Learning Objectives

After this presentation you will be able to:

- Identify the parts of an industrial compressed air system
- Explain how compressed air demand coordinates with air system operation and efficiency
- Compute pressure drops in compressed air systems
- Identify efficient system configurations
- List common energy savings opportunities for air systems
Compress Air System Components

Compressors

Types

Positive Displacement

Dynamic

Reciprocating

Rotary

Centrifugal

Pistons compress air
Single and double acting

Vane volume decreases
Oil lubricated
Or dry types

Smaller size
High speed
Use in high volume applications

Compressor Characteristics

Compressor Energy Consumption Comparison

<table>
<thead>
<tr>
<th>Compressor Types</th>
<th>Power Consumption (kW per 100 ft³/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reciprocating Compressors</td>
<td></td>
</tr>
<tr>
<td>Single Acting</td>
<td>22-24</td>
</tr>
<tr>
<td>Rotary Screw</td>
<td></td>
</tr>
<tr>
<td>Lubricant-free</td>
<td>20-22</td>
</tr>
<tr>
<td>Lubricated</td>
<td>18-19</td>
</tr>
<tr>
<td>Dynamic Compressors</td>
<td></td>
</tr>
<tr>
<td>Centrifugal</td>
<td>16-20</td>
</tr>
</tbody>
</table>

Air compression is energy intensive. Consider life-cycle costs and electric alternatives.
Cost of Compressed Air

Example 1: A reciprocating, single acting compressor with a power consumption of 24 kW per 100 cubic feet per minute (cfm) delivers 300 cfm to a plant air supply. The compressor operates 7500 hour annually. Determine the annual operating cost of the compressor if the annual demand charge is $70/kW-year and the electric energy charge is 0.085 $/kWh.

Solution

Compute the demand and then the demand charge

\[ c_d = \frac{70}{\text{kW-yr}} \quad d_c = \frac{24}{100 \text{ cfm}} \]

Define air flow \( Q = 300 \text{ cfm} \)

\[ D = Q \cdot d_c \]

\[ D = (300 \text{ cfm})(\frac{24 \text{ kW}}{100 \text{ cfm}}) = 72 \text{ kW} \]

Cost of Compressed Air

Example 1: continued

Define the total annual demand charge

\[ C_{DT} = D \cdot c_d \]

\[ C_{DT} = (72 \text{ kW})(70 \$/\text{kW-yr}) = 5040 \$/\text{yr} \]

Compute the annual energy consumed and its cost

\[ E = D \cdot T \quad \text{where} \ T = 7500 \text{ hr/yr} \]

\[ E = (72 \text{ kW})(7500 \text{ hr/yr}) = 540,000 \text{ kWh/yr} \]

Total energy charge

\[ C_{ET} = E \cdot c_e \quad \text{Where} \ c_e = \text{energy cost} = 0.085 \$/\text{kWh} \]

\[ C_{ET} = (540,000 \text{ kWh/yr})(0.085\$/\text{kWh}) = 45,900 \$/\text{yr} \]

Total operating cost

\[ C_T = C_{DT} + C_{ET} = 5040 \$/\text{yr} + 45,900 \$/\text{yr} = 50,940 \$/\text{yr} \]
Example 2: Determine the annual savings if the reciprocating compressor is replaced with a centrifugal compressor with a power consumption of 17 kW/100 cfm. Assume the same demand and energy charges from Example 1.

Solution

Compute the demand and then the demand charge

\[ \text{\(c_d = \$70/kW\text{-yr}\)} \]
\[ \text{\(d_c = 17 \text{ kW/100 cfm}\)} \]

Define air flow

\[ \text{\(Q = 300 \text{ cfm}\)} \]

\[ \text{\(D = Q \cdot d_c\)} \]
\[ D = (300 \text{ cfm})(17 \text{ kW/100 cfm}) = 51 \text{ kW}\]

Define the total annual demand charge

\[ \text{\(C_{DT} = D \cdot c_d\)} \]
\[ C_{DT} = (51 \text{ kW})(70 \$/kW\text{-yr}) = 3570 \$/\text{yr}\]

Compute the annual energy consumed and its cost

\[ \text{\(E = D \cdot T\)} \]
\[ E = (51 \text{ kW})(7500 \text{ hr/yr}) = 382,500 \text{ kWh/yr}\]

Where \(c_e = \text{energy cost} = 0.085 \$/\text{kWh}\)

\[ \text{\(C_{ET} = E \cdot c_e\)} \]
\[ C_{ET} = (382,500 \text{ kWh/yr})(0.085\$/\text{kWh}) = 32,513 \$/\text{yr}\]

Total operating cost

\[ C_T = C_{DT} + C_{ET} = 3570 \$/\text{yr} + 32,513 \$/\text{yr} = 36,083 \$/\text{yr}\]
Compress Air System Components

Air Dryers and Filters

Compressing air increases temperature

- Increased temperature increases air’s ability to retain moisture
- Cooled and/or expanded air releases moisture as condensate throughout the system

Condensate causes:
- Rust & Corrosion
- Process Contamination
- Air waste due to Blow-down

Air Dryers and Filters

Air dryers remove moisture before it enters the system

Dryer types:
- Refrigeration type
- Cool air below dew point. Avoid overcooling for better efficiency
- Desiccant type
- Regenerate using heat

Most Costly

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Compress Air System Components

**Air Filters** remove particulate matter, water, oil

- **Inlet Filter**: Removes particulates, prevents damage to dynamic compressors.
- **Types**: Viscous impingement, Oil baths, Dry.
- **Outlet Filter**: Removes particulates, oil and water, prevents consumer damage.
- Select for minimum pressure drop, filter to level required by consuming equipment.

