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Electrical Equipment
Compressors
## Training Agenda: Compressor

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Introduction

Significant Inefficiencies

- Compressors: 5 to > 50,000 hp
- 70 – 90% of compressed air is lost

Approximately 10% gets to the point of use!!
Introduction

Benefits of managed system

• Electricity savings: 20 – 50%
• Maintenance reduced, downtime decreased, production increased and product quality improved
Introduction

Main Components in Compressed Air Systems

- Intake air filters
- Inter-stage coolers
- After coolers
- Air dryers
- Moisture drain traps
- Receivers
### Training Agenda: Compressor

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Two Basic Compressor Types

Types of Compressors

- Positive displacement
  - Reciprocating
  - Rotary
- Dynamic
  - Centrifugal
  - Axial

Types of Compressors

Type of compressor
### Types of Compressors

#### Reciprocating Compressor

- Used for air and refrigerant compression
- Works like a bicycle pump: cylinder volume reduces while pressure increases, with pulsating output
- Many configurations available
- Single acting when using one side of the piston, and double acting when using both sides

![Diagram of a Reciprocating Compressor](image)
# Types of Compressors

## Rotary Compressor

- Rotors instead of pistons: continuous discharge
- Benefits: low cost, compact, low weight, easy to maintain
- Sizes between 30 – 200 hp
- Types
  - Lobe compressor
  - Screw compressor
  - Rotary vane / Slide vane
Types of Compressors

Centrifugal Compressor

- Rotating impeller transfers energy to move air
- Continuous duty
- Designed oil free
- High volume applications > 12,000 cfm

(King, Julie)
## Types of Compressors

### Comparison of Compressors

- Efficiency at full, partial and no load
- Noise level
- Size
- Oil carry-over
- Vibration
- Maintenance
- Capacity
- Pressure
## Training Agenda: Compressor

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Assessment of Compressors

Capacity of a Compressor

- Capacity: full rated volume of flow of compressed gas
- Actual flow rate: free air delivery (FAD)
- FAD reduced by ageing, poor maintenance, fouled heat exchanger and altitude
- Energy loss: percentage deviation of FAD capacity
Assessment of Compressors

Simple Capacity Assessment Method

- Isolate compressor and receiver and close receiver outlet
- Empty the receiver and the pipeline from water
- Start the compressor and activate the stopwatch
- Note time taken to attain the normal operational pressure $P_2$ (in the receiver) from initial pressure $P_1$
- Calculate the capacity FAD:

$$Q = \frac{P_2 - P_1}{P_0} \times \frac{V}{T} \text{Nm}^3/\text{Minute}$$

- $P_2$ = Final pressure after filling (kg/cm²a)
- $P_1$ = Initial pressure (kg/cm²a) after bleeding
- $P_0$ = Atmospheric pressure (kg/cm²a)
- $V$ = Storage volume in m³ which includes receiver, after cooler and delivery piping
- $T$ = Time take to build up pressure to $P_2$ in minutes
Assessment of Compressors

Compressor Efficiency

- Most practical: specific power consumption (kW / volume flow rate)
- Other methods
  - Isothermal
  - Volumetric
  - Adiabatic
  - Mechanical
Assessment of Compressors

Compressor Efficiency

Isothermal efficiency

$$\text{Isothermal efficiency} = \frac{\text{Actual measured input power}}{\text{Isothermal power}}$$

$$\text{Isothermal power (kW)} = \frac{P_1 \times Q_1 \times \log_{e} r}{36.7}$$

- $P_1$ = Absolute intake pressure kg / cm$^2$
- $Q_1$ = Free air delivered m$^3$ / hr
- $r$ = Pressure ratio $P_2/P_1$
### Assessment of Compressors

#### Compressor Efficiency

**Volumetric efficiency**

\[
\text{Volumetric efficiency} = \frac{\text{Free air delivered m}^3/\text{min}}{\text{Compressor displacement}}
\]

**Compressor displacement**

\[
\text{Compressor displacement} = \pi \times \frac{D^2}{4} \times L \times S \times \chi \times n
\]

- \( D \) = Cylinder bore, meter
- \( L \) = Cylinder stroke, meter
- \( S \) = Compressor speed rpm
- \( \chi \) = 1 for single acting and 2 for double acting cylinders
- \( n \) = No. of cylinders
Assessment of Compressors

Leaks

- Consequences
  - Energy waste: 20 – 30% of output
  - Drop in system pressure
  - Shorter equipment life

- Common leakage areas
  - Couplings, hoses, tubes, fittings
  - Pressure regulators
  - Open condensate traps, shut-off valves
  - Pipe joints, disconnects, thread sealants
Assessment of Compressors

Leak Quantification Method

- Total leakage calculation:

  \[ \text{Leakage (\%)} = \left[ \frac{T \times 100}{T + t} \right] \]

  - \( T \) = on-load time (minutes)
  - \( t \) = off-load time (minutes)

- Well maintained system: less than 10% leakages
• Shut off compressed air operated equipments
• Run compressor to charge the system to set pressure of operation
• Note the time taken for “Load” and “Unload” cycles
• Calculate quantity of leakage (previous slide)
• If Q is actual free air supplied during trial (m3/min), then:

