Pneumatic Troubleshooting

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Lesson One

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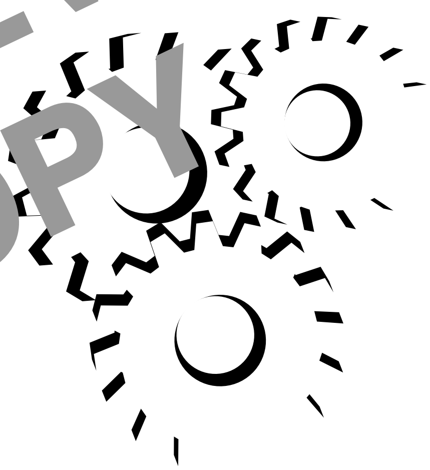


TPC Training Systems

31001

Lesson

1 Pneumatic Systems

TOPICS

The Pneumatic System
The Air-Supply System
Reciprocating Compressors
Regulation and Control
Rotary Compressors
Cooling
Compressor Preventive Maintenance
The Delivered-Air system
Air-Line Filters
Air-Line Lubrication
Troubleshooting the Pneumatic system

OBJECTIVES

After studying this lesson, you should be able to…

- Explain the operation of linear actuators (cylinders) in a typical pneumatic circuit.
- Describe the various types of compressors and how they work.
- Define intercooling and aftercooling.
- Describe basic preventive maintenance procedures for compressors.
- List the components of an effective delivered-air system and explain how they work together.
- Describe the three main types of air-line lubrication.

KEY TECHNICAL TERMS

Compressor 1.04 a device that takes in air from the atmosphere and compresses it to increase its pressure

Intercooling 1.22 cooling of air between compression stages to reduce the final discharge air temperature

Desiccants 1.41 substances that can collect water vapor without changing their solid form

Before you can troubleshoot a pneumatic system, you must understand what components it contains, and how they operate. Although pneumatic systems vary from plant to plant, a basic understanding of the operation and functions of the various components will be useful in troubleshooting the system in your plant.

To maintain the maximum operating efficiency of the plant pneumatic machinery, it is also necessary for you to develop your ability to recognize a potential trouble spot before trouble develops. At the same time, you must correct the cause of the problem with the least interference to the production operation. This lesson will identify the various components that form a pneumatic system.

The Pneumatic System

1.01 Pneumatic systems are usually standard groupings of components with some variation in compressors, filters, separators, coolers, receivers, regulators, distribution piping, and methods of lubrication. Pneumatic system applications vary from simple jets of air used to blow away chips, to air tools, air motors, instrumentation, and complex actuation systems for the control of high-speed precision machines. Different valves are used to direct and control the flow of air in a pneumatic circuit. The function of these valves may be simply to admit or block airflow as required. Others are used to control the speed or sequence of an operation, to modulate pressures to spring-loaded actuators, or to control the flow to air motors, thereby controlling speed.

1.02 A properly designed pneumatic control system is much faster acting than is generally believed. The overall speed of the system can often exceed a comparable electric or electrohydraulic system. Electricity has the advantage of moving at the speed of light, but the job is not complete until actuation takes place. A pneumatically operated valve may actuate in 2 to 5 milliseconds (ms) after the signal arrives, while an electric relay can take up to 50 ms. Over short distances, a pneumatic circuit can be as fast or faster than an electrical circuit. When the transmission distance becomes greater, the advantage then belongs to electricity.

1.03 The principal means of applying pneumatic power is the *cylinder*. The majority of cylinders in use are 4 in. in diameter or smaller, supplying a maximum thrust of 1000 lb force at 80 psi line pressure. Cylinders are essentially *linear actuators*. Methods are available, however, to convert their motion to semirotary motion or to magnify the force for actuating clamps, cutters, and other devices. Cylinders, air motors, air tools, and instrument readouts are the termination point of the pneumatic complex.

