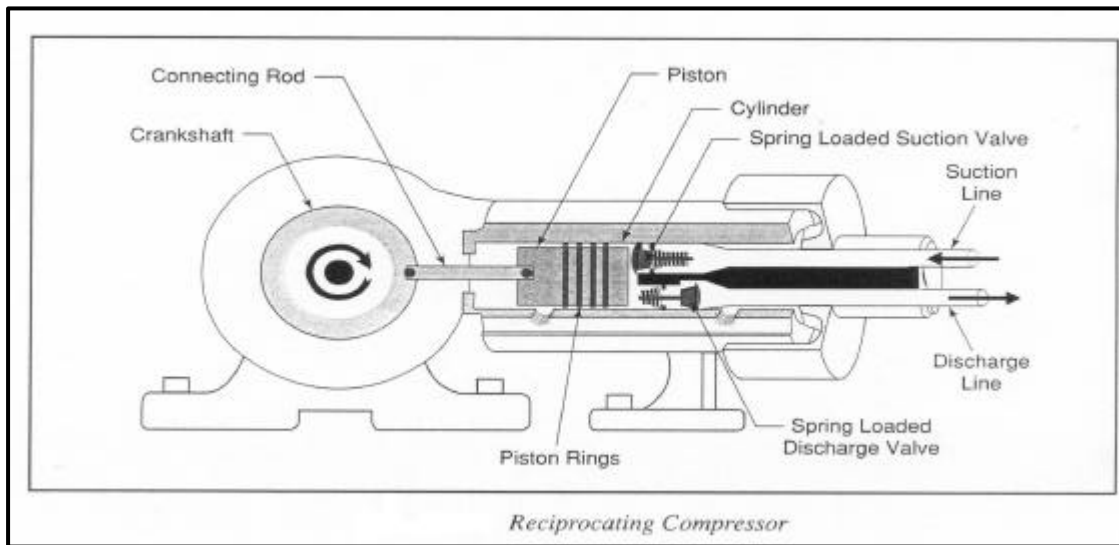**Figure 5. A cross-sectional view of a reciprocating compressor** (King, Julie)

Reciprocating compressors are available in many configurations, the four most widely used are horizontal, vertical, horizontal balance-opposed and tandem. Vertical type reciprocating compressors are used in the capacity range of 50 – 150 cfm. Horizontal balance opposed compressors are used in the capacity range of 200 – 5000 cfm in multi-stage design and up to 10,000 cfm in single stage designs (National Productivity Council, 1993).

The reciprocating air compressor is considered single acting when the compressing is accomplished using only one side of the piston. A compressor using both sides of the piston is considered double acting.

A compressor is considered to be single stage when the entire compression is accomplished with a single cylinder or a group of cylinders in parallel. Many applications involve conditions beyond the practical capability of a single compression stage. Too great a compression ratio (absolute discharge pressure/absolute intake pressure) may cause excessive discharge temperature or other design problems. Two stage machines are used for high pressures and are characterized by lower discharge temperature (140 to 160°C) compared
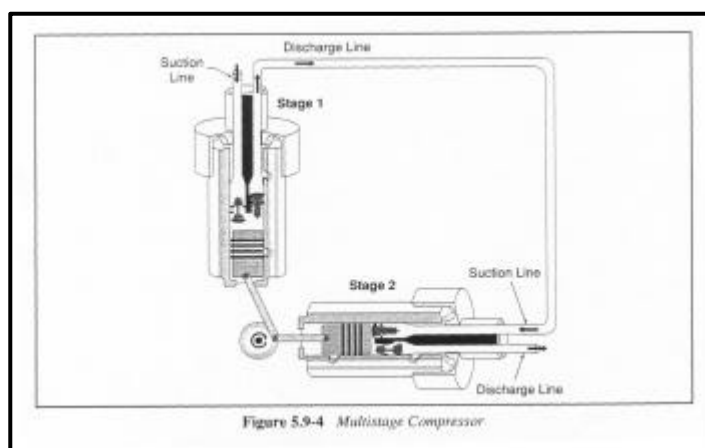

Figure 6. View of a multistage compressor
(King, Julie)

to single-stage machines (205 to 240ºC).

For practical purposes most plant air reciprocating air compressors over 100 horsepower are built as multi-stage units in which two or more steps of compression are grouped in series. The air is normally cooled between the stages to reduce the temperature and volume entering the following stage. (National Productivity Council, 1993).

Reciprocating air compressors are available either as air-cooled or water-cooled in lubricated and non-lubricated configurations, may be packaged, and provide a wide range of pressure and capacity selections.

