Boiler and Chiller Maintenance for Maximum Efficiency
Meet Your Panelists:

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NEEA Northwest Industrial Training

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  industrial-training@industrial.neea.org

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- **Power Factor:**
  
  **Improve Power Factor and Your Facility**
  December 17: 9-10am PST

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- Chiller maintenance
  - Compressor
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  - Economizers
  - Air Handlers

Source: DOE EERE

Source: NREL
Maintenance

- Proactive versus reactive
  - Log books are important
    - Chillers
      - Refrigerant temperatures and pressures
      - Condenser-water entering and leaving temperatures
      - Chilled-water entering and leaving temperatures
      - Run times for automatic refrigerant purge units
    - Real-time monitoring
- Predictive maintenance
Boiler Basics

- **Power (Capacity)**
  - Boiler capacity (MMBtuh or MMBtu/hr)
  - Boiler horsepower (bhp) = 33,475 Btu/hr (9.8 kW)
    - The energy rate needed to evaporate 34.5 lb (15.65 kg or 4.2 gallons) of water at 212°F (100°C) in one hour
    - Equivalent to a 12 hp electric motor
    - Bhp is old terminology—be careful!
  - Motor power (kW) = Horsepower x 0.746/efficiency
    - A 12 hp motor = 12 hp x 0.746/0.91 = 9.83 kW
    - 1 kW = 3,412 Btu/hr
Boiler Basics

- **Power (Capacity)**
  - Boiler horsepower (bhp) can be converted into pounds of steam by multiplying horsepower by 34.5
    
    \[
    200 \text{ bhp} \times 34.5 = 6,900 \text{ lb of steam per hour}
    \]
  - Pounds of steam can be converted to horsepower by dividing pounds steam per hour by 34.5
    
    \[
    5,000 \text{ lb of steam} / 34.5 = 145 \text{ bhp boiler}
    \]
Boiler Basics

- Energy (Quantity)
  - 1 pound steam = 970 Btu  (water-to-steam energy)
  - 1 cf = 1,026 Btu
  - 1 ccf = 102,600 Btu
  - 1 therm = 100,000 Btu
  - 1 kWh = 3,412 Btu
Boiler Basics

- Types of modern boilers
  - Firetube boilers (or Scotch Marine Boilers)
  - Watertube boilers
  - Cast iron boilers
  - Vertical boilers
  - Firebox boilers
  - Electric boilers

Source: DOE EERE
Boiler Basics

- PID Control Scheme
  - Proportional
    - Present error
  - Integral
    - Size
    - Duration
    - Time
  - Derivative
    - Rate of change (surge)
  - A second PID control (10%)
Boiler Basics

- **NOx Control Strategies**
  - **Combustion modification**
    - Reduce air preheat temperature
    - Low excess air (watch CO)
    - Staged secondary combustion
    - Flue gas recirculation
  - **Post-treatment**
    - *Selective Non-Catalytic Reduction*—a NOx reducing agent (such as ammonia or urea) is injected into the boiler exhaust at a temperature range 1,600° to 2,200°F
    - *Selective Catalytic Reduction*—a reducing agent (such as ammonia), combined with a catalyst is injected into the boiler exhaust at a temperature range 500° to 1,100°F

Source: EPA
Boiler Basics

- **Thermostatic**
  - Bellows
  - Bi-metallic

- **Mechanical**
  - Float and lever
  - Inverted bucket
  - Open bucket
  - Float and Thermostatic (F&T)

- **Thermodynamic**
  - Disc
  - Piston
  - Lever
  - Orifice

Source: DOE

Source: Oak Ridge National Laboratory
Boiler Equipment Maintenance

- Clean heat transfer surfaces
  - Clean slag off tube exterior
  - Flush boiler with water to remove loose internal scale and sediment.
  - Prevent scale formation.
    - Pretreatment of boiler make-up water (using water softeners, demineralizers, and reverse osmosis to remove scale-forming minerals)
    - Chemical injection into the boiler feedwater
    - Adopting proper boiler blowdown practices

Source: U.S. Geological Survey
Regular internal tube inspections

- Every 60 days until the water treatment program is properly regulated
- Thereafter, every 6 to 12 months; more often if an unsatisfactory condition is found.