The Air-Supply System

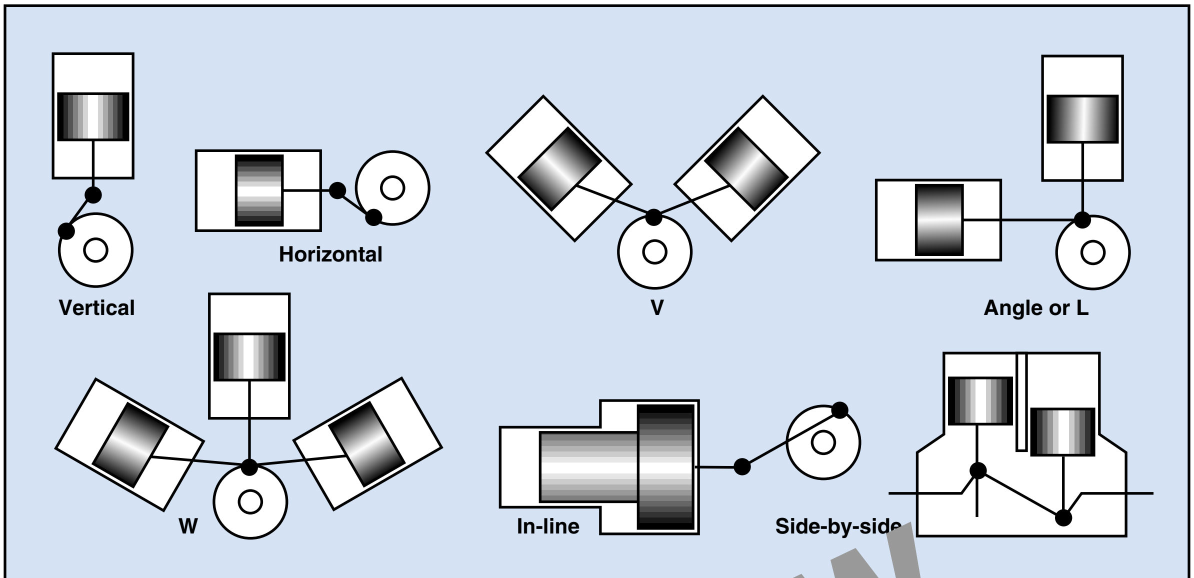
1.04 The heart of any air-supply system is the *compressor*. The types of compressors used vary from system to system, but their function remains the same. That is, they take in a volume of air from the atmosphere and compress it to a smaller volume to increase its pressure. The compressor, with the aid of the pressure-control switches, must also maintain the proper pressure level of the air delivered to the system at all times.

1.05 Compressors can be classified as one of two types—either dynamic or positive-displacement. *Dynamic compressors* use high-speed, rotating vanes or impellers to impact velocity and pressure to the flow of gas being handled. *Positive-displacement compressors* work on the principle of increasing the pressure of a specific quantity of gas by reducing its volume. Positive-displacement compressors can be subdivided into *reciprocating* and *rotary* types. Each of these can be further broken down into subtypes, which describe the compressor's construction.

Reciprocating Compressors

1.06 *Reciprocating compressors* can be classified according to their operation as single-acting or double-acting, and single-stage or multistage. They can also be identified by the physical arrangement of cylinders used to achieve the desired amount of compression. The most common arrangements are vertical, horizontal, in-line, V or Y, W, angle or L, radial, side-by-side, and tandem (see Fig. 1-1 on the following page).

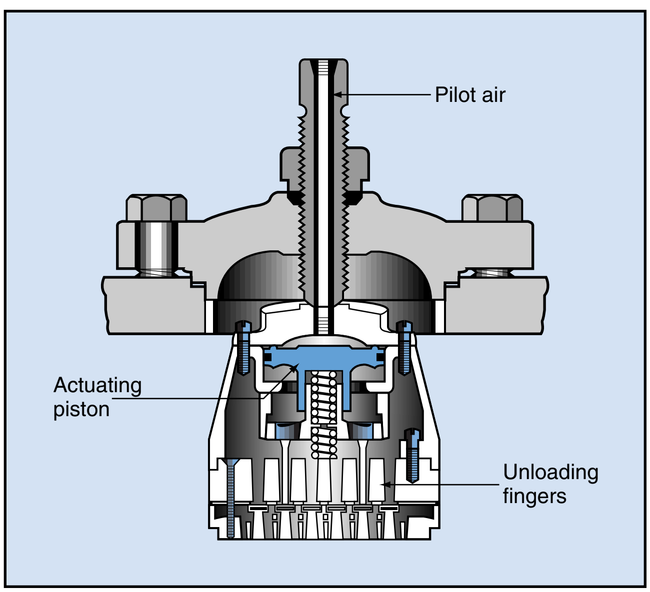
Fig. 1-1. Reciprocating compressor configurations



1.07 In a *single-acting compressor*, compression takes place at only one end of the cylinder. In the *double-acting compressor*, the spaces on both sides of the piston are enclosed, and both ends of the cylinder are used for compression. This is a common arrangement in direct steam-driven compressors and in many large compressors.

1.08 *Multistage compressors* use two or three cylinders, each with a different piston diameter. Multistage compressors can also be constructed with a two-diameter cylinder and piston arrangement. In these compressors the high-stage piston is attached to the top of the low-stage piston and is smaller in diameter. For most continuous-duty compressors, the compression ratio in the first stage can be as high as 12 to 1. Second- or third-stage compression ratios are limited to about 3 to 1.