2.1.2 Rotary compressor

Rotary compressors have rotors in place of pistons and give a continuous pulsation free discharge. They operate at high speed and generally provide higher throughput than reciprocating compressors. Their capital costs are low, they are compact in size, have low weight, and are easy to maintain. For this reason they have gained popularity with industry. They are most commonly used in sizes from about 30 to 200 hp or 22 to 150 kW.

Types of rotary compressors include:
- Lobe compressor (roots blower)
- Screw compressor (rotary screw of helical-lobe, where mail and female screw rotors moving in opposite directions and trap air, which is compressed as it moves forward, see Figure 7)
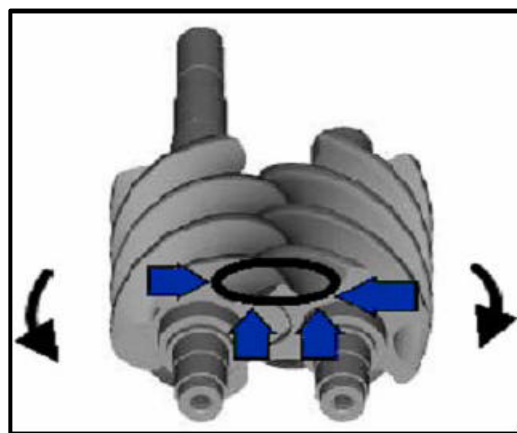- Rotary vane / sliding-vane, liquid-ring, and scroll-type

Figure 7. View of screw compressor
(Reference unknown)

Rotary screw compressors may be air or water-cooled. Since the cooling takes place right inside the compressor, the working parts never experience extreme operating temperatures. The rotary compressor, therefore, is a continuous duty, air cooled or water cooled compressor package.

Because of the simple design and few wearing parts, rotary screw air compressors are easy to maintain, operate and provide great installation flexibility. Rotary air compressors can be installed on any surface that will support the static weight.

2.2 Dynamic Compressors

The centrifugal air compressor (see Figure 8) is a dynamic compressor, which depends on transfer of energy from a rotating impeller to the air. The rotor accomplishes this by changing the momentum and pressure of the air. This momentum is converted to useful pressure by slowing the air down in a stationary diffuser. The centrifugal air compressor is an oil free compressor by design. The oil lubricated running gear is separated from the air by shaft seals and atmospheric vents.

The centrifugal is a continuous duty compressor, with few moving parts, that is particularly suited to high volume applications-especially where oil free air is required.

Centrifugal air compressors are water-cooled and may be packaged; typically the package includes the after-cooler and all controls.

Figure 8. View of centrifugal compressor (King, Julie)
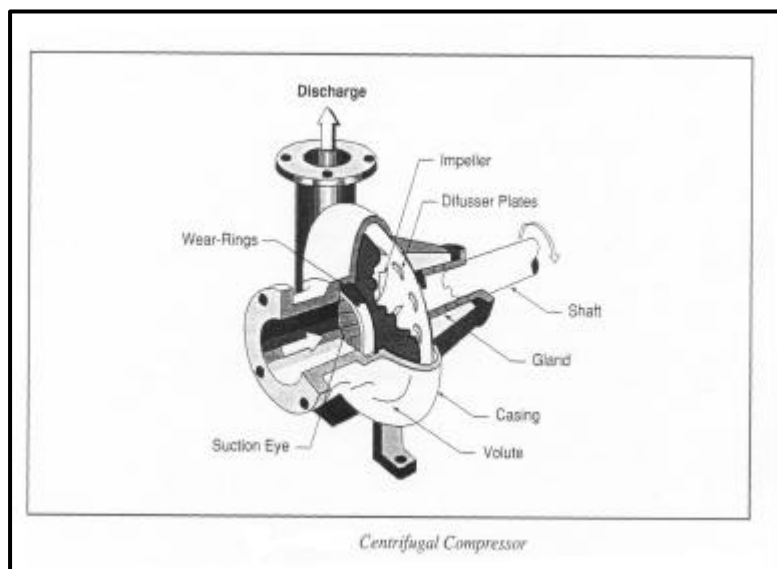
These compressors have appreciably different characteristics as compared to reciprocating machines. A small change in compression ratio produces a marked change in compressor output and efficiency. Centrifugal machines are better suited for applications requiring very high capacities, typically above 12,000 cfm.

Application wise selection criteria of different types of compressors are given in the following table.

