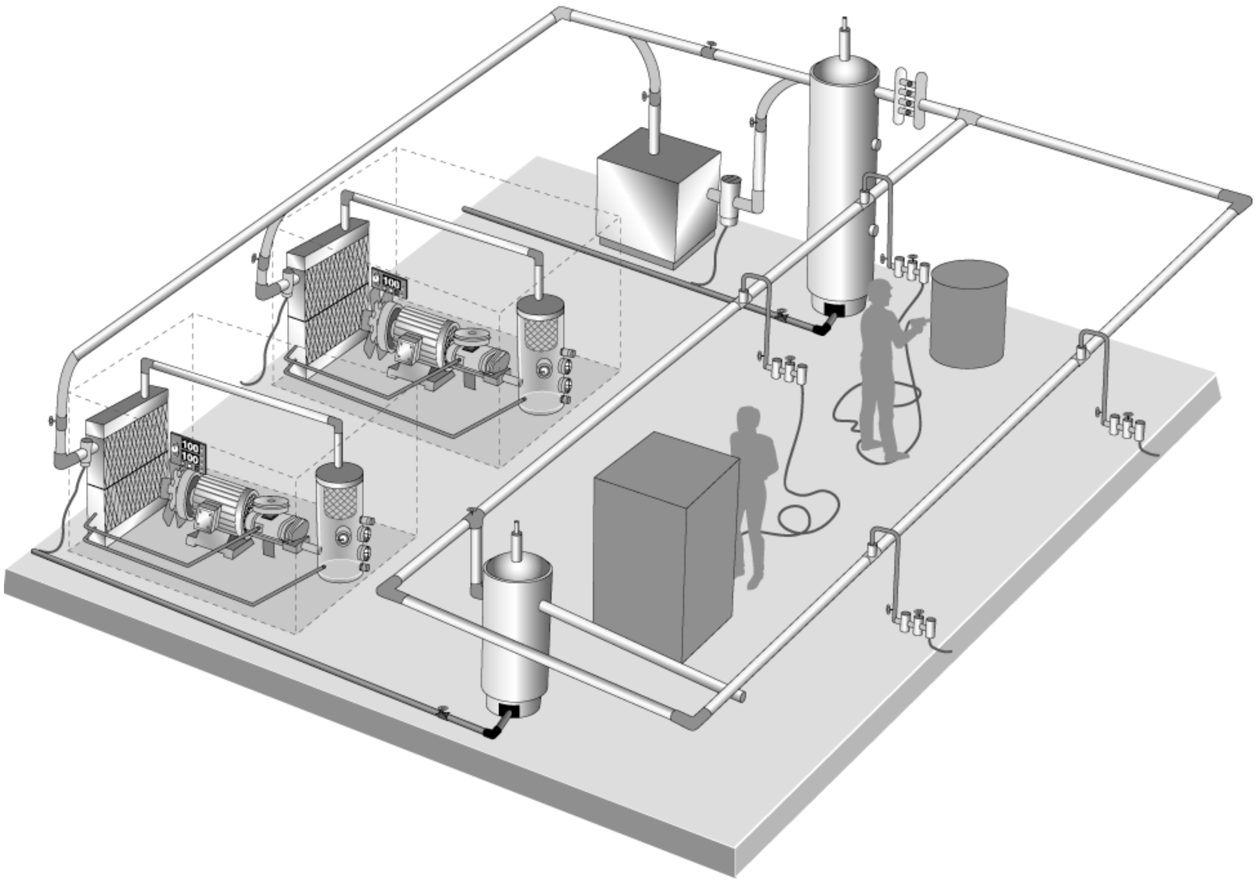
Fundamentals of Compressed Air Systems With SI Units

Pre-Workshop Assignment



TRAINING • EDUCATION • EFFICIENCY
COMPRESSED AIR CHALLENGE

Notice of Disclaimer

Pre-Workshop Assignment

In order to ensure that the Compressed Air Challenge® *Fundamentals of Compressed Air Systems* training is most useful to you, it will be important for you to bring information about your plant's compressed air system to the workshop.

Please complete the four enclosed worksheets:

1. **Compressed Air System Block Diagram**, which asks you to draw a block diagram of your plant's compressed air system.

2. **Compressor Information**, which asks you to identify the type, size, and operation of each air compressor in your plant.