Fig. 1-2. A pressure unloader

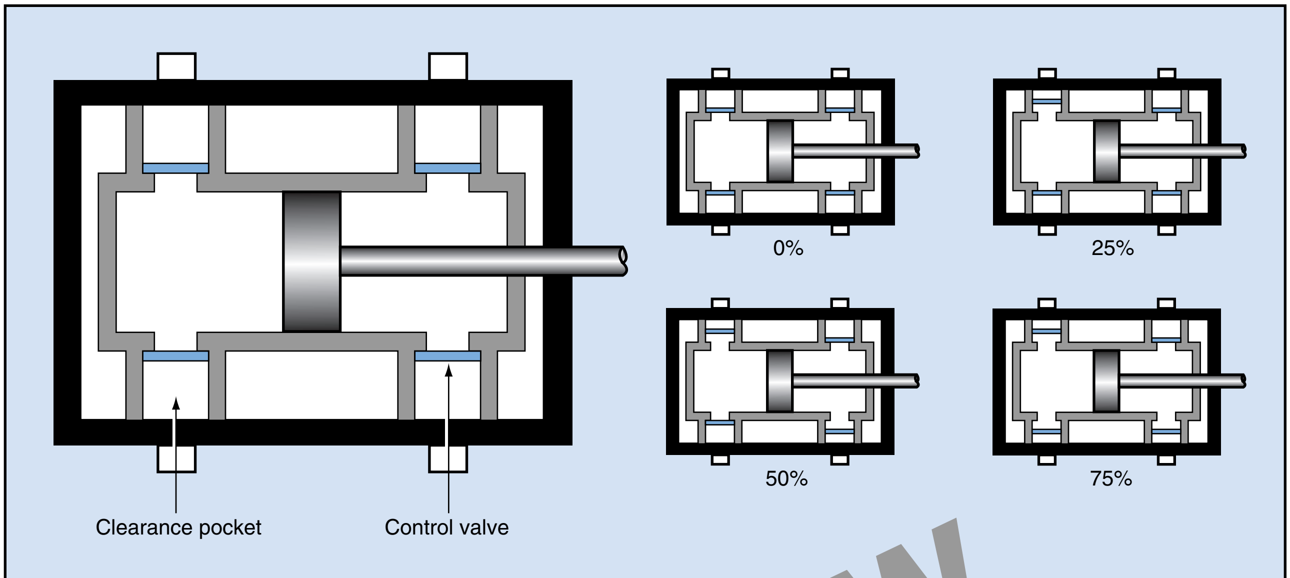


1.09 The *piston displacement* of a reciprocating compressor is equal to the volume of air swept through the cylinder by the piston in one minute. This is limited to the first-stage piston only in multistage compressors. The *capacity* of a compressor, in cubic feet per minute (cfm), is defined as the actual volume of air compressed and delivered at the discharge point, measured in terms of atmospheric conditions (temperature and pressure) at the inlet.

Regulation and Control

1.10 The output of a compressor must be regulated so that it supplies no more than the required amount of delivered compressed air. Regulation can be either manual or automatic. Single-stage and two-stage compressors are often regulated by spring-loaded automatic air relays, which actuate *unloading mechanisms* (see Fig. 1-2). Pressure from the air receiver is transmitted to the unloader piston, which acts against a spring. When pressure in the receiver exceeds a predetermined level, the spring is compressed and the

Fig. 1-3. Pocket unloading



unloader claw is actuated, holding the suction valve open and preventing compression from taking place in the cylinder. This action is termed *suction-valve unloading*.

1.11 When suction-valve unloading is applied to double-acting compressors, two unloaders set at different pressures are generally used. In this manner, it is possible to unload each side of the piston at different pressures, giving full load, half load, and zero load. This is called *three-step unloading*, because three different load conditions can be accomplished.

1.12 In *clearance-pocket unloading*, specially designed pockets are opened to enlarge the clearance volume of the cylinder. This reduces the output of the compressor. Double-acting compressors often use a combination of clearance-pocket and suction-valve unloaders to give 0%, 25%, 50%, and 75% unloading. Figure 1-3 illustrates a typical clearance-pocket design for compressors.

1.13 Another method of controlling the output of a compressor is by *throttling* the intake. When used at less than full-load conditions, this method requires more horsepower than the other methods described. In addition, every air system must be protected against overpressure by a preset relief or dump valve. These are usually found on or near the air receiver. In some cases, they operate simply as a pressure-actuated ON/OFF switch.

Rotary Compressors

1.14 *Rotary compressors* are generally thought of as being in the positive-displacement class. There are four basic types available—rotary-screw, impeller, sliding-vane, and liquid-ring. Rotary compressors attain positive-displacement characteristics by trapping the air in individual cavities. As the compressor rotates, the cavities are reduced in volume, providing compression.