Table 1. General Selection Criteria of Compressors (Confederation of Indian Industries)

Type of Compressor	Capacity (m³/h)		Pressure (bar)	
	From	To	From	To
Roots blower compressor single stage	100	30000	0.1	1
Reciprocating				
- Single / Two stage	100	12000	0.8	12
- Multi stage	100	12000	12.0	700
Screw				
- Single stage	100	2400	0.8	13
- Two stage	100	2200	0.8	24
Centrifugal	600	300000	0.1	450

Table 2. A high-level comparison of important compressor types
(Sustainable Energy Development Office, 2002)

Item	Reciprocating	Rotary Vane	Rotary Screw	Centrifugal
Efficiency at full load	High	Medium - high	High	High
Efficiency at part load	High due to to staging	Poor: below 60% of full load	Poor: below 60% of full load	Poor: below 60% of full load
Efficiency at no load (power as % of full load)	High (10% - 25%)	Medium (30% - 40%)	High-Poor (25% - 60%)	High-Medium (20% - 30%)
Noise level	Noisy	Quiet	Quiet-if enclosed	Quiet
Size	Large	Compact	Compact	Compact
Oil carry over	Moderate	Low-medium	Low	Low
Vibration	High	Almost none	Almost none	Almost none
Maintenance	Many wearing parts	Few wearing parts	Very few wearing parts	Sensitive to dust in air
Capacity	Low - high	Low - medium	Low - high	Medium - high
Pressure	Medium - very high	Low - medium	Medium - high	Medium - high

3. ASSESSMENT OF COMPRESSORS AND COMPRESSED AIR SYSTEMS

3.1 Capacity of a Compressor

The capacity of a compressor is the full rated volume of flow of gas compressed and delivered under conditions of total temperature, total pressure, and composition prevailing at the compressor inlet. It sometimes means actual flow rate, rather than rated volume of flow. This is also called free air delivery (FAD) i.e. air at atmospheric conditions at any specific location. This term does not mean air delivered under identical or standard conditions because the altitude, barometer, and temperature may vary at different localities and at different times.

3.1.1 Assessment of capacity of a compressor

Due to ageing of the compressors and inherent inefficiencies in the internal components, the free air delivered may be less than the design value, despite good maintenance practices. Sometimes, other factors such as poor maintenance, fouled heat exchanger and effects of altitude also tend to reduce free air delivery. In order to meet the air demand, the inefficient compressor may have to run for more time, thus consuming more power than actually required.

The power wastage depends on the percentage deviation of FAD capacity. For example, a worn out compressor valve can reduce the compressor capacity by as much as 20 percent. A periodic

assessment of the FAD capacity of each compressor has to be carried out to check its actual capacity. If the deviations are more than 10 percent, corrective measures should be taken to rectify the same.

The ideal method of compressor capacity assessment is through a nozzle test wherein a calibrated nozzle is used as a load, to vent out the generated compressed air. Flow is assessed, based on the air temperature, stabilizationpressure, orifice constant, etc.

3.1.2 Simple method of capacity assessment at the shop floor

- Isolate the compressor along with its individual receiver that are to be taken for a test from the main compressed air system by tightly closing the isolation valve or blanking it, thus closing the receiver outlet.
- Open the water drain valve and drain out water fully and empty the receiver and the pipeline. Make sure that the water trap line is tightly closed once again to start the test.
- Start the compressor and activate the stopwatch.
- Note the time taken to attain the normal operational pressure P_2 (in the receiver) from initial pressure P_1.
- Calculate the capacity as per the formulae given below (Confederation of Indian Industries):

Actual Free air discharge

$$Q = \frac{P_2 - P_1}{P_0} \times \frac{V}{T} \ Nm^3 / Minute$$

Where

P_2	=	Final pressure after filling (kg/cm^2 a)
P_1	=	Initial pressure (kg/cm^{2}a) after bleeding
P_0	=	Atmospheric Pressure (kg/cm^2 a)
V	=	Storage volume in m^3 which includes receiver, after cooler, and delivery piping
T	=	Time take to build up pressure to P_2 in minutes

The above equation is relevant where the compressed air temperature is the same as the ambient air temperature, i.e., perfect isothermal compression. In case the actual compressed air temperature at discharge, say t_2 $^{\circ}$C is higher than ambient air temperature say t_1 ^{0}C (as is usual case), the FAD is to be corrected by a factor $(273 + t_1) / (273 + t_2)$.

3.2 Compressor Efficiency

Several different measures of compressor efficiency are commonly used: *volumetric efficiency, adiabatic efficiency, isothermal efficiency and mechanical* efficiency.

Adiabatic and isothermal efficiencies are computed as the isothermal or adiabatic power divided by the actual power consumption. The figure obtained indicates the overall efficiency of a compressor and drive motor.

3.2.1 Isothermal efficiency

Isothermal Efficiency = Actual measured input power *I IsothermalPower*

Isothermal power (kW) = P_1 x Q_1 x $\log_e r / 36.7$
Where P_1 = Absolute intake pressure kg/ cm^2
              Q_1 = Free air delivered m^3/hr.
              r   = Pressure ratio P_2/P_1

The calculation of isothermal power does not include power needed to overcome friction and generally gives an efficiency that is lower than adiabatic efficiency. The reported value of efficiency is normally the isothermal efficiency. This is an important consideration when selecting compressors based on reported values of efficiency.