**Receiving (Storage) tanks**

- **Inlet Filter**
- **Compressor**
- **Outlet Filter/Dryer**

Store compressed air, cover peak air demand, remove pressure pulses from reciprocating compressor outputs, reduce compressor cycling.
Compress Air System Components

Piping and Pressure Drop

Factors affecting system air pressure
- Required flow rate (cfm)
- Pipe diameter and length
- System configuration

Air tools operate best at rated inlet pressure

System divided into supply and demand sides

Typical Air Pressure Profile

In-line components produce significant pressure losses

115 psi
Compressor
Set Point Range

105 psi
Dryer, Filter
Separator P drops

90 psi
Maintain dryers and filters to minimize Pressure drop (clean/replace filters)

87 psi
Piping System P Drop 3 psi typical

76 psi
Valves, hose, disconnects P drops as consumption site
Pressure Drop in Air Supplies

Factors that affect supply pressure

- Consumed Air Volume
- Pipe Length
- Pipe Diameter
- Air Temperature /Velocity

Pressure Drop Formula (SI units)

\[ \Delta P = \frac{1600 \cdot Q^{1.85} \cdot L}{d^5 \cdot P_i} \]

- \( \Delta P \) = pressure drop (Pascals, PA)
- \( Q \) = Air Flow required (m\(^3\)/sec)
- \( L \) = Pipe length (m)
- \( d \) = pipe diameter (m)
- \( P_i \) = Inlet pressure absolute (Pascals, PA)

Pressure Drop Tables

Enter the Inlet Pressure in PSI gage below
Pressure drops in terms of 1000 ft (305 m) of pipe

Spreadsheets allow calculation of specific inlet pressure and length

Enter gage inlet pressure
Enter pipe length
Pressure Drop Example

Determine the pressure drop of 100 ft of 1 inch pipe carrying a air flow of 110 CFM using the spreadsheet given. The inlet pressure from the compressor header is 100 PSI.

Enter 100 ft into correct cell and examine table

Drop excessive. Consider 2 inch pipe

Pressure Drop in Air Supplies

Pressure drop of fittings and valves

<table>
<thead>
<tr>
<th>Pipe Fitting</th>
<th>Equivalent pipe length in pipe diameters (L/D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 degree standard elbow</td>
<td>30</td>
</tr>
<tr>
<td>45 degree standard elbow</td>
<td>16</td>
</tr>
<tr>
<td>90 degree long-radius elbow</td>
<td>20</td>
</tr>
<tr>
<td>90 degree street elbow</td>
<td>50</td>
</tr>
<tr>
<td>Gate Valve, Full Open</td>
<td>13</td>
</tr>
<tr>
<td>Globe Valve, Full Open</td>
<td>450</td>
</tr>
<tr>
<td>Standard Tee, Flow through Run</td>
<td>20</td>
</tr>
<tr>
<td>Standard Tee, Flow through Branch</td>
<td>60</td>
</tr>
</tbody>
</table>

Avoid globe valves in air supplies due to high loss
Pressure Drop in Air Supplies

Using the Equivalent Length Table

Table gives the equivalent pipe length of a valve or fitting for a given pipe diameter. Multiply table value by pipe diameter to get equivalent length.

Example: Compare the pressure drops of a 2 inch gate and globe valve for an air flow of 0.236 m³/sec and an inlet pressure of 95 psi

Convert valve L/D ratios to 2 inch pipe lengths

For gate valve

\[ L_{\text{gate}} = 2 \text{ in} \cdot \left(\frac{3}{12 \text{ in}}\right) = 26 \text{ in} \]

\[ L_{\text{gate}} = 26 \text{ in} \cdot \left(\frac{1 \text{ ft}}{12 \text{ in}}\right) = 2.17 \text{ ft} \]

For globe valve

\[ L_{\text{globe}} = 2 \text{ in} \cdot (50 \text{ in}) = 900 \text{ in} \]

\[ L_{\text{globe}} = 900 \text{ in} \cdot \left(\frac{1 \text{ ft}}{12 \text{ in}}\right) = 75 \text{ ft} \]

Example continued

Convert the inlet pressure and pipe diameter to metric units for the formula

\[ P_i = 95 \text{ psi} \cdot \left(\frac{6895 \text{ PA}}{1 \text{ psi}}\right) = 655025 \text{ PA} \]

\[ d = 2 \text{ in} \cdot \left(\frac{0.0254 \text{ m}}{1 \text{ in}}\right) = 0.0508 \text{ m} \]