1.15 *Sliding-vane compressors* are widely used. They may be either single- or two-stage in construction. Single-stage units generally are used for pressures of up to 50 psi and two-stage for pressures of up to 125 psi. Sliding-vane compressors are available with capacities of up to 4000 cfm.

1.16 *Rotary-screw compressors* are available as wet-screw or dry-screw types. They are considered relatively high-speed units (usually 3000 to 12,000 rpm). Capacity in rotary-screw compressors is proportional to speed. Compressors are available with ratings from 120 cfm to 20,000 cfm. Single-stage units are capable of producing pressures of up to 50 psi. Two-stage models can develop pressures of up to 150 psi.

1.17 *Impeller* (or two-lobe rotary) *compressors* have a pressure limitation of about 15 psi. Because of this pressure limitation, they are often considered blowers rather than compressors. These compressors are available with capacities ranging from 5 to about 50,000 cfm.

1.18 The *liquid-ring* (or liquid-piston) *compressor* is less efficient than other types, but it has the advantages of relatively low-cost operation and minimum maintenance requirements. Available capacities range from 10,000 cfm at 15 psi to 300 cfm at 100 psi.

1.19 *Diaphragm compressors* are generally used for light-duty applications. Most of them can furnish only small capacities (1 to 3 cfm) of delivered air at 30 to 40 psi.

1.20 *Centrifugal* and *axial-flow rotary compressors* are classed as *dynamic* or *non*positive-displacement. Both of these types operate at high speeds and are capable of delivering very large amounts of air (up to 100,000 cfm) at pressures of up to 125 psi. When used for high-volume, low-pressure applications, these compressors are very economical.

Cooling

1.21 As air is compressed, it generates heat. This heat must be dissipated effectively if the compressor is to be efficient. High intake temperatures also lower compressor efficiency. These effects can be reduced by cooling the compressor cylinder and drawing intake air from as cool a source as possible. Another way is to use a compressor that reaches the desired degree of compression in several stages, rather than in a single stage. In this way, the heating effect per stage is less. Effective cooling results in increased overall efficiency.

1.22 In multistage compressors, it is desirable to cool the air between stages to reduce the final discharge air temperature. This cooling between stages is called *intercooling*. If the final discharge temperature is still too high for the system, it can be further reduced by *aftercooling*. This cooling is usually done as close to the compressor discharge point as possible. Aftercooling provides the added advantage of removing water from the air.

1.23 The cylinders of small and medium-sized single-stage compressors may be cooled satisfactorily by a fan mounted on the compressor crankshaft. The fan provides a generous flow of air over and around the heads and cylinders. Cylinders are normally finned in such cases to increase the surface area exposed to the airstream. When the compressor is located in a warm place, it may be necessary to bring cooler air to the fan from another location through ducts. Forced-air cooling may be necessary for large, intermittently used compressors and for small-capacity two-or three-stage units. Most large compressors and the majority of multistage compressors normally are water-cooled.

1.24 Water cooling in compressors is similar to the cooling system of an automobile engine. The cylinders and heads have water jackets for circulating cooling water. Compressor cooling requires that the compressor temperature be kept as low as possible. The amount of cooling that can take place is dependent on the temperature and volume of the cooling water. When the compressor is water-cooled, the intercooler and aftercooler are also water-cooled.

The Programmed Exercises on the next page will tell you how well you understand the material you have just read. Before starting the exercises, remove the Reveal Key from the back of your book. Read the instructions printed on the Reveal Key. Follow these instructions as you work through the Programmed Exercises.

1-1. When a volume of air is reduced by a compressor, its pressure ________.	1-1. INCREASES Ref: 1.04
1-2. Compressors classified according to operation are identified or referred to as positive-displacement and ________ compressors.	1-2. DYNAMIC Ref: 1.05
1-3. Reciprocating compressors are classified according to their ________ and the ________ of their cylinders.	1-3. OPERATION; PHYSICAL ARRANGEMENT Ref: 1.06, Fig. 1-1
1-4. Reciprocating compressors that have two or more pistons of different size are called ________ compressors.	1-4. MULTISTAGE Ref: 1.08
1-5. In a compressed-air system, suction-valve unloaders are actuated by air pressure from the ________.	1-5. RECEIVER Ref: 1.10, Fig. 1-2
1-6. Name the four types of positive-displacement rotary compressors.	1-6. ROTARY-SCREW, SLIDING-VANE, IMPELLER, LIQUID-RING Ref: 1.14
1-7. Dynamic compressors have ________ displacement.	1-7. NONPOSITIVE Ref: 1.20
1-8. The amount of cooling that can take place in a water-cooled compressor depends on the ________ and ________ of the water.	1-8. TEMPERATURE; VOLUME Ref: 1.24

Compressor Preventive Maintenance

1.25 Atmospheric pollution and abrasive materials such as grit, pipe scale, rust, and corrosive liquids and gases are all possible sources of air contamination. To protect the compressor, the air intake should be located where the air is the coolest and cleanest. Even with the most ideal location, additional conditioning of intake air is required to prevent corrosion, remove impurities, and eliminate solid particles. No compressor should be operated without an adequate intake air filter.