3.2.2 Volumetric Efficiency

$$\boxed{\text{Volumetric efficiency} \quad = \quad \frac{\text{Free air delivered } m^3/\text{min}}{\text{Compressor displacement}}}$$

       Compressor Displacement = ? x $D^2/4$ x L x S x ? x n

      Where   D = Cylinder bore, metre
                       L = Cylinder stroke, metre
                       S = Compressor speed rpm
                       ? = 1 for single acting and
                           2 for double acting cylinders
                       n = No. of cylinders

For practical purposes, the most effective guide in comparing compressor efficiencies is the specific power consumption, i.e. kW/volume flow rate, for different compressors that would provide identical duty.

3.3 Performance Assessment of Distribution Losses In the compressed air system

3.3.1 Leak can set and consequences

A system of distribution pipes and regulators convey compressed air from the central compressor plant to process areas. This system includes various isolation valves, fluid traps, intermediate storage vessels, and even heat trace on pipes to prevent condensation or freezing in lines exposed to the outdoors. Pressure losses in distribution typically are compensated for by higher pressure at the compressor discharge.

At the intended point of use, a feeder pipe with a final isolation valve, filter, and regulator carries the compressed air to hoses that supply processes or pneumatic tools.

Leaks can be a significant source of wasted energy in an industrial compressed air system, sometimes wasting 20 to 30 percent of a compressor's output. A typical plant that has not been well maintained will likely have a leak rate equal to 20 percent of total compressed air production capacity. On the other hand, proactive leak detection and repair can reduce leaks to less than 10 percent of compressor output.

In addition to being a source of wasted energy, leaks can also contribute to other operating losses. Leaks cause a drop in system pressure, which can make air tools function less efficiently, adversely affecting production. In addition, by forcing the equipment to run longer, leaks shorten the life of almost all system equipment (including the compressor package itself). Increased running time can also lead to additional maintenance requirements and increased unscheduled downtime. Finally, leaks can lead to adding unnecessary compressor capacity.

While leakage can come from any part of the system, the most common problem areas are:
- Couplings, hoses, tubes, and fittings
- Pressure regulators
- Open condensate traps and shut-off valves
- Pipe joints, disconnects, and thread sealants.

Leakage rates are a function of the supply pressure in an uncontrolled system and increase with higher system pressures. Leakage rates identified in cubic feet per minute (cfm) are also proportional to the square of the orifice diameter. See table below.

Table 3. Leakage Rates for different supply pressure and orifice sizes (US DOE, 2004)

Leakage Rates* (cfm)						
Pressure (psig)	**Orifice Diameter (inches)**					
	1/64	**1/32**	**1/16**	**1/8**	**1/4**	**3/8**
70	0.29	1.16	4.66	18.62	74.40	167.80
80	0.32	1.26	5.24	20.76	83.10	187.20
90	0.36	1.46	5.72	23.10	92.00	206.60
100	0.40	1.55	6.31	25.22	100.90	227.00
125	0.48	1.94	7.66	30.65	122.20	275.50
* For well-rounded orifices, values should be multiplied by 0.97 and by 0.611 for sharp ones						

3.2.2 Leak quantification

For compressors that have start/stop or load/unload controls, there is an easy way to estimate the amount of leakage in the system. This method involves starting the compressor when there are no demands on the system (when all the air-operated, end-use equipment is turned off). A number of measurements are taken to determine the average time it takes to load and unload the compressor. The compressor will load and unload because the air leaks will cause the

compressor to cycle on and off as the pressure drops from air escaping through the leaks. Total leakage (percentage) can be calculated as follows:

$$\text{Leakage (\%)} = [(T \times 100)/(T+t)]$$

where: T = on-load time (minutes)
         t = off-load time (minutes)

Leakage will be expressed in terms of the percentage of compressor capacity lost. The percentage lost to leakage should be less than 10 percent in a well-maintained system. Poorly maintained systems can have losses as high as 20 to 30 percent of air capacity and power.