Source: Putzmaus® America
Boiler Equipment Maintenance

- Inspect all gasketing on front and rear doors.
- Add/restore boiler refractory
  - Patch and wash coat as required
- Check all hand hole plates and man hole plates for leaks at normal operating temperatures and pressures

Source: Bill Maloney
Boiler Equipment Maintenance

- Optimize deaerator vent rate
  - Will typically find a historically high vent rate in order to keep the concentration of non-condensables in the boiler feed water low
  - With improved water quality, vent rate can be decreased

Source: Hurst Boiler & Welding Company, Inc.
Boiler Piping Maintenance

- Fix broken steam traps
  - One 1/8" diameter stuck-open steam trap orifice on a large boiler can cost $1,000 (15 psig) to $5,000 (140 psig) per year in increased natural gas consumption
  - 1 lb/hr ~ 1,000 Btu/hr

- Insulate steam pipes with at least 1/2" insulation
  - For a 350°F process steam pipe (100 ft), savings are $5,000 for 2" diameter and $10,000 for 4" diameter pipe
  - Install removable insulation on uninsulated valves and fittings.
Boiler Combustion Maintenance

- Blue flame is good

- Yellow flame indicates incomplete combustion
Boiler Combustion Maintenance

- Calibrate jackshaft linkages for optimum air:fuel ratio

Source: Industrial Controls, Inc.
Boiler Combustion Maintenance

- **Proper burner air:fuel ratio**
  - Excess air is the extra amount of air added to the burner above that which is required to completely burn the fuel (beyond stoichiometric)

<table>
<thead>
<tr>
<th>Excess %</th>
<th>Temp. °F (Flue-Comb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>Oxy</td>
</tr>
<tr>
<td>9.5</td>
<td>2.0</td>
</tr>
<tr>
<td>28.1</td>
<td>4.0</td>
</tr>
<tr>
<td>81.6</td>
<td>6.0</td>
</tr>
</tbody>
</table>

- Efficiency improvements
  - 82.8% → 85.4% = 2.6%
  - 68.2% → 76.0% = 7.8%
Burner tips

- Burner tips should be cleaned on a regular basis

- Clean the tips by hand to avoid changing the shape or performance of the tip

Photos courtesy of John Zink Company
Boiler Blowdown

- Blowdown for steam boilers
  - Check the normal operating water level (NOWL) in the boiler.
    - If the Low Water Cut-Out (LWCO) is mechanical (a float), it must be blown down (drained) on a regular basis to prevent sediment from accumulating in the float chamber.
  - Improve water treatment to minimize boiler blowdown.
    - Helps control boiler water quality and operating efficiency by removing suspended and dissolved solids from the water in the boiler drum.
    - Test water daily and regenerate water softener when hardness exceeds 17 parts per million (or 1.0 Grain per Gallon).
    - Blowdown represents an energy loss to the steam system.
Chiller Basics

- Chiller components

Source: EERE
Chiller Basics

Efficiency ratings

- One ton (12,000 Btu/hr) equals 3.516 kW at 100% efficiency

- **Coefficient of Performance (COP)**
  
  \[ \text{COP} = \frac{\text{Rated Cooling Output, kBtuh}}{\text{Rated electrical input, kBtuh}} \]

- Energy Efficiency Ratio (EER) for Peak
  
  \[ \text{EER} = \frac{\text{Cooling output (Btuh)}}{\text{Electricity consumed (watt)}} \]
  
  \[ \text{EER} = \text{COP} \times 3.413 \]

- Integrated Energy Efficiency Ratio (IEER) for Part-Load
  
  \[ \text{IEER} = (0.020 \times A) + (0.617 \times B) + (0.238 \times C) + (0.125 \times D) \]

  Cooling Capacity / IEER /1000 x Annual Cooling Hours = kWh

- Full Load Value (FLV)
  
  \[ \text{FLV} = \frac{kW}{\text{ton efficiency rating}} \]
  
  \[ = \frac{3.516}{\text{COP}} \]
  
  \[ = \frac{12}{\text{EER}} \]

### Efficiency Ratings Table

<table>
<thead>
<tr>
<th>FLV (kW/ton)</th>
<th>COP</th>
<th>EER</th>
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</thead>
<tbody>
<tr>
<td>0.6</td>
<td>5.9</td>
<td>20</td>
</tr>
<tr>
<td>0.75</td>
<td>4.7</td>
<td>16</td>
</tr>
<tr>
<td>1.0</td>
<td>3.5</td>
<td>12</td>
</tr>
<tr>
<td>1.5</td>
<td>2.3</td>
<td>8</td>
</tr>
</tbody>
</table>