System leakage (m3/minute) = \(Q \times \frac{T}{(T + t)}\)
### Assessment of Compressors

#### Example

- Compressor capacity (m³/minute) = 35
- Cut in pressure, kg/cm² = 6.8
- Cut out pressure, kg/cm² = 7.5
- Load kW drawn = 188 kW
- Unload kW drawn = 54 kW
- Average ‘Load’ time = 1.5 min
- Average ‘Unload’ time = 10.5 min

**Leakage** = \( \left[ \frac{1.5}{1.5 + 10.5} \right] \times 35 = 4.375 \text{ m}^3/\text{minute} \)
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Energy Efficiency Opportunities

1. Location
   - Significant influence on energy use

2. Elevation
   - Higher altitude = lower volumetric efficiency

<table>
<thead>
<tr>
<th>Altitude Meters</th>
<th>Barometric Pressure milli bar*</th>
<th>Percentage Relative Volumetric Efficiency Compared with Sea Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>At 4 bar</td>
</tr>
<tr>
<td>Sea level</td>
<td>1013</td>
<td>100.0</td>
</tr>
<tr>
<td>500</td>
<td>945</td>
<td>98.7</td>
</tr>
<tr>
<td>1000</td>
<td>894</td>
<td>97.0</td>
</tr>
<tr>
<td>1500</td>
<td>840</td>
<td>95.5</td>
</tr>
<tr>
<td>2000</td>
<td>789</td>
<td>93.9</td>
</tr>
<tr>
<td>2500</td>
<td>737</td>
<td>92.1</td>
</tr>
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* 1 milli bar = 1.01972 x 10^-3 kg/cm^2
### 3. Air Intake

- Keep intake air free from contaminants, dust or moist
- Keep intake air temperature low
  
  *Every 4 °C rise in inlet air temperature = 1% higher energy consumption*
- Keep ambient temperature low when an intake air filter is located at the compressor
## Energy Efficiency Opportunities

### 4. Pressure Drops in Air Filter

- Install filter in cool location or draw air from cool location
- Keep pressure drop across intake air filter to a minimum

*Every 250 mm WC pressure drop = 2% higher energy consumption*
## Energy Efficiency Opportunities

### 5. Use Inter and After Coolers

- **Inlet air temperature rises at each stage of multi-stage machine**
- **Inter coolers**: heat exchangers that remove heat between stages
- **After coolers**: reduce air temperature after final stage
- **Use water at lower temperature**: reduce power
6. Pressure Settings

- Higher pressure
  - More power by compressors
- Lower volumetric efficiency
- Operating above operating pressures
  - Waste of energy
  - Excessive wear
Energy Efficiency Opportunities

6. Pressure Settings

a. Reducing delivery pressure
Operating a compressor at 120 PSIG instead of 100 PSIG: 10% less energy and reduced leakage rate

b. Compressor modulation by optimum pressure settings
Applicable when different compressors connected

c. Segregating high/low pressure requirements
Pressure reducing valves no longer needed
Energy Efficiency Opportunities

6. Pressure Settings

d. Design for minimum pressure drop in the distribution line

- Pressure drop: reduction in air pressure from the compressor discharge to the point of use
- Pressure drop < 10%
- Pressure drops caused by
  - corrosion
  - inadequate sized piping, couplings hoses
  - choked filter elements
6. Pressure Settings

d. Design for minimum pressure drop in the distribution line

<table>
<thead>
<tr>
<th>Pipe Nominal Bore (mm)</th>
<th>Pressure drop (bar) per 100 meters</th>
<th>Equivalent power losses (kW)</th>
</tr>
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<tbody>
<tr>
<td>40</td>
<td>1.80</td>
<td>9.5</td>
</tr>
<tr>
<td>50</td>
<td>0.65</td>
<td>3.4</td>
</tr>
<tr>
<td>65</td>
<td>0.22</td>
<td>1.2</td>
</tr>
<tr>
<td>80</td>
<td>0.04</td>
<td>0.2</td>
</tr>
<tr>
<td>100</td>
<td>0.02</td>
<td>0.1</td>
</tr>
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Typical pressure drop in compressed air line for different pipe size (Confederation of Indian Industries)
7. Minimizing Leakage

- Use ultrasonic acoustic detector
- Tighten joints and connections
- Replace faulty equipment

8. Condensate Removal

- Condensate formed as after-cooler reduces discharge air temperature
- Install condensate separator trap to remove condensate
## Energy Efficiency Opportunities

| Electrical Equipment/Compressors |  
|----------------------------------|---
| 9. Controlled usage              |  
| • Do not use for low-pressure applications: agitation, combustion air, pneumatic conveying |  
| • Use blowers instead           |  
| 10. Compressor controls         |  
| • Automatically turns off compressor when not needed |
### Energy Efficiency Opportunities

## 9. Maintenance Practices

- **Lubrication**: Checked regularly
- **Air filters**: Replaced regularly
- **Condensate traps**: Ensure drainage
- **Air dryers**: Inspect and replace filters
Training Session on Energy Equipment

Compressors & Compressed Air Systems

THANK YOU FOR YOUR ATTENTION