COMPRESSED AIR SYSTEMS
Compression Efficiency

100 units of electrical energy input
Compression Efficiency

100 units of electrical energy input

8 units of thermal energy loss
Compression Efficiency

100 units of electrical energy input

High-pressure air is the desired product from the compressor

8 units of thermal energy loss
Compression Efficiency

100 units of electrical energy input

High-pressure air is the desired product from the compressor

The actual product is high-pressure, high-temperature air

8 units of thermal energy loss
Compression Efficiency

100 units of electrical energy input

8 units of thermal energy loss

90 units of thermal energy rejection

High-pressure air is the desired product from the compressor

The actual product is high-pressure, **high-temperature** air
Compression Efficiency

10% to 20%

100 units of electrical energy input

High-pressure air is the desired product from the compressor

The actual product is high-pressure high-temperature air

90 units of thermal energy rejection

10 to 20 units of shaft energy output from an air motor

The laws of thermodynamics are not violated because the air discharged is very cold

8 units of thermal energy loss
Compression Efficiency

10% to 20%

100 units of electrical energy input

High-pressure air is the desired product from the compressor

The actual product is high-pressure high-temperature air

90 units of thermal energy rejection

10 to 20 units of shaft energy output from an air motor

8 units of thermal energy loss

• Compressed air is the most expensive common utility.
• Compressed air systems require management.
• The compressed air system
Compressed Air Management Focus Areas

- **Compression**
- **Conditioning**
- **Use**
- **Leaks**
Compressed Air Management Focus Areas

- Compression
- Conditioning
- Use
- Leaks
Compressed Air Management Focus Areas

- Compression
- Conditioning
- Use
- Leaks
Compressed Air Management Focus Areas

- Compression
- Conditioning
- Use
- Leaks
Driving Force

• What is the main driving force for change??
Driving Force

• What is the main driving force for change??
What is the main driving force for change?

- Energy savings
- Reliability
- Maintenance
- Productivity
- Quality

[$]
Measure to Manage

• What you are not measuring you are not managing
Compressed Air Management Focus Areas

- The compressed air system
System Pressure

- Compressor power is proportional to discharge pressure
  - Pressure reduction of 10 psiΔ (70 kPaΔ) reduces power requirement 5%
    - Increase in centrifugal compressor capacity (possibly 10%)
- System leak rate is proportional to system pressure
  - Pressure reduction of 10 psiΔ (70 kPaΔ) reduces loss 9%
- Many compressed air demands are proportional to system pressure
  - Pressure reduction of 10 psiΔ (70 kPaΔ) reduces consumption 9%
  - Pneumatic tools may lose efficiency
Compressed Air Management Focus Areas

- Compression
- Conditioning
- Use
- Leaks
Compressor Types

• The most common types of industrial air compressors:
  – Reciprocating
    • Lubricated
    • Lubricant free
  – Rotary screw
    • Lubricant injected
    • Lubricant free
  – Centrifugal (inherently lubricant free)
Compressor Comparison

Percent of Full Load Power [%]

Percent Full Load Flow [%]
Full-load Power Comparison

Percent of DAR Full Load Power [% of DAR]

Percent Full Load Flow [%]

Lubricant free rotary screw
Centrifugal
Lubricant injected rotary screw
Double Acting Reciprocating
Compressor Control Comparison

Graph showing the comparison of different types of compressors:
- Rotary Screw
- Double Acting Reciprocating
- Lubricant injected rotary screw

Y-axis: Percent of DAR Full Load Power [% of DAR]
X-axis: Percent Full Load Flow [%]

The graph illustrates the efficiency of different types of compressors at various load percentages.
Compressor Control Comparison

![Graph showing the comparison of different types of compressors. The x-axis represents the percent full load flow (%), and the y-axis represents the percent of DAR full load power (% of DAR). The graph compares Centrifugal, Double Acting Reciprocating, and Centrifugal compressors. The Centrifugal compressor shows a higher power requirement at lower flow rates, while the Double Acting Reciprocating compressor has a more linear relationship.]
Compressor Control Comparison

