

# Pneumatics

## Conditioning

The last discussion on pneumatics discussed ideal gas laws, absolute and relative pressure scales, absolute and relative temperature scales, and sizing of air receivers.

We also said that an advantage that air has over hydraulic oil is that air is free. That's true, but compressed air is not free. We're going to talk about why this is the case. Everything you do to air to get it into a compressed state and ready for use costs money. Once you have compressed the air, you have to condition it for use in a pneumatic system.

### Filters

Conditioning includes filtering particulates out of the air. Air filters remove particles down to 5  $\mu\text{m}$ . For comparison, human hair ranges from 70  $\mu\text{m}$  to 100  $\mu\text{m}$ ; human baby hair is about 30  $\mu\text{m}$ .

We've said that air is free, and free air comes with free water in the form of humidity. In a compressed air system, this water can condense, which leads to internal corrosion and other problems because liquid water doesn't compress like air does. We have to remove this condensed water before it gets to valves, cylinders, and motors. A manual-drain filter has a wing nut at the bottom that you have to loosen from time to time to let the water out.

If the filter is in an inconvenient location, you can use an automatic drain instead.

Air filters do not remove water vapor...only condensed water. So if there's humidity in the air upstream of the filter, it will still be in the air downstream from the filter.

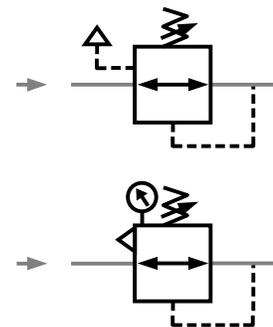
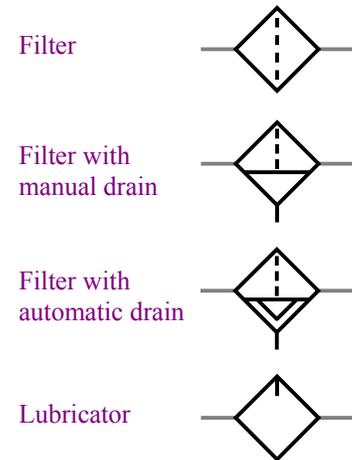
Hydraulic systems don't require lubrication, because the compressed medium is a lubricant...the hydraulic oil lubricates the valves, cylinders, motors, etc. Pneumatic systems have lubricating units which add oil droplets to the compressed air stream. You want to install the lubricator as close as possible to where the air is used. Large droplets may travel about 20 feet downstream; the smallest droplets may travel 300 feet downstream. So if there's 400 feet of pipe between the compressor and a pneumatic device, you'll want to install a lubricator close to the device.

Again, we're using a diamond shape for the conditioning device. This is the shape we use for a variety of devices used for conditioning the air: heaters, coolers, etc. are shown in Appendix G.

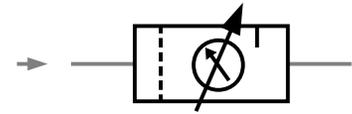
Not all pneumatic systems require lubrication. Since pneumatic systems exhaust to the atmosphere, they also send oil mist into the air. To solve this environmental problem, makers of cylinders, motors, and valves have developed self-lubricating devices that require no additional oil. Seals contain either a liquid or solid lubricant, good for the life of the part.

Another device used to modify the air is a *regulator*, which reduces the pressure downstream. In a factory, the compressor may produce 120 psi, but some machines using compressed air may require a lower pressure...say, 90 psi.

At the top of the regulator symbol is an adjustable spring. There's a dotted pilot line connected to the bottom of the regulator...this means that the downstream pressure will start to close the valve if it exceeds the spring force. Any excess air will be vented from the regulator...that's the triangle symbol at the upper right. Sometimes the vent triangle is shown right on the regulator, just pasted onto the side. The symbol at the bottom also includes a pressure gauge, so you know what the pressure is when you crank on the adjustable spring.



Very often, these three components are packaged as a single unit, the filter-regulator-lubricator (FRL), placed just upstream of a pneumatic machine. The combined symbol has several parts:



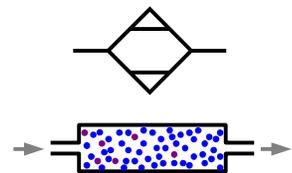
- **Vertical dotted line.** The filter.
- **Short solid line from the top.** Lubrication.
- **Long arrow moving up to the right.** Adjustable spring, to adjust the downstream pressure.
- **Circle with a short arrow.** Pressure gauge.

This symbol is a shorthand for drawing three different symbols... it saves you time when you're drawing a circuit, and it reduces clutter on the finished drawing. Plus, even though the different parts may not be all in a single housing, they're often sold connected together as a single unit, so you order one part number instead of three.

