Compressed Air Energy Management
Meet Your Panelist:

Mike Carter
NEEA Northwest Industrial Training

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Upcoming In-Class Trainings

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  **Compressed Air Challenge – Level 1**
  February 21: Boise, ID

- **Chilled Water and Cooling Towers**
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Compressed Air Energy Management

- Bottom line cost savings today!
  - Compressed air is the most expensive utility.
  - Compare annual energy cost for 1 hp air motor at $1,358 versus 1 hp electric motor at $194.
  - Easily averages $100 per cfm per year (3-shifts)!

Typical Demand Components

- Normal Production 50%
-Leaks 25%
-Excessive Pressure 5%
-Wrong application 20%
Compressed Air Energy Management

- Basics
- Supply Side
  - Compressors
  - Prime Movers
  - Controls
  - Air Treatment
- Demand Side
  - Distribution
  - Storage
- Energy-Savings Ideas

Source: Compressed Air Challenge
**Compressed Air Basics**

- **Heat of Compression**
  - Roughly 80% to 90% of the electrical energy going to a compressor becomes available heat.
  - Waste heat temperature rises.
    - Air delta 30°F to 40°F
    - Water discharge at 130°F max

Source: Atlas Copco
Compressed Air Basics

- Single-stage versus Multi-stage
  - Multi-stage more efficient.
    - Intercooling, load reduction, lower leakage potential
  - Higher pressures with multi-stage.

Source: Atlas Copco
Compressed Air Basics

- **Power versus Energy**
  
  - Kilowatt (kW) is a measure of **power**, like the speedometer of your car that records the rate at which miles are traveled.
    - A bigger engine is required to travel at a faster rate.
  
  - Kilowatt-hour (kWh) is a measure of **energy** consumption, like the odometer on your car (miles).
  
  - Energy cost = energy consumption x unit cost
    - kWh x $/kWh
      - A 100-kW compressor motor operating 16 hours per day costs $58,400 per year

  Energy cost = 100 kW x 5,840 hr x $0.10/kWh
  = $58,400
Compressed Air Basics

- **Power versus Energy**
  - **Motor power** (kW) = Horsepower x 0.746/motor efficiency
    - A 100 hp motor = 100 hp x 0.746/0.90 ME= 83 kW
  - Pay the price for improved energy efficiency!
    - The operating cost over the lifetime of a compressed air system can far exceed the original purchase price.

![Compressed Air Costs Pie Chart]

- Electricity 76%
- Equipment 12%
- Maintenance 12%
Compressed Air Basics

Source: DOE Compressed Air Challenge
Compressors

Reciprocating

Centrifugal

Helical-Screw

Source: Gardner Denver; used with permission

Source: Atlas Copco Airpower; used with permission

Source: Atlas Copco Airpower. Used with permission.
Compressors

- **Positive Displacement**
  - Reciprocating
    - Single-Acting
    - Double-Acting
  - Rotary
    - Helical-Screw
    - Liquid-Ring
- **Centrifugal**
- **Dynamic**
  - Variable capacity
    - Variable pressure
  - Constant pressure
  - Radial
     - Sliding-Vane
     - Lobe
Compressors

- Reciprocating single-acting air cooled compressor
  - Lowest first cost, but least efficient.

- Higher flow capacities require dynamic compressors
  - Centrifugal
  - Axial

Source: Research Associates
Compressors

- Spend a little more for a double-acting two-stage unit and achieve better efficiency.
- Lubricated compressors are often more efficient than a similar non-lubricated unit.
  - They contribute oil content to the system.
  - May impact the compressor air quality.

<table>
<thead>
<tr>
<th>Energy Consumption</th>
<th>Reciprocal</th>
<th>Rotary Screw</th>
<th>Centrifugal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air cooled</td>
<td>Water cooled</td>
<td>Water cooled</td>
</tr>
<tr>
<td>bhp per 100 cfm</td>
<td>Single-Stage</td>
<td>Single-Stage</td>
<td>Two-Stage</td>
</tr>
<tr>
<td>kW per 100 cfm</td>
<td>22-27</td>
<td>21</td>
<td>16-18</td>
</tr>
</tbody>
</table>
Prime Movers

- Electric Motors
- Diesel or Gasoline Engine
- Steam or Natural Gas Turbine
The objective is to keep compressors off when they are not needed, thereby reducing energy use.