Percent of DAR Full Load Power [% of DAR]

Percent Full Load Flow [%]

Lubricant free rotary screw

Double Acting Reciprocating

Double Acting Reciprocating

ENERGY MANAGEMENT SERVICES 27
Compressor Control Comparison

![Graph showing compressor control comparison]

- **Lubricant free rotary screw**
- **Centrifugal**
- **Lubricant injected rotary screw**
- **Double Acting Reciprocating**
- **Rotary Screw**
- **Double Acting Reciprocating**
Compressor Control Importance

• What would be the economic impact of a leak abatement program that eliminates 10% of the compressed air demand?
  – Ideally the savings would be 10% of the compressor energy
Leak Reduction Impact

![Graph showing the impact of leak reduction on energy efficiency. The x-axis represents percent full load power, and the y-axis represents percent full load flow. A dotted line indicates a 90.0% reduction at 60% flow. Modulation or suction throttle is noted.]
Leak Reduction Impact

Energy Management Services

2.5%Δ

Modulation or Suction Throttle

10%Δ
Leak Reduction Impact – Alternate Control Strategy

Percent Full Load Power [%] vs. Percent Full Load Flow [%]

Average Load-Unload Operating Condition

8.0%Δ

10%Δ
Compressor Control Impacts Leak Reduction

- Modulation or Suction Throttle
- Average Load-Unload Operating Condition

- 2.5%Δ
- 8.0%Δ
- 10%Δ
• Total air flow is 180% of the full load flow of one compressor.
• Total power requirement is approximately 225% of the full load power of one compressor.
• Total air flow is 180% of the full load flow of one compressor.
• Total power requirement is approximately 190% of the full load power of one compressor.
  – The potential energy savings is 35% of the full load energy of one compressor.
  • Storage must be considered.
  • Start-stop capabilities must be considered.
Measurements

- Compressor power:
  - Measured by power monitoring
  - Estimated by motor current
  - Estimated by motor data
Measurements

- Compressor power:
  - Measured by power monitoring
  - Estimated by motor current
  - Estimated by motor data

Current
Voltage
Power Factor

Data Monitoring
and Management System

Flow Meter

Pressure

Air – Oil Separator

Lubricant

Energy Management Services
Compressed Air Management Focus Areas

- Compression
- Conditioning
- Use
- Leaks
Typically, drying is needed because equipment using compressed air must be “moisture free”

- The **actual requirement** is to have no droplets or frost in the compressed air piping
- The actual dew point requirement is dependent on the minimum temperature the compressed air piping will come in contact with

**Dryness** is related to the cost of drying and the cost of the drying equipment
Dryers

• There are basically 3 types of dryers
  1. Aftercoolers
  2. Refrigerated dryers
  3. Desiccant dryers
Dryers

• There are basically 3 types of dryers

1. Aftercoolers
   a. Low equipment and operating costs
   b. Dew point provided is +80°F (+27°C)

2. Refrigerated dryers
   a. Medium equipment and operating costs
   b. Dew point provided is +38°F (+3°C)

3. Desiccant dryers
   a. High equipment and operating costs
   b. Dew point provided is -40°F (-40°C)
Dryers

• There are basically 3 types of dryers

1. Aftercoolers
   a. Low equipment and operating costs
   b. Dew point provided is +80°F (+27°C)
   c. Performance is monitored by discharge temperature

2. Refrigerated dryers
   a. Medium equipment and operating costs
   b. Dew point provided is +38°F (+3°C)
   c. Performance is monitored by cooler discharge temperature

3. Desiccant dryers
   a. High equipment and operating costs
   b. Dew point provided is -40°F (-40°C)
   c. Performance is monitored dew point sensor
Liquid Removal Traps and Drains

- Liquid removal traps and drains have several forms
  - Float-type traps
  - Timed valves
  - Zero loss traps
Liquid Removal Traps and Drains