### Air Dryers

Some applications require extremely dry air:

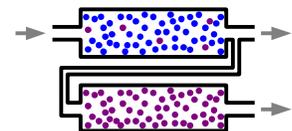
- Dentistry
- Shot-peening
- Paint spraying
- Food handling
- Powder blowing
- Freezing environment



We remove moisture using a desiccant: a material that readily absorbs water from the air, like silica gel. The symbol for an air dryer has two lines parallel to the flow direction.

Eventually, the desiccant material in a dryer will be saturated with water, and it won't dry anymore. So one approach is to use two desiccant towers. While one tower is in use, a little of the dry air is bled off and allowed to expand to 1 atm. This dry, low pressure air is fed through the second tower. When compressed air at 100 psi expands to 14.7 psi, it can carry away about 7 times as much moisture as it carried in.

Once tower #1 starts to saturate, a solenoid valve on a timer switches the flow, so tower #2 does the drying, and tower #1 gets dried out again.



Advantage: you can package the dryer in a small space. No pumps, motors, etc. required.

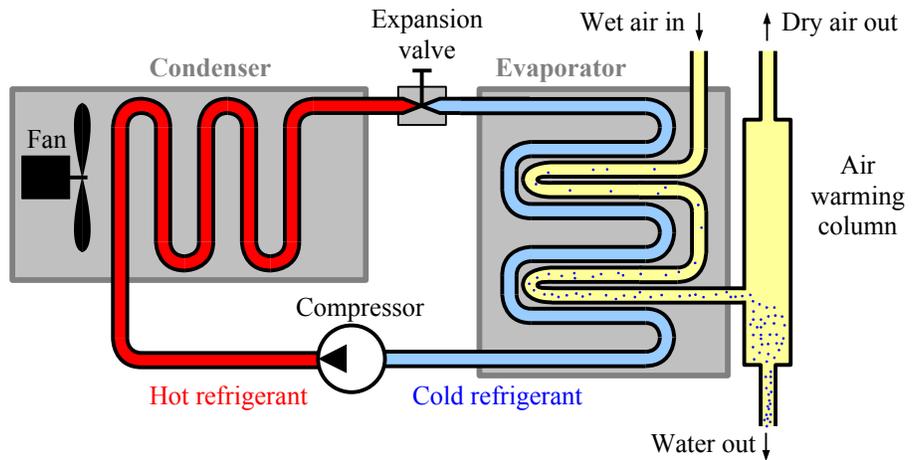
Disadvantage: you lose 10-15% of the air you've spent money to compress. In a small system, the money lost won't be great. In a large system, it could be significant.

Alternative: use heat to recharge the desiccant. Heat takes longer, so you need larger towers and more desiccant.

Another way to remove water is by chilling the air to 39°F, using a refrigeration system. Water condenses out of the air.

It's not shown well in this diagram, but you run the dried air past the hot coils of the condenser, and the exiting air is back to room temperature. You won't get *any* condensation in the downstream pneumatic system, unless some part of the system gets below 39°F... pretty unlikely.

A refrigeration system uses more power than a dessicator system, but it doesn't waste air. If you have a large pneumatic system, this may be the way to go.



### Pressure Loss in Pneumatic Systems

Several things drive up the cost of compressed air:

- Leaks
- Undersized pipes and fittings (pressure drops due to friction)
- Long pipes (friction)
- Multiple fittings (friction)
- Dryers (air consumption or electricity)
- Inefficiency of motors and compressors

We can calculate the pressure loss due to friction in pipes and fittings using the Harris Formula, given in the textbook as:

$$p_f = \frac{0.1025 L Q^2}{3600 CR d^{5.31}} \cdot \text{Variables are pressure drop } p_f \text{ (psi), pipe length } L \text{ (ft.), air flow rate } Q \text{ (scfm), compression ratio}$$

$CR = \frac{p_{\text{compressed air}} \text{ (psia)}}{p_{\text{atm}} \text{ (psia)}}$ , and inside pipe diameter  $d$  (in.). Figure 14.3 in the textbook lists values of  $d^{5.31}$  for common pipe sizes.

There's an easy way to use the Harris Formula with valves, elbows, and other fittings. The friction caused by each fitting is equivalent to a certain length of pipe of the same size. For example, the friction in a 1" gate valve is equivalent to the friction in 0.56 feet of 1" diameter pipe. Look at the table in figure 14-4, page 514... there are equivalent lengths listed for 6 different fittings in 7 different pipe sizes.

For example, consider a pneumatic system comprising 100 feet of 3/4" ID pipe with four 90° elbows and one fully open gate valve, with 35 scfm passing through the pipe, starting at 80 psig. What is the final pressure at the end of the line?