- Use the appropriate controls (unloading, modulating, variable speed).
  - Reduce air usage
  - Lower input energy
- For multiple units use a modern electronic central air management system.
  - Keeps all the baseline units on at full-load
  - Only one trim unit operates at part-load
Controls

- Evolution of lubricant-cooled rotary screw compressed air controls
  - Load/Unload (Blowdown)—low input kW is not reached until air/oil separator tank pressure is blown down.
    - It can take several seconds to several minutes for the pressure in a lubricant sump/separator to be fully relieved (blue line #2).
  - Inlet Valve Modulation—features a gradually closing inlet valve at the compressor inlet controlled by a regulator (red line #1).
Evolution of lubricant-cooled rotary screw compressed air controls

- **Variable Displacement** — the sealing point of the compression chamber is moved effectively reducing the rotor length and inlet air displacement.
  - Controlled by slide/turn/spiral/poppet valve.

- **Variable Speed Drive** — best applied to compressors that operate primarily as trim units, or as single units with loads below 75% to 80% demand.
  - Motor drive speed controlled to modify air supply.

Source: Air Technologies
Compressors operate at highest efficiency at full load or off.

- Optimum controls result in big savings.
- For example, at 50% full-load flow, kW input varies from 51% to 83%.

Source: Improving Compressed Air System Performance: A Sourcebook for Industry, DOE
Air Treatment

Source: Ingersoll-Rand Company
Dryers

- Refrigerated dryer water reduction process
  - Temperature reduction results in higher relative humidity.
  - Relative humidity stays at 100% due to constantly decreasing temperatures.
  - Water reduction only occurs when temperature decreases below dew point.

Source: Atlas Copco
Air Treatment

- **Dryers**
  - **Refrigerated air dryer (non-cycling)**
    - Nominal pressure dew point of 35°F to 50°F.
    - Power requirement is 0.8 kW/100 cfm.
    - Lower inlet pressures and higher inlet air temperatures decrease the dryer flow rating.
    - Given a 100 psig and 100°F inlet dryer rating:
      - 125 psig, 80°F = 143% flow rating
      - 80 psig, 130°F = 40% flow rating
Air Treatment

- **Dryers**
  - **Desiccant** air dryers
    - Desiccant adsorbs water vapor.
    - Provides a pressure dew point of -40°F to -100°F.
    - Requires some purge air (3% to 7% heater type or 12% to 15% heaterless).
    - Power requirement is 2 to 3 kW/100 cfm.
Air Treatment

- **Dryers**
  - **Membrane** dryers
    - 10% to 20% of full load rating sweep air required.
    - Sweep air actual use is directly proportional to amount of flow through the dryer.
    - Power requirement is 3 to 4 kW/100 cfm.
    - 40°F to -40°F Dew Point
Air Treatment

- **Dryers**
  - **Heat of compression/regeneration dryers**
    - Takes hot discharge air prior to aftercooler and routes it through the drying tower (50% RH) and removes water vapor from desiccant beads.
      - Saturated air then goes to aftercooler.
    - No purge air required.
    - Power requirement is 0.8 kW/100 cfm.
    - Recommended on oil-free systems only (to prevent a fire hazard).