1.26 The filtering requirements are determined largely by the type of air-operated equipment used. Pneumatic bags, air cushions, and mats are not affected to a great degree by air contamination, except for possible corrosive action.

1.27 In most industrial applications, the compressed air for conventional air cylinders, valves, and air tools is in direct contact with the sliding surfaces. Because these surfaces can be abraded or corroded by contaminated air, filtration is necessary.

1.28 Atmospheric air is generally far from clean and, in industrial areas in particular, it may be heavily contaminated with dust and other contaminants. In one week, a continuously operating, unfiltered, medium-sized compressor can draw in as much as a pound of solids. The solids intake is greater in heavily contaminated atmospheres, such as near cement works, quarries, and foundries. After a time, these solids will accumulate on pistons, cylinder heads, and cylinder valves.

1.29 Dust coming into contact with an oil mist or oil spray tends to be washed out of the air and collected in the lubricant. These contaminants build up on the internal surfaces of the components, causing abrasion. Solid contaminants present in the air have to be removed at the compressor if the system is to operate efficiently. In all cases, an effective planned maintenance program will ensure that the air system is kept as clean as possible.

1.30 There are three basic types of intake filters—dry, oil-bath, and oil-wetted. The *dry filter* is used wherever oil-free air is required. This type is often located close to the compressor so it can stop any foreign material that may enter the inlet piping. *Oil-bath air filters* direct incoming air through an oil bath, then through a wire mesh filter medium that traps the oil and dirt. In *oil-wetted air filters*, the incoming air is passed through many layers of oil-coated, crimped wire mesh. The mesh is arranged to break up the airstream into thousands of tiny currents.

1.31 Compressor manufacturers normally recommend the proper size and type of filters to be used on their machines. Consider the manufacturer's recommended size to be the minimum required. In some cases, compressors are fitted with filters by the manufacturer. If relatively clean air is always available, or if the compressor is used only intermittently, adequate protection can be obtained with a simple wire-mesh strainer at the intake. In all other cases, however, an intake filter should be used.

1.32 The size of the filter is generally determined by the machine's intake requirements. The type is dictated by the duty required. Dry filters are normally adequate for dealing with average to fairly heavy dust concentrations. Oil-bath or oil-wetted filters are more effective in heavily contaminated atmospheres. They require more regular attention, however.

The Delivered-Air System

1.33 In addition to the air inlet filtration, compressed air that is delivered to the system after leaving the compressor often requires further conditioning to remove water, oil, and solid particles. Additional solid matter may be added to the delivered air by pipe scale, rust, and sediment in the distribution system. The degree of conditioning required by the air is largely determined by the way in which the delivered air is used. Accumulated contaminants in pipelines can be removed, to some extent, by blowing through the air lines before connecting tools or appliances. This does not, however, protect the tools while they are being used.

1.34 Water in the lines can wash lubricating oil off rubbing surfaces and add to corrosion. Water also tends to promote rust and scale buildup in pipes and fittings. For these reasons, corrosion-resistant piping should be used.

1.35 In most systems, water, oil, and solid contaminants must be removed from the delivered air.

This is true for paint spraying, food agitation, and any application in which contamination might lead to erratic action or failure of sensitive devices. The efficiency of any air-powered system is directly related to the cleanliness of the air it receives.

1.36 As much as possible, use a filter/separator combination. The air filter will remove solid contaminants and the separator will remove oil and water. The ideal location for the filter/separator, generally, is just after the compressor or receiver. Branch tool lines or feeds extracted from a supply header or main can also be provided with individual protection as required. Figure 1-4 shows a typical plant installation and filter location.

1.37 Filter/separators can also be used in the main supply lines, branch lines, and individual feed lines to provide the required degree of water removal. Individual feed lines often have filter/separators installed as close as possible to the point of use to provide final conditioning of air.

1.38 Water is a particularly troublesome contaminant. Water condenses in the system as the delivered air cools. The problem of water accumulation becomes more acute in high ambient air temperatures and high relative humidity conditions. If the delivered air has a high moisture content, the sudden expansion of the air at supply points causes freezing at valves or other outlets. Even the supply lines themselves can freeze.

1.39 Rapid cooling in an aftercooler (and separator) ahead of the air receiver condenses much of the water vapor and keeps it from entering the distribution lines. Additional moisture also settles out in the receiver.