3.3.3 Steps in simple shop floor method of leak quantification

The methods for simple shop floor measurement for " Leak Quantification" of a compressed air system are as follows:

- Shut off compressed air operated equipments (or conduct a test when no equipment is using compressed air).
- Run the compressor to charge the system to set pressure of operation
- Note the subsequent time taken for "Load" and "Unload" Cycles of the compressors. For accuracy, take ON & OFF times for 8 – 10 cycles continuously. Then calculate total 'ON' Time (T) and Total 'OFF' time (t).
- Use the above expression to find out the quantity of leakage in the system. If Q is the actual free air being supplied during trial (m^3/min), then the system leakage (m^3/min) would be:

$$\textbf{System leakage (}m^3\textbf{/minute)} = Q \times T / (T + t)$$

Example

In the leakage test in a process industry, following results were observed

Compressor capacity (m^3/minute)	= 35
Cut in pressure, kg/cm^2	= 6.8
Cut out pressure, kg/cm^2	= 7.5
Load kW drawn	= 188 kW
Unload kW drawn	= 54 kW
Average 'Load' time	=1.5 minutes
Average 'Unload' time	= 10.5 minutes

Quantity of Leakage = [(1.5)/(1.5+10.5)] x 35 = 4.375 m^3/minute

4. ENERGY EFFICIENCY OPPORTUNITIES

4.1 Location of Compressor

The location of air compressors and the quality of air drawn by the compressors will have a significant influence on the amount of energy consumed. Compressor performance as a breathing machine improves with cool, clean, dry air at intake.

4.2 Air Intake Temperature

The effect of intake air on compressor performance should not be underestimated. Intake air that is contaminated or hot can impair compressor performance and result in excess energy and maintenance costs. If moisture, dust, or other contaminants are present in the intake air, such contaminants can build up on the internal components of the compressor, such as valves, impellers, rotors, and vanes. Such build-up can cause premature wear and reduce compressor capacity.

The compressor generates heat due to its continuous operation. This heat gets dissipated to compressor room/ chamber leading to hot air intake. This results in lower volumetric efficiency and higher power consumption. As a general rule, *" Every 4°C rise in inlet air temperature results in a higher energy consumption by 1percent to achieve equivalent output"*. Hence the intake of cool air improves the energy efficiency of a compressor (see table 4).

Table 4. Effect of intake air temperature on compressor power consumption
(Confederation of Indian Industries)

Inlet Temperature (°C)	Relative Air Delivery (%)	Power Saved (%)
10.0	102.0	+ 1.4
15.5	100.0	Nil
21.1	98.1	- 1.3
26.6	96.3	- 2.5
32.2	94.1	- 4.0
37.7	92.8	- 5.0
43.3	91.2	- 5.8

When an intake air filter is located at the compressor, the ambient temperature should be kept at a minimum, to prevent reduction in mass flow. This can be accomplished by locating the inlet pipe outside the room or building. When the intake air filter is located outside the building, and particularly on a roof, ambient considerations may be taken into account.

4.3 Pressure Drops in Air Filter

A compressor intake air filter should be installed in, or have air brought to it from a clean, cool location. The compressor manufacturer normally supplies, or recommends, a specific grade of intake filter designed to protect the compressor. The better the filtration at the compressor inlet,

the lower the maintenance at the compressor. However, the pressure drop across the intake air filter should be kept at a minimum (by size and by maintenance) to prevent a throttling effect and a reduction in compressor capacity. A pressure differential gauge is one of the best tools to monitor the condition of the inlet filter. The pressure drop across a new inlet filter should not exceed 3 pounds per square inch (psi). Table 5 indicates the effect of pressure drop across air filter on power consumption.

Table 5. Effect of pressure drop across the filter on increase in power consumption
(Confederation of Indian Industries)

Pressure Drop Across air filter (mmWC)	Increase in Power Consumption (%)
0	0
200	1.6
400	3.2
600	4.7
800	7.0

As a general rule *"For every 250 mm WC pressure drop increase across at the suction path due to choked filters etc, the compressor power consumption increases by about 2 percent for the same output."*

Hence, it is advisable to clean inlet air filters at regular intervals to minimize pressure drops. Manometers or differential pressure gauges across filters may be used to monitor pressure drops so as to plan filter-cleaning schedules.

4.4 Elevation

Altitude has a direct impact on the volumetric efficiency of a compressor. The effect of altitude on volumetric efficiency is given in the Table 6.

It is evident that compressors located at higher altitudes consume more power to achieve a particular delivery pressure than those at sea level, as the compression ratio is higher.

Table 6. Effect of altitude on compressor volumetric efficiency
(Confederation of Indian Industries)

Altitude Meters	Barometric Pressure milli bar*	Percentage Relative Volumetric Efficiency Compared with Sea Level	
		At 4 bar	At 7 bar
Sea level	1013	100.0	100.0
500	945	98.7	97.7
1000	894	97.0	95.2
1500	840	95.5	92.7
2000	789	93.9	90.0
2500	737	92.1	87.0

* 1 milli bar = 1.01972×10^{-3} kg/cm^2

4.5 Inter and After-Coolers

Most multi-stage compressors use intercoolers, which are heat exchangers that remove the heat of compression between the stages of compression. Intercooling affects the overall efficiency of the machine.