Source: Henderson Engineering Company, Inc.
<table>
<thead>
<tr>
<th>Dryer Type</th>
<th>Dew Point</th>
<th>Air Capacity Reduction</th>
<th>Power Consumption</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigerant</td>
<td>35F to 50F</td>
<td>None</td>
<td>0.8 kW/100 cfm</td>
<td>- -</td>
</tr>
<tr>
<td>Desiccant</td>
<td>-40F to 100F</td>
<td>10% to 18%</td>
<td>2 to 3 kW/100 cfm</td>
<td>Coalescing prefilter</td>
</tr>
<tr>
<td>Membrane</td>
<td>40F to -40F</td>
<td>15% to 20%</td>
<td>3 to 4 kW/100 cfm</td>
<td>Low capacity</td>
</tr>
<tr>
<td>Heat of Compression</td>
<td>10F to -40F</td>
<td>None</td>
<td>0.8 kW/100 cfm</td>
<td>Centrifugal, Oil-free rotary screw</td>
</tr>
</tbody>
</table>
Distribution

- Required pressure levels must take into account system losses from dryers, separators, filters, and piping.
  - A properly designed system should have a pressure loss of much less than 10% of the compressor’s discharge pressure, measured from the receiver tank output to the point-of-use.

Source: Graco Inc.
Storage

- Air Receivers
  - Can provide dampening of pressure pulsations, radiant cooling, and collecting of condensate.
  - Stabilizes system header pressure and “flattens” the load peaks.
  - Provides the time needed to start or avoid starting standby air.
    - Storage buys time, not capacity.
Air Receivers

- Select optimum size for a short-duration peak load converting a high rate of flow into a low rate of flow in the main system.

Pump up decay formula

\[
V = \frac{T \times C \times P_a}{(P_1 - P_2)}
\]

- \(V\) = Receiver Capacity (\(\text{ft}^3\))
- \(T\) = Time (minutes) for pressure drop
- \(P_1\) = Initial Receiver Pressure (psig)
- \(P_2\) = Final Receiver Pressure (psig)
- \(C\) = Air Demand (acfm)
- \(P_a\) = Atmospheric Pressure (psia)
Energy-Savings Ideas

- **Know your real costs!**
  - Compare annual energy cost for 1 hp air motor at $1,358 versus 1 hp electric motor at $194.
    - 30 scfm at 90 psi required by air motor
    - 6 to 7 bhp at compressor shaft required for 30 scfm
    - 7 to 8 hp input electric power required for 6 to 7 bhp
    - 5-day per week, 2 shift, $0.05/kWh
  - Energy cost for 6,000 hrs at $0.10/kWh = $125/cfm
    - At 4 cfm/hp, a 250 hp compressor costs about $125,000 annually!
Energy-Savings Ideas

- Only use compressed air when it is absolutely necessary!
- Examples of potentially inappropriate uses of compressed air:
  - Open blowing
  - Sparging
  - Aspirating
  - Atomizing
  - Padding
  - Dilute-phase transport
  - Dense-phase transport
  - Vacuum generation
  - Personnel cooling
  - Open hand-held blowguns or lances
  - Diaphragm pumps
  - Cabinet cooling
  - Vacuum venturis

- If possible, switch to motors, mechanical actuators, and other means to accomplish the same function.
Energy-Savings Ideas

- Use 3/4” diameter hose for >3 hp tools or >50' lengths

- Leaks often account for 20% to 30% of compressor output.
  - A 1/32” leak in a 90 psi compressed air system would cost approximately $185 annually.

Source: Ingersoll-Rand
Energy-Savings Ideas

- Produce only the pressure you really need
  - Reducing system pressure by 10 psi saves 8% to 10%.
  - For every 1 pound per square inch (1 psi) increase in discharge pressure, energy consumption will increase by approximately 0.8% to 1% for a system in the 100 psig range with 30% to 50% unregulated usage.*

*Except for centrifugal compressors
Energy-Savings Ideas

- Produce only the pressure you really need
  - Demand expander valve
    - Separates the supply side (compressors) from the demand side (users).
    - Maintains a higher pressure on the supply side.
    - Claims of 10% to 15% energy savings.

Source: Gardner Denver

Diagram:
- 115 psig
- 90 psig
- Demand expander opens at 90 psig
- Receiver
- Trim unit
- 90 psig to plant
- 115 psig to plant

HP

150

150

150

150

Source: Questline Academy
Heat Recovery

- **Air-cooled** compressors offer recovery efficiencies of 80% to 90%.
  - Ambient atmospheric air is heated by passing it across the system’s aftercooler and lubricant cooler.
    - As a rule, approximately 5,000 British thermal units per hour (Btuh) of energy are available for each 100 cfm of capacity (at full-load).
    - Air temperatures of 30°F to 40°F above the cooling air inlet temperature can be obtained.
    - Space heating or water heating.