3. **Compressed Air System Control Information**, which asks you to identify how your plant's compressors are controlled (optional).

4. **Electricity Cost Information**, which asks you to identify the electricity costs of your plant.

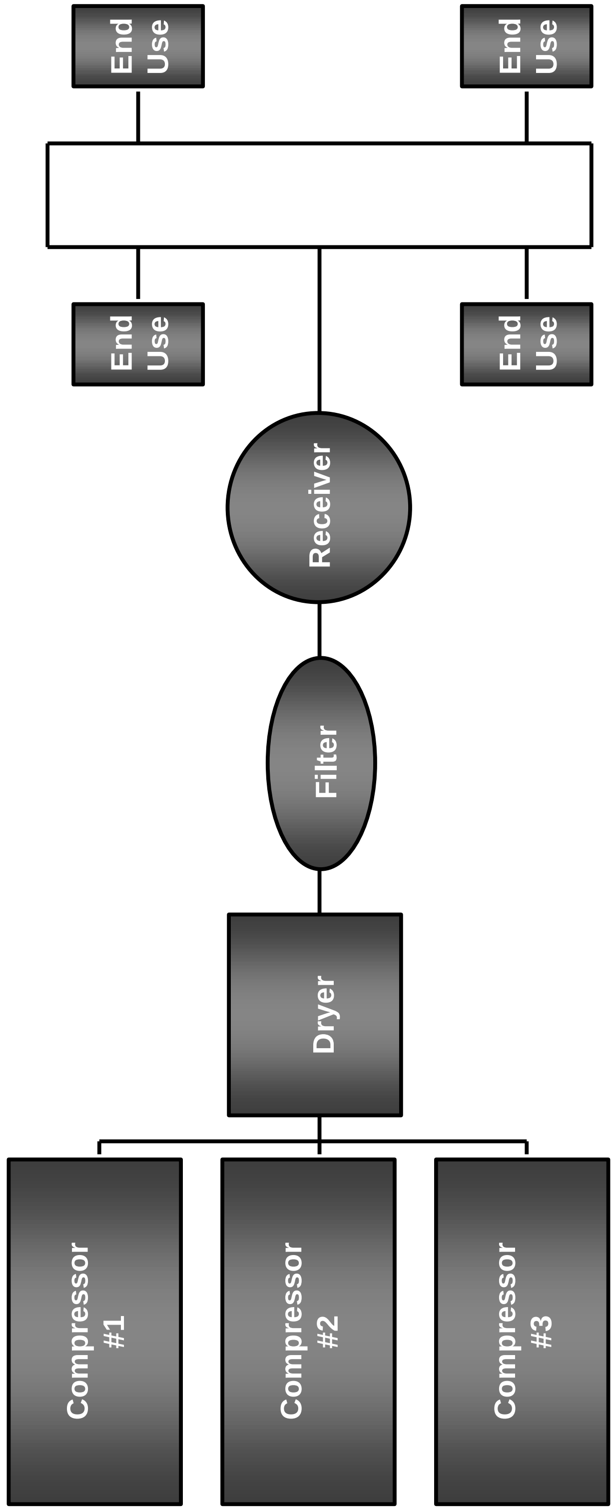
A compressed air systems terminology refresher has also been included. These terms will be used during the workshop. The better you understand them, the easier it will be for you to participate in the workshop exercises.

We will use all of this information during the workshop, so please be sure to **bring the four completed worksheets to the workshop**.

You will also need to bring a **calculator**.

Thank you.

Sample Block Diagram

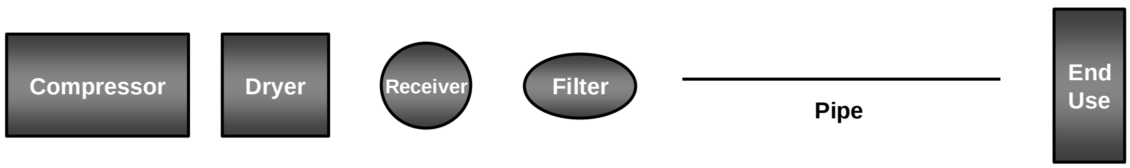


Compressed Air System Block Diagram

Directions: Please (1) review the Sample Block Diagram, and then (2) complete a block diagram of your plant's compressed air system using the shapes shown below.