As mechanical energy is applied to a gas for compression, the temperature of the gas increases. After-coolers are installed after the final stage of compression to reduce the air temperature. As the air temperature is reduced, water vapor in the air is condensed, separated, collected, and drained from the system. Most of the condensate from a compressor with intercooling is removed in the intercooler(s), and the remainder in the after-cooler. Almost all industrial systems, except those that supply process air to heat-indifferent operations, require after-cooling. In some systems, after-coolers are an integral part of the compressor package, while in other systems the after-cooler is a separate piece of equipment. Some systems have both.

Ideally, the temperature of the inlet air at each stage of a multi-stage machine should be the same as it was at the first stage. This is referred to as "perfect cooling" or isothermal compression. But in actual practice, the inlet air temperatures at subsequent stages are higher than the normal levels resulting in higher power consumption, as larger volume is handled for the same duty (See Table 7).

Table 7. Illustration of Effect of Intercooling on Compressor Power Consumption
(Confederation of Indian Industries)

Details	Imperfect Cooling	Perfect Cooling (Base Value)	Chilled Water Cooling
First Stage inlet temperature ^{0}C	21.1	21.1	21.1
Second Stage inlet temperature ^{0}C	26.6	21.1	15.5
Capacity (nm^3/min)	15.5	15.6	15.7
Shaft Power (kW)	76.3	75.3	74.2
Specific energy consumption kW (nm^3/min)	4.9	4.8	4.7
Percent Change	+ 2.1	Reference	- 2.1

Use of water at lower temperature reduces specific power consumption. However, very low cooling water temperature could result in condensation of moisture in the air, which if not removed would lead to cylinder damage.

Similarly, inadequate cooling in after-coolers (due to fouling, scaling etc.), allow warm, humid air into the receiver, which causes more condensation in air receivers and distribution lines, which in consequence, leads to increased corrosion, pressure drops and leakages in piping and end-use equipment. Periodic cleaning and ensuring adequate flow at proper temperature of both intercoolers and after-coolers are therefore necessary for sustaining desired performance.

4.6 Pressure Setting

For the same capacity, a compressor consumes more power at higher pressures. Compressors should not be operated above their optimum operating pressures as this not only wastes energy, but also leads to excessive wear, leading to further energy wastage. The volumetric efficiency of a compressor is also less at higher delivery pressures.

4.6.1 Reducing delivery pressure

The possibility of lowering (optimizing) the delivery pressure settings should be explored by careful study of pressure requirements of various equipment, and the pressure drop in the line between the compressed air generation and utilization points. Typical power savings through pressure reduction is shown in Table 8.

If one point-of-use or a minority of users require higher pressures than the remainder of the plant, consider putting those operations on its own system or add a booster package at the point-of-use, therefore keeping the larger system operating at lower pressures. The operating of a compressed air system gently affects the cost of compressed air. Operating a compressor at 120 PSIG instead of 100 PSIG, for instance, requires 10 percent more energy as well as increasing the leakage rate. Every effort should be made to reduce the system and compressor pressure to the lowest possible setting.

Table 8: Effect of reduction in delivery pressure on power consumption
(Confederation of Indian Industries)

Pressure Reduction		Power Savings (%)		
From (bar)	To (bar)	Single-stage Water-cooled	Two-stage Water-cooled	Two-stage Air-cooled
6.8	6.1	4	4	2.6
6.8	5.5	9	11	6.5

Note: A reduction in the delivery pressure by 1 bar in a compressor would reduce the power consumption by 6 – 10 percent.

4.6.2 Compressor modulation by optimum pressure setting

Very often in an industry, different types, capacities and makes of compressors are connected to a common distribution network. In such situations, proper selection of a right combination of compressors and optimal modulation of different compressors can conserve energy.

Where more than one compressor feeds a common header, compressors have to be operated in such a way that the cost of compressed air generation is minimal.

- If all compressors are similar, the pressure setting can be adjusted such that only one compressor handles the load variation, whereas the others operate more or less at full load.
- If compressors are of different sizes, the pressure switch should be set such that only the smallest compressor is allowed to modulate (vary in flow rate).
- If different types of compressors are operated together, unload power consumptions are significant. The compressor with lowest no load power must be modulated.
- In general, the compressor with lower part load power consumption should be modulated.
- Compressors can be graded according to their specific energy consumption, at different pressures and with energy efficient ones made to meet most of the demand.

4.6.3 Segregating high & low pressure requirements

If the low-pressure air requirement is considerable, it is advisable to generate low-pressure and high-pressure air separately and feed to the respective sections instead of reducing the pressure through pressure reducing valves, which invariably waste energy.