1.40 Drain traps provide an additional means of removing condensation from the system. These traps are normally located at suitable low points in the distribution system. The trap is an automatic drain device that holds system pressure until the liquid (water or oil) accumulates to a predetermined level. The trap then opens momentarily, discharging the accumulated liquid.

1.41 An alternative to line filter/separators is *adsorption drying*. Adsorption dryers take advantage of the properties of substances called *desiccants*. Desiccants have the ability to collect water vapor from the air on their surfaces without changing their solid form. Desiccants are capable of collecting up to 99.9% of the water vapor in compressed air, if required. For most ordinary applications 75% to 90% is sufficient. With certain adsorption desiccants, such as *alumina* and *silica gel*, the collected water can be easily expelled by heating the desiccant. Thus, the adsorbent material can be

Fig. 1-4. Pneumatic system layout

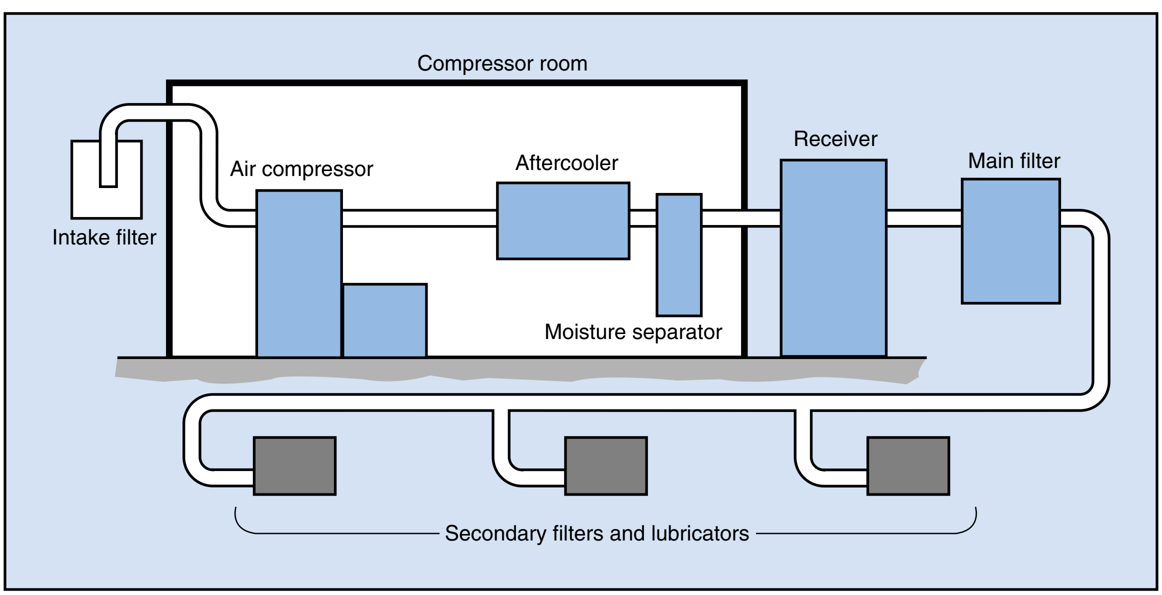
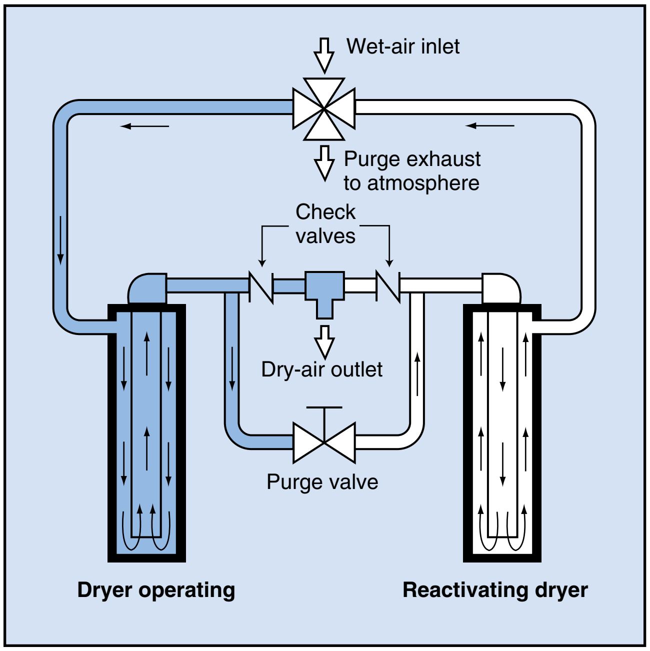


Fig. 1-5. Adsorption dryer



reused many times. Some dryers operate on the principle of *absorption*. In an absorption dryer, the desiccant changes form while absorbing the moisture.