Name: ____________________________ *Date:* ____________

Plant: ____



Your System

Compressor Types and Nameplate Information

Five Types of Industrial Air Compressors

1.	**Single-acting Reciprocating**	Uses a piston(s) with compression on the top side. Usually air-cooled, most are less than 25 hp, but can be as large as 150 hp.
2.	**Double-acting Reciprocating**	Uses a piston(s) with compression on both sides**.** Usually water cooled and greater than 10 hp.
3.	**Lubricant-injected Rotary Screw**	Male and female screw rotors mesh, trap air, and reduce the volume along the length of the rotors to the discharge point. Lubricant is injected into the compression chamber. Usually 3-900 hp and air-cooled in smaller sizes. Most common industrial air compressor over 10 hp.
4.	**Lubricant-free rotary screw**	Like lubricant injected, except either water-injected or multistage dry. Air- or water-cooled from 25-4,000 hp.
5.	**Centrifugal**	Uses a continuously flowing air stream which has kinetic energy imparted to it by high speed rotating impellers, and is further converted to pressure in a diffuser. Usually multi-stage, water-cooled, and greater than 300 hp.

Nameplate Information

- The compressor manufacturer, model information, rated cfm, and maximum full-load discharge pressure can be found on the compressor nameplate or the documentation furnished with the compressor.
- The motor horsepower can be found on the motor nameplate or the documentation furnished with the compressor (or replacement motor).
- The compressor discharge pressure is dependent on how the controls are set and where the signal locations are. Discharge pressure can be determined from control set points or readouts. Record compressor discharge pressure during typical operation.

Compressor Information

Directions: Please (1) review the fact sheet titled Compressor Types and Nameplate Information, and (2) complete this form for each of your plant's compressors larger than 30 hp.

Name: ___________________________ *Date:* ___________

Plant: ____

Nameplate Information

Compressor # ______ *(from block diagram)*
Manufacturer _____________________________________
Model _____________________________________
Compressor Type _____________________________________
Motor Nameplate Horsepower ______ *hp*
Rated CFM ______ *cfm*
Maximum Design Full Load Pressure ______ *psig*
Age/Comments: ____

____

Operating Schedule Information

Number of Days of Operation Annually _________________________________
Number of Hours per Day _________________________________
Compressor Discharge Pressure ______ *psig*

Notes on Load Profile, Part-load and Unloaded Operation:

____

____

Compressed Air System Control Information

Compressor controls are designed to match compressor delivery with compressed air demand, by maintaining the compressor discharge pressure within a specified range. This discharge pressure should be set as low as possible to minimize energy use. Control strategies need to be developed using a systems approach, taking into account system dynamics and storage. There are six basic types of individual compressor controls:

1. **Start/Stop** — Turns the motor driving the compressor on or off in response to a pressure signal (reciprocating and rotary screw).

2. **Load/Unload** — Allows the motor to run continuously, but unloads the compressor when a predetermined pressure is reached. The compressor reloads at a predetermined lower discharge pressure. Also known as constant speed or constant run control (reciprocating, rotary screw, and centrifugal).

3. **Modulating** — Restricts inlet air to the compressor to progressively reduce compressor output to a specified minimum, when the compressor is unloaded. Also known as throttling or capacity control (rotary screw and centrifugal).

4. **Dual/Auto Dual** — For small reciprocating compressors, allows the selection of either start/stop or load/unload. For lubricant injected rotary screw compressors, provides modulation to a pre-set reduced capacity followed by unloading with the addition of an over-run timer to stop the compressor after running unloaded for a pre-set time.

5. **Variable Displacement** — Allows progressive reduction of the compressor displacement without reducing the inlet pressure. (reciprocating {multi-step} and rotary screw {turn, spiral, or poppet valves}).

6. **Variable Speed** — Adjusts the compressor capacity by varying the speed of the electric motor driving the compressor in response to system signals.

Compressed Air System Control Information (Continued)

Systems with multiple compressors use more sophisticated controls to orchestrate compressor operation and air delivery to the system. **Network controls** use the on-board compressor controls' microprocessors linked together to form a chain of communication that makes decisions to stop/start, load/unload, modulate, vary displacement, and vary speed. Usually, one compressor assumes the lead role with the others being subordinate to the commands from this compressor. **System master controls** coordinate all of the functions necessary to optimize compressed air as a utility. System master controls have many functional capabilities, including the ability to monitor and control all components in the system, as well as trending data to enhance maintenance functions and minimize costs of operation.