4.6.4 Design for minimum pressure drop in the distribution line

Pressure drop is a term used to characterize the reduction in air pressure from the compressor discharge to the actual point-of-use. Pressure drop occurs as the compressed air travels through the treatment and distribution system. A properly designed system should have a pressure loss of much less than 10 percent of the compressor's discharge pressure, measured from the receiver tank output to the point-of-use.

The longer and smaller diameter the pipe is, the higher the friction loss. To reduce pressure drop effectively, a loop system with two-way flow can be used. Pressure drop caused by corrosion and the system components themselves are important issues.

Excess pressure drop due to inadequate pipe sizing, choked filter elements, improperly sized couplings and hoses represent energy wastage. Table 9 illustrates the energy wastage, if the pipes are of smaller diameter.

Typical acceptable pressure drop in industrial practice is 0.3 bar in mains header at the farthest point and 0.5 bar in distribution system.

Table 9. Typical pressure drop in compressed air line for different pipe size
(Confederation of Indian Industries)

Pipe Nominal Bore (mm)	Pressure drop (bar) per 100 meters	Equivalent power losses (kW)
40	1.80	9.5
50	0.65	3.4
65	0.22	1.2
80	0.04	0.2
100	0.02	0.1

4.7 Minimizing Leakage

As explained earlier, compressed air leakage accounts for substantial power wastage. Since air leaks are almost impossible to see, other methods must be used to locate them. The best way to detect leaks is to use an ultrasonic acoustic detector (see figure 10), which can recognize the high-frequency hissing sounds associated with air leaks.

Ultrasonic leak detection is probably the most versatile form of leak detection. It is readily adapted to a variety of leak detection situations.

Leaks occur most often at joints and connections. Stopping leaks can be as simple as tightening a connection or as complex as replacing faulty equipment, such as couplings, fittings, pipe sections, hoses, joints, drains, and traps. In many cases, leaks are caused by failed cleaning of threads or by bad or improperly applied thread sealant. Select high quality fittings, disconnects, hose, tubing, and install them properly with appropriate thread sealant to avoid future leakages.

Figure 9. Ultrasonic leak detector (Tashian, Paul)

4.8 Condensate Removal

After compressed air leaves the compression chamber, the compressor's after-cooler reduces the discharge air temperature well below the dew point (for most ambient conditions) and therefore considerable water vapor is condensed. To remove this condensation, most compressors with built-in after-coolers are furnished with a combination condensate separator/trap.

In situations such as this, an isolation valve should be mounted near the compressor discharge. A drain line should be connected to the condensate drain in the base. The drain line must slope downward from the base to work properly. It is possible that additional condensation can occur if

the downstream piping cools the air even further and low points in the piping systems should be provided with drip-legs and traps. It is also important that the discharge piping is the same size as the discharge connection at the compressor enclosure. All piping and fittings must be suitably rated for the discharge pressure.

Careful review of piping size from the compressor connection point is essential. Lengths of pipes, sizes of pipes, number and type of fittings and valves must be considered for optimum efficiency of the compressor.

4.9 Controlled Usage of Compressed Air

Since the compressed air system is already available, plant engineers may be tempted to use compressed air to provide air for low-pressure applications such as agitation, pneumatic conveying or combustion air. Using a blower that is designed for lower pressure operation will cost only a fraction of compressed air generation energy and cost.

4.10 Compressor Controls

Air compressors become inefficient when they are operated at significantly below their rated cfm output. To avoid running extra air compressors when they are not needed, a controller can be installed to automatically turn compressors on and off, based on demand. Also, if the pressure of the compressed air system is kept as low as possible, efficiency improves and air leaks are reduced.

4.11 Maintenance Practices

Good and proper maintenance practices will dramatically improve the performance efficiency of a compressor system. Following are a few tips for efficient operation and maintenance of industrial compressed air systems:

- Lubrication: Compressor oil pressure should be visually checked daily, and the oil filter changed monthly.
- Air Filters: The inlet air filter can easily become clogged, particularly in dusty environments. Filters should be checked and replaced regularly.
- Condensate Traps: Many systems have condensate traps to gather and (for those traps fitted with a float operated valve) flush condensate from the system. Manual traps should be periodically opened and re-closed to drain any accumulated fluid; automatic traps should be checked to verify they are not leaking compressed air.
- Air Dryers: Drying air is energy-intensive. For refrigerated dryers, inspect and replace prefilters regularly as these dryers often have small internal passages that can become plugged with contaminants. Regenerative dryers require an effective oil-removal filter on their inlets, as they will not function well if lubricating oil from the compressor coats the desiccant. The temperature of deliquescent dryers should be kept below 100°F to avoid increased consumption of the desiccant material, which should be replenished every 3-4 months depending on the rate of depletion.