- Liquid removal traps and drains have several forms
  - Float-type traps
    - Commonly experience maintenance issues
  - Timed valves
    - Waste significant amounts of compressed air
  - Zero loss traps
    - Minimal maintenance requirements
    - Minimal compressed air loss
Compressed Air Management Focus Areas

- Compression
- Conditioning
- Use
- Leaks
Compressed Air Uses

- Leaks
- Debris removal
- Pneumatic cylinders
- Pneumatic actuators
- Filter element cleaning
- Dense phase transfer
- Dilute phase transfer

- Tank agitation
- Pneumatic instruments
- Pneumatic tools
- Pneumatic motors
- Liquid atomization
- Component cooling
- Personnel cooling
Compressed Air Use

- A 1 kW air operated device requires approximately 7 kW of electrical energy input to the compressor
Compressed Air Use

- A 1 kW air operated device requires approximately 7 kW of electrical energy input to the compressor

- Evaluate all uses to determine if appropriate or inappropriate
  - If inappropriate
    • A suitable alternative must be economically viable
  - If appropriate
    • Minimize the use

- Understand the affect of compressed air users on system operation
Inappropriate Compressed Air Use

- Direct open blowing is an example of an inappropriate compressed air demand
  - A ⅛ inch pipe can pass 100 scfm
    - Typically this will cost ~$7,000/yr
  - A low pressure blower can be employed in this service
    - The operating cost will be less than $1,400/yr
  - Compressor control strategy must be incorporated in the investigation
Appropriate Compressed Air Use Reduction

• Appropriate compressed air demands can be reduced through cost effective means
  – Reduce compressed air supply pressure
    • Complete system
    • Point of use
  – Reduce operation period
    • On-off solenoid valve connected to main equipment
  – Incorporate air amplification devices
    • Induction nozzles can reduce compressed air consumption by a factor of 5 or more
  – Incorporate secondary receivers
    • “Averages” compressed air demand
Smelting Pot Cooling

- Compressed air is the expedient resource to cool smelting pot hot-spots
  - Compressed air should never be used in an open pipe arrangement
  - Induction nozzles reduce the compressed air consumption to less than $\frac{1}{5}$ the open pipe flow and maintain the same cooling effect
• Particulate filter units clean filter media by several methods.
  – Compressed air consuming methods.
    • Timed control pulse-jet.
    • Traditional $\Delta p$ control pulse-jet.
    • Controlled $\Delta p$ control pulse-jet.
    • Reverse airflow acoustic horn.
  – Mechanical shaker.
Filter Unit Management

- $\Delta p$ control provides significant compressed air consumption reduction
  - $\Delta p$ control provides filter media life extension
  - Non-adjacent rows can be pulsed to reduce reloading a previously cleaned row.
  - Units with variable load can experience dramatic cleaning demand changes
  - Reduced emissions can occur because the filter elements typically require a pre-load of particulates to clean effectively
Pressure-Flow Controllers – Demand Expanders

• Maintaining the pressure of the distribution system to a minimum will reduce compressed air demand
• Providing compressed air storage will minimize unnecessary compressor starts
• Some increase in compressor specific power results from increasing compression pressure

Reducing system pressure 10 psi:
- Reduces leaks 9%
- Reduces the compressed air demand of most end-use components 9%

Controller
Compressor Controller
85 psig to 100 psig

Large Volume Receiver
Pressure controlled to 80 psig ±1 psi
Compressed Air Management Focus Areas