The objective of an effective automatic system control strategy is to match system demand with compressors operated at or near their maximum efficiency levels. This can be accomplished in a number of ways, depending on fluctuations in demand, available storage, and the characteristics of the equipment supplying and treating the compressed air.

Some systems use pressure/flow controllers to separate the supply side of a compressor system from the demand side.

Compressor System Control Information (Optional)

Directions: Please (1) review the fact sheet titled Compressed Air System Control Information, and then (2) complete this form for each of your plant's compressors that are larger than 30 hp. Note: This worksheet is optional.

Name: ___________________________ *Date:* ___________

Plant: ____

Individual Compressor Control

Compressor #1

- ☐ *Start/Stop*
- ☐ *Load/Unload*
- ☐ *Modulating*
- ☐ *Dual*
- ☐ *Variable Displacement*
- ☐ *Variable Speed*
- ☐ *Unknown*

Compressor #2

- ☐ *Start/Stop*
- ☐ *Load/Unload*
- ☐ *Modulating*
- ☐ *Dual*
- ☐ *Variable Displacement*
- ☐ *Variable Speed*
- ☐ *Unknown*

Compressor #3

- ☐ *Start/Stop*
- ☐ *Load/Unload*
- ☐ *Modulating*
- ☐ *Dual*
- ☐ *Variable Displacement*
- ☐ *Variable Speed*
- ☐ *Unknown*

System Control for Multiple Compressors

- ☐ *Single Master (Sequencing) Control*
- ☐ *Multi-Master (Network) Control*
- ☐ *None*
- ☐ *Unknown*

System Pressure Control

- ☐ *Pressure/flow Controller*
- ☐ *None*
- ☐ *Unknown*

Understanding Your Electric Bill

Electricity costs are often the largest component of your compressed air costs. When adding a new compressor or fixing problems with your old system, you can significantly increase or decrease your electric bill. As a result, it is important to understand certain features of your monthly electric bill.

1. Two components of your electric bill are demand and energy charges. Demand charge is based on the maximum level of power you use during that month (measured in kilowatts or kW), and is expressed in dollars per kW. The energy charge is based on the amount of energy consumed (measured in kilowatt-hours or kWh), and is expressed in dollars per kWh.

2. These demand and energy charges usually make up the main components of the electricity rate (or price) you are on. Sometimes there is a customer charge that is also added, and other charges such as fuel adjustment clauses can be incorporated.

3. Rates usually vary by season, particularly the demand charges. This is usually based on the fact that, during periods where the need for power is high, the cost to generate or purchase power goes up.

4. Rates are usually tiered by levels of use. Typically, the more you use, the cheaper the cost per kWh. However, if you use more during peak periods, you may increase the price you pay.

5. When estimating the cost impact of compressed air system changes, it is important to consider changes in both energy and demand. If you add a compressor to handle just periods of peak air demand, it may add significantly to your electricity demand and not much to your energy use. As a result, your price of electricity may go up considerably. Conversely, if you fix leaks in your system, it may save both energy and demand, since it could allow you to shut down compressors or run them less frequently.

6. For the purpose of the Fundamentals training, the average cost of electricity will be used to simplify calculations. In Level II training, you will learn more about the demand and energy charges by using the marginal cost of electricity.

7. Consult your local electric utility representative for more information.

Electricity Cost Information

Directions: Please (1) review the fact sheet titled Understanding Your Electricity Bill, and then (2) complete this form for each of the past twelve months. If you cannot locate bills from each of the past twelve months, use as many as possible, since seasonal variations can significantly affect your cost information.

Name: ______________________________ *Date:* ____________________

Plant: ____

Month	*Total Bill ($)*	*Usage (kWh)*
______	________________	______________________
______	________________	______________________
______	________________	______________________
______	________________	______________________
______	________________	______________________
______	________________	______________________
______	________________	______________________
______	________________	______________________
______	________________	______________________
______	________________	______________________
______	________________	______________________
______	________________	______________________

Totals (a) ________________ (b) ______________________

Average Electricity Cost [divide (a) by (b)] = ____________*Dollars per kWh*

Compressed Air System Terminology

The following terms will be used in the workshop. The better you understand them, the easier it will be for you to participate in the workshop exercises.