1.42 An adsorption dryer normally consists of two cylinders of desiccant. They are interconnected in such a way that one of them is being used to dry the compressed airstream, while the other is being reactivated (heated to expel adsorbed water) so that it can be used again. Figure 1-5 shows a schematic of a typical adsorption dryer.

1.43 Inlet air is directed through the four-way valve to the left adsorber where it is dried before passing to the outlet pipe. A small portion of the dried air is used to purge the right cylinder. The embedded heater provides additional heat to drive off the water adsorbed in the right cylinder during the drying cycle. When all of the water is expelled, the heater is turned off and a purge of dry air cools the desiccant.

1.44 In a typical adsorption dryer the reactivated cycle is two hours—one hour of heating and one hour of drying. When reactivation is completed, the four-way inlet valve is switched, putting the right adsorber on line. The left adsorber then begins reactivation.

Air-Line Filters

1.45 *Air-line filters* are normally used at takeoffs (tool points) in the system. They usually provide both filtration and separation within each unit. These mechanical filters are shaped in such a way that air entering the unit is directed into a swirling motion. Centrifugal force then causes larger solid particles and the bulk of water and oil droplets to *impinge* (strike sharply) against the walls of the unit. The separated liquid and solid material fall to a settling chamber at the bottom of the unit.

1.46 The airstream, having given up some of its contaminants, then passes through the filter element. The filter traps and retains all solid particles larger than the pore or screen size of the filter element.

Air-Line Lubrication

1.47 In certain applications, it is desirable to add lubricant to the compressed air. This can be accomplished by *air-line lubricators*. The three basic types of air-line lubricators are *wick, oil-fog*, and *oil-mist*. Lubricant is normally applied as a final treatment *after* filtering and separating the air, and after reducing the air pressure at the point of use.

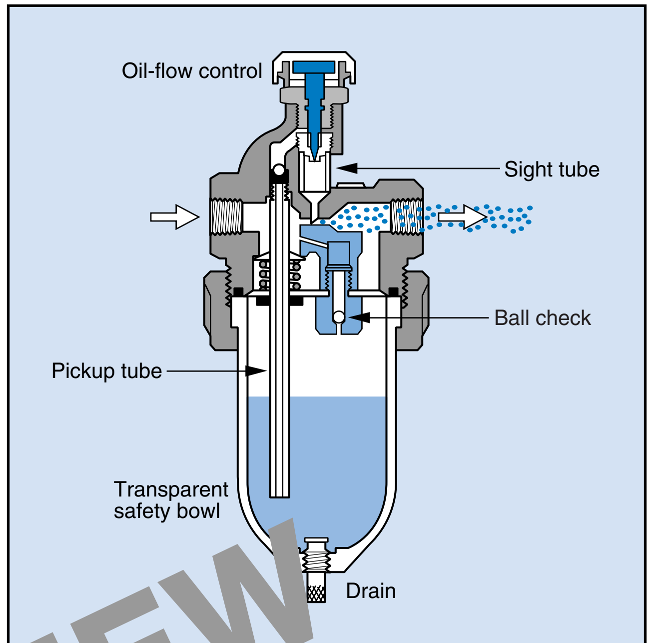
1.48 The most widely used air-line lubricator is the oil-fog type, like the one shown in Fig. 1-6. A bowl or reservoir is provided for the oil supply. As the air enters the lubricator, a small amount is diverted into the bowl to apply pressure to the oil. This forces oil up through a tube and into the metering valve. The metering valve permits droplets of oil to enter a venturi tube, where they are atomized and carried along with the air. One drop of oil for every 10 cfm of air consumed is the usual rate of lubrication. After lubricating oil is added, the air should travel no more than about 30 ft. Beyond this point, the lubricant begins to settle or condense, and loses it effectiveness.

Troubleshooting the Pneumatic System

1.49 Troubleshooting a pneumatic system is more challenging than planned maintenance work, but both are important to the efficient operation of the total system. As you will see in the following lesson in this course, troubleshooting is simply a matter of following certain logical steps, in a specific sequence, to locate the cause of a system malfunction.

1.50 When you first start to troubleshoot a pneumatic system, it will seem to take a lot of time. This time will be reduced as you become more familiar with the system and proficient in your troubleshooting techniques. Remember as you carry out your duties that whenever you find the supposed cause of the trouble, always check the other areas in the pneumatic system to make sure that you have completely identified the real cause of the problem.