First, calculate the total equivalent length. Pipe length is 100 ft. Each elbow has an equivalent length of 2.10 ft., therefore the four elbows have an equivalent length of  $4 \times 2.10 \text{ ft.} = 8.40 \text{ ft.}$  . The valve has an equivalent length of 0.44 ft. The total equivalent length is  $L = 100 \text{ ft.} + 8.40 \text{ ft.} + 0.44 \text{ ft.} = 108.84 \text{ ft.}$  . From the textbook,  $d^{5.31} = 0.3577$  , so the pressure loss is

$$p_f = \frac{0.1025 \cdot 108.84 \text{ ft.} \cdot (35 \text{ scfm})^2}{3600 \cdot \frac{(80 + 14.7) \text{ psia}}{14.7 \text{ psia}} \cdot 0.3577} = 1.6 \text{ psi}$$

Subtract the pressure loss from the inlet pressure to find the outlet pressure:  $80 \text{ psig} - 1.6 \text{ psi} = 78.4 \text{ psig}$  . As you might

expect, there are similar pressure losses due to friction in hydraulic systems, but viscosity also comes into play...so there are lots of tables and charts.

### Inefficiency

Another cost of pneumatic systems is the inefficiency of motors and compressors. Here, we're talking about the electric motor that drives the compressor, not an air motor in the pneumatic system. The textbook introduces this equation for

calculating the power required to drive a compressor:  $HP_{theoretical} = \frac{p_{in} Q}{65.4} \left[ \left( \frac{p_{out}}{p_{in}} \right)^{0.286} - 1 \right]$  where pressures are in psia and

flow rate is in scfm. The horsepower we actually need is equal to the theoretical horsepower divided by the efficiencies of

the compressor and the electric motor running the compressor:  $HP_{needed} = \frac{HP_{theoretical}}{\eta_{compressor} \eta_{motor}}$  where the symbol for efficiency

is the Greek lower-case letter "eta".

For example, consider an 80% efficient compressor coupled to a 90% efficient motor.

$HP_{needed} = \frac{HP_{theoretical}}{0.8 \times 0.9} = 1.39 HP_{theoretical}$ . The actual horsepower that the motor has to provide is 1.4 times the theoretical horsepower. If you need 10 horsepower output from the compressor, then you install a 14 horsepower motor to run the compressor.

### Gas-Loaded Accumulator

Sometimes we combine hydraulic and pneumatic systems together. For example, if you have a hydraulic system that sees sudden, large pressure spikes due to intermittent loading (like the car crusher shown here), you can add a *gas-loaded accumulator* to the system. It stores hydraulic power for when you need a little boost.

It works just like the accumulator on a well pump...the blue tank that sits in your basement, hooked up to the water supply.

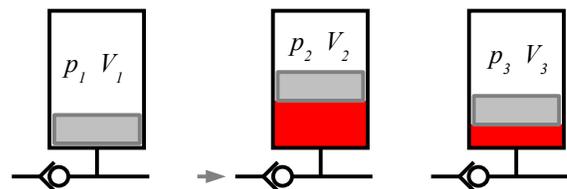
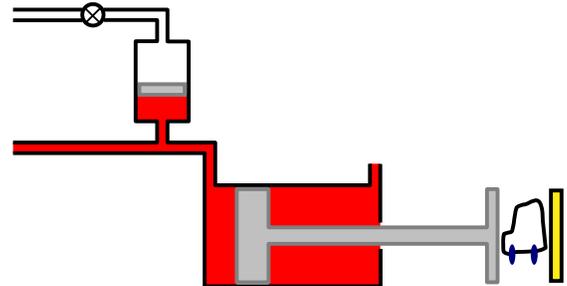
Let's look at what happens in the accumulator.

The first thing we do is charge the accumulator with some compressed air...the *preload*. The hydraulic system is not running, so there's no oil pressure.

Next, we turn on the hydraulic pump. Now there's oil pressure in the hydraulic system, and the oil pressure pushes the piston up. This compresses the air, so air pressure  $p_2$  goes up, and air volume  $v_2$  goes down.

Now we crush the car. The oil in the accumulator adds to the oil produced by the pump, so we have enough oil to crush the car. The piston moves down, so the air pressure  $p_3$  drops and the air volume  $v_3$  increases.

If we assume that the temperature of the air in the accumulator doesn't change very much, then we can use the ideal gas laws to calculate pressure and volume.



Dr. Barry Dupen, Indiana University-Purdue University Fort Wayne. Revised May 2016. This document was created with Apache Software Foundation's OpenOffice software v.4.1.0.

This work is licensed under Creative Commons Attribution-ShareAlike 4.0 International (CC BY-SA 4.0) See [creativecommons.org](http://creativecommons.org) for license details.