- Compression
- Conditioning
- Use
- Leaks
## Compressed Air Leak Chart

### Compressed Air Leak Impact Cost (Energy Only)

<table>
<thead>
<tr>
<th>Orifice Diameter [inches]</th>
<th>Orifice Diameter [inches]</th>
<th>Orifice Diameter [mm]</th>
<th>Leak Rate [Sft³/min]</th>
<th>Leak Rate [Nm³/hr]</th>
<th>Leak Cost [$/yr]</th>
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<td>0.2</td>
<td>0.4</td>
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<td>Comp Air Average Cost</td>
<td>0.35 $/10³sft³</td>
<td>12.4 $/10³Nm³</td>
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<td>Comp Air Impact Cost</td>
<td>0.25 $/10³sft³</td>
<td>8.7 $/10³Nm³</td>
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Based on an Electrical Cost of 100.00 $/MWh

Based on Efficiency & Control that is Excellent
## Leak Survey

### Leak Descriptions Used in this Survey

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<th>Minimal</th>
<th>Feel but cannot hear in quiet environment</th>
<th>0.1 sft³/min</th>
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<tr>
<td>Small</td>
<td>Feel and hear in quiet environment</td>
<td>0.7 sft³/min</td>
</tr>
<tr>
<td>Medium</td>
<td>Feel and hear in moderate noise</td>
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<td>Feel and hear in high noise</td>
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<tr>
<td>Severe</td>
<td>Feel and hear at great distance</td>
<td>8.7 sft³/min</td>
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### Compressed Air Cost

- **$0.20** /10³sft³

### Operating Period

- **8,760 hr/yr**

### Estimated Compressed Air Loss

- **150 Sft³/min**
- **$15,791 /yr**

### Owner

- Alcoa-California-City of Industry

### Table

<table>
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<tr>
<th>Number</th>
<th>Location</th>
<th>Description (What is leaking)</th>
<th>Leak Descriptor</th>
<th>Leak Rate Estimate [sft³/min]</th>
<th>Sound Intensity at 3 ft [dB]</th>
<th>Leak Loss Estimate [$/yr]</th>
<th>Repair Difficulty</th>
<th>Isolation Characteristic</th>
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Leaks

- Compressed air leaks can produce significant waste in a system not only in terms of energy loss but also in terms of maintenance and equipment life
  - Leaks are a significant factor in determining long range strategy
  - A $\frac{1}{8}$ inch diameter leak will discharge more than 10 scfm
    - This translates into more than $1,000/\text{yr}$ of energy
World-Class Leak Management

• Continuous system observation and identification of failures
  – Compressed air cost awareness

• Annual focused compressed air leak survey
  – Systematic system investigation
  – Field identification
  – Master database
  – Traps and drains are primary targets
  – Leak detection equipment

• Leak repair prioritization (based on loss estimate)
• Benchmark demand
Compressed Air Management Focus Areas

- Compression
- Conditioning
- Use
- Leaks
- Compression
- Conditioning
- Use
- Leaks
Compressed Air Management Focus Areas

- Compression
- Conditioning
- Use
- Leaks
Compressed Air Management Focus Areas

- Compression
- Conditioning
- Use
- Leaks
Compressed Air Management Focus Areas

- The compressed air system
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High Performance Building Enclosures Commercial & Industrial Applications

Tennessee Department of Environment & Conservation Webinar
Sept 12, 2018
Objectives

Understand the basic components of the building enclosure and the possible consequences resulting from Air Barrier design flaws and construction deficiencies.

Discuss building enclosure design details, construction sequencing and installation practices that will result in energy efficient buildings that complement the energy efficient HVAC systems designed and installed in new construction.

Develop an understanding of building enclosure commissioning and retro-commissioning process, design review, functional performance and whole building testing.

Introduce understanding of air barrier opportunities using real commercial and industrial examples.
Air Barrier Systems

An air barrier system is a combination of air barrier components, and air barrier assemblies connected by air barrier transitions that are designed to provide a continuous barrier to the movement of air through a building enclosure.