Fig. 1-6. An air-line lubricator



1-8. The intake filter of an air compressor should be placed where the air is ________ and ________.	1-8. COOLEST, CLEANEST Ref: 1.25
1-9. Dust washed out of the air by an oil mist collects in the ________.	1-9. LUBRICANT Ref: 1.29
1-10. The size of an intake filter is determined by the compressor's air ________ requirements.	1-10. INTAKE Ref: 1.32
1-11. The air delivered to a pneumatic system should be conditioned by removing water, oil, and ________.	1-11. SOLID PARTICLES Ref: 1.33
1-12. Filter/separators can be placed in the supply, branch, or ________ lines of a pneumatic system.	1-12. INDIVIDUAL FEED Ref: 1.37
1-13. In two-cylinder adsorption dryers, one cylinder dries the air while the other cylinder is being ________.	1-13. REACTIVATED Ref: 1.42
1-14. An air-line filter removes oil and water droplets and solid particles from the air through ________.	1-14. CENTRIFUGAL FORCE Ref: 1.45
1-15. Air-line lubricators usually add oil to the airstream at the rate of one drop for every ________ cfm.	1-15. 10 Ref: 1.48

Answer the following questions by marking an "X" in the box next to the best answer.

1-1. A compressor increases the pressure of the air by

- ☐ a. decreasing its temperature
- ☐ b. decreasing its volume
- ☐ c. increasing its volume
- ☐ d. removing the moisture

1-2. Reciprocating compressors are classified by their operating characteristics (single- or double-acting) and their

- ☐ a. intercooler capacity
- ☐ b. driver motor size
- ☐ c. bore and stroke
- ☐ d. physical arrangement

1-3. Which of the following is used to activate suction-unloading valves?

- ☐ a. Compressor speed
- ☐ b. Intercooler air pressure
- ☐ c. Receiver air pressure
- ☐ d. All of the above

1-4. Which of the following is classed as a dynamic compressor?

- ☐ a. Liquid-ring
- ☐ b. Centrifugal
- ☐ c. Impeller (two-lobe rotary)
- ☐ d. Rotary-screw

1-5. The amount of cooling that occurs in a water-cooled compressor is determined mainly by the

- ☐ a. water temperature and volume
- ☐ b. size of the heat exchanger
- ☐ c. air contamination
- ☐ d. liquid capacity of the system

1-6. Dust particles that contact oil sprays or mist usually

- ☐ a. settle in the intercooler
- ☐ b. improve lubrication
- ☐ c. decrease abrasion
- ☐ d. collect in the lubricant

1-7. What determines the type of air filter used on an air compressor?

- ☐ a. Compressor speed
- ☐ b. Compressor size
- ☐ c. Number of secondary filters
- ☐ d. Duty or application

1-8. Which of the following best determines the amount of conditioning required by the compressed air after it leaves the compressor?

- ☐ a. How the air is used
- ☐ b. Volume of air used
- ☐ c. Pressure of the air
- ☐ d. Type of primary air filter

1-9. In which of the following locations within the distribution system can the filter/separator be installed?

- ☐ a. Branch lines
- ☐ b. Main supply lines
- ☐ c. Individual feed lines
- ☐ d. All of the above

1-10. Oil is usually added to the airstream at the rate of

- ☐ a. one drop/100 cfm
- ☐ b. two drops/100 cfm
- ☐ c. one drop/10 cfm
- ☐ d. two drops/10 cfm

SUMMARY

A pneumatic system is a combination of two or more components designed to do work by using air under pressure. In modern industry, the entire system is divided into major subsystems. They are: (1) the air-supply system, (2) the piping or distribution system, (3) the air-line conditioning system, and (4) the air control and actuation system.

The air-supply system compresses and stores the air. Air then flows through the piping or distribution system. The air is cleaned, dried, and lubricated in the air-line conditioning system, and is actually put to use in the air control and actuation system.

Each of these subsystems is important to the operation of the total system, because without any one section, the total system will not funtion. As a maintenance craftsman, one of your responsibilities is to maintain the pneumatic system in the proper working order. This includes not only minor adjustments, but also major overhauls.

The components used in pneumatic systems vary from plant to plant. Specific components used in any particular industrial plant are determined by the needs of the plant and its operating requirements. Even in so-called "duplicate" plants, pneumatic systems vary slightly. This variance is brought about by modifications to the production equipment and changes in the plant layout.

Answers to Self-Check Quiz

1-1. b. Decreasing its volume. Ref: 1.04

1-2. d. Physical arrangement. Ref: 1.06, Fig. 1-1

1-3. c. Receiver air pressure. Ref: 1.10, Fig. 1-2

1-4. b. Centrifugal. Ref: 1.20

1-5. a. Water temperature and volume. Ref: 1.24

1-6. d. Collect in the lubricant. Ref: 1.29

1-7. d. Duty or application. Ref: 1.32

1-8. a. How the air is used. Ref: 1.33

1-9. d. All of the above. Ref: 1.37

1-10. c. One drop/10 cfm. Ref: 1.48

Contributions from the following sources are appreciated:

Figure 1-2. Ingersoll-Rand Co.
Figure 1-6. Dyna-Quip