5. OPTION CHECKLIST

- Find and fix current compressed air leaks and try to prevent the same. Check for leaks and pressure losses throughout the system regularly (monthly).

- Avoid the improper, yet common practice of cracking drains in an effort to insure moisture free performance at a particular point-of-use.

- Regulate all point-of-use operations at the lowest possible pressure using a quality regulator.

- Eliminate the use of air hoists, and air motors.

- Shut off the air supply to "off-line" production equipment.

- Isolate single users of high pressure air.

- Monitor pressure drops in piping systems.

- Evaluate your need for modulating compressors.

- Use high efficiency motors in place of standard motors.

- Consider multiple staged compressors.

- Lower the output pressure as far as possible.

- Use waste heat off the compressor to help the rest of the plant save energy.

- Avoid delivering higher pressure to the entire plant just to meet the requirements of one user.

- Understand multiple compressor system controls.

- Utilize intermediate controls/expanders/high quality back pressure regulators.

- Understand the requirements for clean-up equipment.

- Use the drying technology that gives you the maximum allowable pressure dew point.

- Choose "best in class" products for all compressor parts in case of replacements.

- Monitor the differential pressure across the air filter. Excessive pressure drop in filters also wastes energy.

- Use cool outside air for the compressor intake.

- Adopt a systematic preventive maintenance strategy for your compressor.

- Impart training and create awareness among employees for efficient operation and maintenance of compressor systems.

- Ensure the entire system is monitored by good housekeeping practices.

- Ensure condensation can be removed swiftly from the distribution network, or does not occur.

- Check that receivers are sized to store air for short heavy demands.

6. WORKSHEETS

Worksheet 1. Compressor Master Data

Air compressor reference	Units	1	2	3	4
Make	--				
Type	--				
No. of stages	--				
Discharge capacity	Nm^3/min				
Discharge pressure	$kg/cm^2.g$				
Speed	rpm				
Receiver capacity	m^3				
Motor rating					
Power	kW				
Full-load current	A				
Voltage	V				
Power factor	PF				
Speed	rpm				
Frequency	Hz				
Specific power consumption	$kW/m^3/min$				

Worksheet 2. Leakage Test in Compressed Air System

Particulars	Unit	Remark
Compressed air users	No.	Mention area of the plant
Load time (t1)	Sec	Measured
Unload time (t2)	Sec	Measured
Capacity of compressor	Nm3/min	Rated
Leakage = [t1/(t1+t2)] x 100	%	Estimated
Leakage cfm = % Leakage x Capacity of Compressor		Estimated

Procedure:
- Leakage test is conducted when entire plant is shut-down or when all compressed air users are not working. It would be advantageous if separate sections could be isolated from one another by isolating valves.
- A dedicated compressor is switched on to fill the system network with compressed air.
- Since there are no compressed air users, the air compressor will unload the moment the system pressure reaches the set point (say, 8 kg/cm2.g).
- If the system has no leaks, the air compressor will remain unloaded indefinitely.
- However, since there are bound to be system leaks, the receiver pressure gradually begins to drop, until the lower set point is reached, at which point the air compressor is loaded again and begins to generate compressed air.
- Load and unload times are measured using a stopwatch over 5–6 cycles, and average load and unload times are worked out.
- Compressed air leakage (%) and quantity are then evaluated.

Worksheet 3. Capacity Testing of Compressor

Air compressor reference	Units	1	2	3	4
Receiver volume plus volume of pipeline between receiver and the cir compressor	m^3				
Receiver temperature	°C				
Initial receiver pressure (P_1)	kg/cm^2.a				
Final receiver pressure (P_2)	kg/cm^2.a				
Time taken to fill receiver from P_1 to P_2 (t)	mins.				
Atmospheric pressure (P_o)	kg/cm^2.a				
Air compressor capacity (free air delivery) Q	Nm^3/min				

Note: Each compressor must have its own receiver.

Procedure:

1. The air compressor being tested for capacity is first isolated from the rest of the system, by operating the isolating non-return valve.

2. The compressor drive motor is shut-off.

3. The receiver connected to this air compressor is emptied.

4. The motor is re-started.

5. The pressure in the receiver begins to rise. Initial pressure, say 2 kg/cm^2 , is noted. The stopwatch is started at this moment.

6. The stopwatch is stopped when receiver pressure has risen to, say, 9 kg/cm^2.

7. Time elapsed is noted.

8. Compressor capacity is evaluated as:-

$$(Nm^3/min) = \left(\frac{P_2 - P_1}{P_o}\right) \times \left(\frac{V_R}{t}\right) \times \left(\frac{273}{273 + T}\right)$$

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