Absorption - The chemical process by which a hygroscopic desiccant, having a high affinity with water, melts and becomes a liquid by absorbing the condensed moisture.

Adsorption - The process by which a desiccant with a highly porous surface attracts and removes the moisture from compressed air. The desiccant is capable of being regenerated.

Capacity - The amount of air flow delivered under specific conditions, usually expressed in cubic feet per minute (cfm).

> **Capacity, Actual -** Quantity of gas actually compressed and delivered to the discharge system at rated speed and under rated conditions. Actual capacity is generally expressed in actual cubic feet per minute (acfm) at conditions prevailing at the compressor inlet. Also called Free Air Delivered (FAD).
>
> **Rated Capacity -** Volume rate of air flow at rated pressure at a specific point.
>
> **Required Capacity -** Cubic feet per minute (cfm) of air required at the inlet to the distribution system.

Cubic Feet Per Minute (cfm) - Volumetric air flow rate.

> **Cfm, Free Air (or Free Air Delivered {FAD}) -** Cfm of air delivered to a certain point at a certain condition, converted back to ambient conditions. This term sometimes is used for the capacity of an air compressor. This is the same as acfm, being the delivered flow rate measured at prevailing ambient conditions.
>
> **Actual Cfm (acfm) -** Flow rate of air at a certain point at a certain condition at that point. When used for the capacity of an air compressor, it is the delivered rate of flow, measured at prevailing ambient conditions of pressure, temperature and relative humidity.

Compressed Air System Terminology (Continued)

Inlet Cfm - Cfm flowing through the compressor inlet filter or inlet valve under rated conditions. Also used to describe the rate of flow of a centrifugal type air compressor. **Acfm** and **icfm** should be the same for displacement type air compressors, but may not be the same in some designs of centrifugal air compressors. There may be air losses through shaft seals of each stage, so that the delivered rate of flow in **acfm** may be up to 5% less than the **icfm** entering the compressor.

Standard Cfm - Flow of free air measured and converted to a standard set of reference conditions. There may be confusion with this term since all standards are not the same. The Compressed Air Challenge® and The Compressed Air & Gas Institute have adopted the International Standards Organization (ISO) definition of standard air as: 14.5 psia (1 bar); 68EF (20 C); dry (0% relative humidity).

When the term scfm is used, the applicable standard should be stated.

Deliquescent - Melting and becoming a liquid by absorbing moisture.

Desiccant - A material having a large proportion of surface pores, capable of attracting and removing water vapor from the air.

Demand - Flow of air at specific conditions required at a point or by the overall facility.

Humidity, Relative - The relative humidity of a gas (or air) vapor mixture is the ratio of the partial pressure of the vapor to the vapor saturation pressure at the dry bulb temperature of the mixture.

Dew Point - The temperature at which moisture in the air will begin to condense if the air is cooled at constant pressure. At this point the relative humidity is 100%.

Pressure Dew Point - For a given pressure, the temperature at which water will begin to condense out of air.

Specific Humidity - The weight of water vapor in an air-vapor mixture per pound of dry air.

Compressed Air System Terminology (Continued)

Power – The rate at which work is done.

Brake Horsepower (bhp) - Horsepower delivered to the output shaft of a motor or engine, or the horsepower required at the compressor shaft to perform work.

Load Factor - Ratio of average compressor load to the maximum rated compressor load over a given period of time.

Full-Load - Air compressor operation at full speed with a fully open inlet and discharge delivering maximum air flow.

Specific Power - A measure of air compressor efficiency, usually in the form of bhp/100 acfm or acfm/bhp.

Total Package Input Power - The total electrical power input to a compressor, including drive motor, cooling fan, motors, controls, etc.

Pressure - Force per unit area, measured in pounds per square inch (psi).

Gauge Pressure - The pressure determined by most instruments and gauges, usually expressed in psig. Barometric pressure must be considered to obtain true or absolute pressure.

Pressure Drop - Loss of pressure in a compressed air system or component due to friction or restriction.

Pressure Range - Difference between minimum and maximum pressures for an air compressor. Also called cut in-cut out or load-no load pressure range.

Rated Pressure - The operating pressure at which compressor performance is measured.

Receiver - A vessel or tank used for storage of gas under pressure. In a large compressed air system there may be primary and secondary receivers.

Surge - A phenomenon in centrifugal compressors where a reduced flow rate results in a flow reversal and unstable operation.