Thermal and Moisture barriers don’t work without Air barriers.
Air Barrier Figure of Merit

CFM of Air Leakage per SF of Enclosure Area with Pressure – Difference of 75 Pascals – (CFM75/SF)

AB Material 0.004 CFM/SF@75

AB Assembly 0.04 CFM/SF@75

AB Building 0.4 CFM/SF@75
Commercial Code Advancement & Air Leakage History

- **1955-1975**: USACE Standard 0.25 cfm/SF @ 75 Pa
- **1989**: 90.1
- **2001**: 90.1
- **2004**: 90.1
- **2007**: 90.1
- **2010**: 90.1

**Energy Utilization Index (KBTU/SF/Year)**

- **Average 1.8 cfm/SF @ 75 Pa**

**Air Leakage CFM75/SF/Envelope area**

- **90-1975**: 27%
- **1975-1989**: 14%
- **1989-2001**: 4.5%
- **2001-2004**: 12%
- **2004-2007**: 4.5%
- **2007-2010**: 18%
Benefits of a Robust Air Barrier:

Energy Load: 9–40%
Typical Savings: 5–20%

Increased Comfort: Cold, Hot, Humid

IEQ: Pollen, Insects, Allergies, Mold

Durability: Fewer Moisture Problems

Maintenance: Reduced Stains, Ceiling Tiles, Outside Cladding

Smaller HVAC Equipment Design

Equipment Synergy: eg. Pressure Control

Life Safety
Good Air Barriers Avoid Moisture Problems

Blamed on the inside vinyl wallpaper vapor barrier. However - this is an interior wall; moisture entered the interior wall through the open metal studs due to a missing air barrier.
Humid air sucked in above the ceiling tiles due to a missing air barrier is condensing on chilled water pipes and dripping onto ceilings and into offices.
Air Barrier Defect with a negative pressure plenum return brings humid air into the wall assemblies. Mold remediation only treats symptoms – this problem will come back.)
**Common HVAC Design**

Positive pressure building, BUT Negative pressure plenum inadvertently brings in outside air: Energy, Comfort, IEQ, Insect problems.

Moist air condenses on cool surfaces and drips onto ceiling tiles: Stains, moisture problems, durability problems.

Designer compensates by oversizing equipment: Greater suction.

Air Barrier System – Simple But Not Easy
Everyone touches the Air Barrier

But no one is in charge of the air barrier
Commercial Case Study: Clubhouse
Commercial Case Study: Clubhouse
Commercial Case Study: Clubhouse
No Air Barrier
Commercial Case Study: Clubhouse Negative Pressure

Inside

Outside
Commercial Case Study: Clubhouse
Industrial Case Study: Manufacturing
Industrial Case Study: Manufacturing
Industrial Case Study: Not Roof Leaks

Overhead Leaks Heat Map
8 – 25 – 2017
w.r.t. Wet Roof areas
Summary:
The roof is “water tight” but not “air tight”. Extreme Negative pressure (-30 Pascals) acts like a vacuum to the roof and wall, and sucks vast amounts of outdoor air through these assemblies. When humid summertime air is in contact with the metal deck that has been cooled from the process areas below, condensation will occur inside the roof assembly and drip into the building space.
Building Envelope Commissioning

- Ideally an Owner Driven Team
- New and Existing Building
- BECx Quality Control Plan (Design Review)
- Inspections: Existing – New Construction
- Confidence Testing, Functional Testing
- Air Leakage Testing
- Fundamental & Enhanced BECx
Experience shows we can cost effectively fix about half of the air leakage in a typical building. We won’t be able to cover that here. This is NOT weatherization.

The First Step is to identify the specific problems.

Air Leakage Tests only identify the magnitude of the air leaks – but they don’t tell you where.