- **Water-cooled** compressors offer recovery efficiencies of 50% to 60% for space heating only.
  - Limited to 130°F
Compressed Air System Design

- When designing a compressed air system, what parameters should be included?
  - Average air demand (flow measurement, air survey, flow/pressure relationship)
  - Peak air demand (flow measurement, air survey, flow/pressure relationship)
  - Facility expansion plans
  - Maintenance requirements
  - Ventilation needed
  - Air quality required by application
  - Minimum required air pressure
Compressed Air System Design

- Working pressure directly affects the power requirement.
  - Minimize pressure drops!

\[ \Delta p = 450 \times \frac{Q_v^{1.85} \times L}{d^5 \times p_i} \]

- \( \Delta p = \) pressure drop (bar)
- \( Q_v = \) Air flow, free air (l/s)
- \( d = \) Internal pipe diameter (mm)
- \( L = \) Length of the pipe
- \( p_i = \) Absolute initial pressure (bar)

*Source: Atlas Copco*

This is how the pressure drop across different components in the network affects the requisite working pressure.
John H. Harland Corporation printing plant in Atlanta, Georgia

- Fifteen new presses used compressed air in three components:
  - Batching modules (20 scfm at 130 psig)
  - Collators (1.1 scfm at 100 psig)
  - Print engines (also 1.1 scfm at 100 psig)

- Problems:
  - Air demand doubled to over 600 scfm.
  - Open-blowing air bars accounted for the greatest demand.
  - Joggers and lift cylinders were unable to work properly at the manufacturer’s recommended pressure levels.
  - Hoses supplying the batching modules from the airdrops were too small.
  - Many push-to-connect tube fittings tended to leak on start-up.
  - Condensation was collecting on the metal components of the print engines, causing engine shut down.

- Solutions
  - Compressed air bars were converted to blowers.
  - Hoses were replaced with shorter and larger diameter hoses.
  - Each module was provided with a dedicated storage tank to reduce source pressure.
  - Onboard compressors were converted to operate manually.

- Results
  - Each machine’s air demand declined from 27 scfm to only 4.5 scfm.
  - Site’s total air demand reduced to approximately 300 scfm at 81 psig.
  - Facility took 70 hp of compressor capacity offline.
  - Avoided having to purchase between 500 and 600 hp of compressor capacity ($500,000 + $200,000 O&M).
Southeastern Container blow molding plant in Enka, NC

- The blow molders require clean, dry compressed air at an operating pressure of 600 psig in order to produce a high quality Coca-Cola bottle.

- **Problems**
  - Blow off rate setting of 87% vented compressed air unnecessarily.
  - Three booster compressors had severe internal and external leakage rates around the valve cover plates and unloader valves.
  - Discovered 367 scfm of low-pressure leaks and 505 scfm of high-pressure leaks in the distribution system.
  - Vortex coolers used for cooling and hardening the bottlenecks was wasteful.

- **Solutions**
  - Blow off point set below 75% without any risk of surge.
  - Vortex coolers replaced by cabinet cooler.
  - Electromechanical vibrator replaced compressed air to prevent jamming of pre-form feed lines.
  - Central vacuum system replaced venturi vacuum producers for pick-and-place operation.
  - Replaced the unloader valves and cover plates around the booster compressors with newer, more advanced models.

- **Results**
  - Lowering of the blow-off set points saved $100,000.
  - Other actions saved $80,000.
Next Steps

- Facility air system audit?
- On-site training/seminar?
- Air system design consultation?

Workshops

- State Level, DOE EERE Industrial Tech Program sponsored
- Fundamentals of Compressed Air Systems, also web-edition (OH, UT, MN, CO, NV, IN, CA)
- Advanced Management of Compressed Air Systems (CA, IL)

Improving Compressed Air System Performance sourcebook

http://www.compressedairchallenge.org
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