Convert the equivalent pipe lengths to meters for use in the formula

\[ L_{\text{globe}} = 75 \text{ ft} \cdot \left(\frac{0.3048 \text{ m}}{1 \text{ ft}}\right) = 22.86 \text{ m} \]

\[ L_{\text{gate}} = 2.17 \text{ ft} \cdot \left(\frac{0.3048 \text{ m}}{1 \text{ ft}}\right) = 0.6614 \text{ m} \]
Pressure Drop in Air Supplies

Example continued

Pressure Drop Formula (SI units)

\[ \Delta P = \frac{1600 \cdot Q^{1.85} \cdot L}{d^5 \cdot P_i} \]

Compute pressure drop for the globe valve.

\[ Q = 0.236 \text{ m}^3/\text{sec} \]

\[ \Delta P_{\text{globe}} = \frac{1600 \cdot (0.236)^{1.85} \cdot 22.86}{(0.0508)^5 \cdot (655025)} \]

\[ \Delta P_{\text{globe}} = \frac{2530}{0.222} = 11395 \text{ PA} \]

\[ \Delta P_{\text{globe}} = 11395 \text{ PA} \cdot \left( \frac{1 \text{ psi}}{6895 \text{ PA}} \right) = 1.65 \text{ psi} \]

Pressure Drop in Air Supplies

Example continued

Pressure Drop Formula (SI units)

\[ \Delta P = \frac{1600 \cdot Q^{1.85} \cdot L}{d^5 \cdot P_i} \]

Compute the drop for the gate valve

\[ \Delta P_{\text{gate}} = \frac{1600 \cdot (0.236)^{1.85} \cdot 0.6614}{(0.0508)^5 \cdot 655025} \]

\[ \Delta P_{\text{gate}} = \frac{73.2}{0.222} = 330 \text{ PA} \]

\[ \Delta P_{\text{gate}} = 330 \text{ PA} \cdot \left( \frac{1 \text{ psi}}{6895 \text{ PA}} \right) = 0.05 \text{ psi} \]

Gate valve pressure drop is almost insignificant at this flow rate while globe valve is excessive for this application.
Supply-side Components

Structure of Air Supply

Compressor 1
Compressor 2
Compressor 3

Compressor n

Common Header

Wet Receiver
Air Dryer
Air Filter

To Consumers

Compressor number and sequence depends on overall load

Air Supply Load Profile

Air demand varies over time and process utilization

Stage compressors to handle load change

1 compressor baseload 2nd compressor peak

Air Demand

Compressor Output

Volume (cfm)

Time

12:00 am 6:00 am 12:00 noon 6:00 pm

# 1 ON # 1 and 2 ON # 1 ON

12:00 am 6:00 am 10:00 am
Air System Layout for Efficiency

Consider location of largest air demand and compressors
Optimal designs minimize pressure drops and maximize compressor utilization

Efficient system layouts
Loop systems provide parallel flow paths that reduce pressure drop

Typical pressure drops: Header 1 PSI; Branch: 1 PSI; Drop: 1 PSI
Total < 4 PSI
Air System Layout for Efficiency

Efficient system layouts

Grid systems shown below in not as efficient as loop system. Satisfactory.

Avoid this configuration

Difficult compressor coordination

Multiple Pressure Requirements

Throttling to reduce pressure wastes energy.
Consider multiple systems sized to handle flows

Example: Air pressures required 300 cfm at 25 psi, 500 cfm at 90 psi and 50 cfm at 150 psi
## Energy Saving Opportunities

### ESOs for air supplies Include:

<table>
<thead>
<tr>
<th>Minimize Pressure Drops</th>
<th>Optimal Air Drying</th>
<th>Use Waste Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size piping to maintain 3 to 4 psi max drop</strong>&lt;br&gt;<strong>Maintain in/out compressor filters</strong>&lt;br&gt;<strong>Filter p drop of 2 psi increases drive energy 1%</strong></td>
<td><strong>Do not over dry</strong>&lt;br&gt;<strong>Air with dew point &gt; lowest system temp produces condensate</strong>&lt;br&gt;<strong>Identify lowest system temp</strong>&lt;br&gt;<strong>Do not cool below this temp</strong></td>
<td><strong>Cooling water and air used for space heating</strong>&lt;br&gt;<strong>Vent air out when not needed</strong></td>
</tr>
</tbody>
</table>

### Other ESO’s for air supplies

<table>
<thead>
<tr>
<th>Minimize Leaks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Leakage 2-20% of capacity</strong>&lt;br&gt;<strong>Function of maintenance</strong>&lt;br&gt;<strong>Badly maintained 30-40%</strong>&lt;br&gt;<strong>Inspect and service valves for leakage</strong>&lt;br&gt;<strong>Isolate unused sections of system</strong></td>
</tr>
</tbody>
</table>
End Lesson 29

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Compressed Air Systems
Dr. Carl J. Spezia
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