Visualizing air leaks: Synthetic Smoke, Thermographic Imaging, Bubbles, Active inspection, Strategic use of fans.
Industrial Refrigerator

Locating leaks with fan driven bubble soap
Safe Haven Space (New Building)
Establishing an Effective Energy Management Program – First Steps

Webinar
September 12, 2018

Presented by:
Thomas D. “Dan” Mull, PE, PEM, CEM
Institute of Energy Professionals
EM Program – First Steps

Organizations have historically looked at initiating energy management programs as a way of reducing operating costs. When utility expenditures become a major point of budgetary concern, the emphasis on program development and implementation typically increases.
EM Program – First Steps

When the decision has been made to implement an energy management program, the first thing most organizations want to do is conduct an energy survey (audit/assessment), so they can get better control of their energy expenditures; i.e. reduce operating costs.
EM Program – First Steps

While energy surveys are an integral part of any program, they are not the first step. It is true that properly conducted energy survey can identify potential opportunities for saving energy and reducing operating expenditures, they can also:
EM Program – First Steps

• Quantify potential environmental benefits
• Provide training to upgrading the energy management knowledge of site personnel and
• Identify best operating practices, so that they can be replicated at other facilities.
EM Program – First Steps

A successful and sustainable program begins with a Strategic Energy Plan (SEP). The plan does not have to be overly detailed or lengthy, but it must do the following:
EM Program – First Steps

1. Provide visible assurance to personnel that management fully supports and endorses the efforts to establish an energy management program. This is typically done with the issuance of a Mission Statement.
**EM Program – First Steps**

**Mission Statement**
As the industry leader in the development of aerospace materials, Alpha Metals is committed to the continual enhancement of our research, development and manufacturing services in the most environmentally responsible manner possible. An integral part of this is the prudent use of our energy and natural resources. To this end Alpha Metals will promote the most cost-effective strategies focused on enhanced technologies, environmental responsibility and sustainability, to assure the efficient use of our resources, while optimizing R&D, increasing productivity and enhancing the safety of our workplace.
2. The next step in the Strategic Energy Plan is to provide a clear **Objective/Goal Statement**; i.e., what specifically are we trying to achieve? Following is a generic Objective/Goal Statement.
EM Program – First Steps

Objective/Goal Statement
Alpha Metals will implement a world-class strategic operational support (Energy Management) program focused on minimizing the use of energy/natural resources and reducing our carbon footprint. The program will emphasize effective resource utilization and sustainability, with the objective of becoming an industry leader in the optimization of resources, minimization of costs and environmental stewardship. Over the next five (5) years our goal is to reduce controllable energy expenditures by 5% annually, based upon 2017 levels.
3. In order to gauge success we must establish benchmarks for operations based upon historical energy consumption. They must be meaningful and a measure of performance. For example, in the case of our fictitious metals company, it might be kWh/lbm of metal produced.
EM Program – First Steps

4. With a clear objective/goal and a way to measure performance, the next step is to consider conducting energy surveys. If it is to be successful pre-survey work must be done. Specifically, we must have a comprehensive understanding of:
EM Program – First Steps

4. Overall historical energy consumption for all purchased utilities
   - Locally available utility rate structures for utilities and specific rates under which the facility is currently being billed
   - Existing energy instrumentation
   - Primary energy consuming equipment utilized in the facility
EM Program – First Steps

4. With this information as a basis, qualified energy professionals can conduct a survey to identify and quantify potential energy and environmental savings initiatives.
World-Class EM Program

A world-class Energy Management Program provides a strategic and sustainable approach to resource optimization, thereby minimizing operating costs, enhancing efficiency, and reducing a company’s environmental impact. Integral parts should include:
World-Class EM Program

- Strategic Energy Planning
- Understanding Utility Rate Structures and How to Optimize Their Application
- Assessing Current Energy Utilization and Establishing Performance Benchmarks
- Conducting Energy Surveys/Assessments of Critical Systems Supporting Core Business Operations to Identify Initiatives for Improvement
World-Class EM Program

• Emphasizing the Implementation of Identified Initiatives
• Implementing an Aggressive Preventive Maintenance Program for Sustained Efficient Operation
• Continually Adopting Technology Where Cost-Effective
• Periodically Reviewing Initiatives to Assure Effectiveness and Modifying Where Warranted.
EM Program – First Steps

In summary, an effective and sustainable energy management effort begins with a plan, a Strategic Energy Plan.

Thanks, Dan