### Load Point Table

<table>
<thead>
<tr>
<th>Load Point</th>
<th>Cap</th>
<th>DB °F</th>
<th>Weight Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100%</td>
<td>95</td>
<td>2%</td>
</tr>
<tr>
<td>B</td>
<td>75%</td>
<td>81.5</td>
<td>61.7%</td>
</tr>
<tr>
<td>C</td>
<td>50%</td>
<td>68</td>
<td>23.8%</td>
</tr>
<tr>
<td>D</td>
<td>25%</td>
<td>65</td>
<td>12.5%</td>
</tr>
</tbody>
</table>
Chiller Maintenance

1. Maintain a daily log

2. Compressor
   a) Oil and refrigerant analysis
   b) Mechanicals

3. Water-side
   a) Chiller water tubes
   b) Cooling towers

4. Economizers and air-handling units

Source: ORNL
Chiller Compressor Maintenance

- Visual check of compressor oil
  - Oil level
  - Color (darker is worse)
  - Change oil on large systems once a year and clean particles from case

- Have the condition of your system fluid checked by a qualified lab, a minimum of four times per year

- Monitor for refrigerant leaks

- Periodically analyze refrigerant for moisture, acid, and rust

- Take superheat and subcooling temperature readings to obtain the chiller's maximum efficiency
Chiller Compressor Maintenance

- Inspect journal and thrust bearings and drive gears
- Check the motor terminals for pitting, corrosion, or loose connections
- Check amp draws on all motor loads
- Check the crankcase heaters for proper operation

Source: New York Power Authority
Chiller Compressor Maintenance

- Centrifugal chillers
  - Guide vane linkage assembly and drive mechanism
  - Guide vane control shaft seal
- Reciprocating machines
  - Compressor suction and discharge valves.
- Check for high vibration on a capillary line (causes leaks) and secure all vibrating lines.

Source: John Tomczyk, Ferris State University

Source: Atlas Copco Airpower

Source: John Tomczyk, Ferris State University
Check for tube corrosion

- Eddy current testing can identify internal pitting, freeze damage, cracks, and wear
- Remove the sludge with bristle brushes on the end of long metal rods.
- If badly fouled, use chemicals
- Ensure that the pipe insulation is dry and not broken off.

Source: Maverick Inspection Ltd.
Chiller Water-side Maintenance

- Install water gauges so you can see pressure drops; particularly through the evaporator.
  - Water supplied to the unit should have a minimum differential pressure of 15 psi at the chiller.

- Check for proper water flow
  - Overflow can cause vibration, damaging the copper tubes.
    - Keep chilled water flow rate between 3 to 12 feet per second.
  - Put a bypass valve on the end of the pipe run going to the chillers.

Source: Denver Water
Chiller Water-side Maintenance

- Apply proper water filtering
  - Full Stream
  - Side Stream
  - Basin Sweeping

Source: LAKOS
Chiller Water-side Maintenance

- Check cold water basin
  - Pump leaks or obstructions
  - Clean sump strainer
    - If atmosphere is extremely dirty, it may be necessary to clean strainer weekly
  - Check and adjust bleed rate
  - Make-up water valve is working
  - Heater controls are working

- Clean debris and dirt from water tower condenser and unclog spray nozzles, especially in the spring.
  - Clean pre-strainers
  - Spray should be uniform
Chiller Water-side Maintenance

- Check for heat transfer fill section fouling
- Inspect cooling tower louvers and shields
- Clean condenser coils
  - A 1/32” scale buildup results in a 7% reduction in energy efficiency
  - 2% efficiency decrease for every leaving water 1F temperature increase

Source: Baltimore Aircoil Company

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Chiller Water-side Maintenance

- Check fan belt for proper tension and any belt wear or improper alignment
  - Idler pulley spins freely
- Check fan bearings and lubricate, if necessary.
  - Check drive alignment
- For gear drives, check oil level.

Source: Virginia Department of Mines, Minerals, and Energy
Chiller Economizer Maintenance

- Re-enabling economizers
  - Address any outstanding performance issues

- Maintain the calibration of enthalpy sensors

- Measure the difference between the indoor and outdoor pressure during economizer operation
  - Avoid building over-pressurization
  - Relief air system must have an adequate airflow path

Source: Platts
Chiller Economizer Maintenance

- Verify that the outside air sensor is in a good, representative location
  - Never in direct sun; not too close to air outlets
- Make sure the mixed air sensors are located correctly as well
  - In a place with good mixing

Source: energycodes.gov
Chiller Air Handler Maintenance

- Cycle your dampers open and closed periodically
  - Avoid stuck dampers
- Adjust actuators to achieve full damper closure
  - Close gaps
- Worn for blade and jamb seals.
- Grease serviceable (not sealed) blower shaft bearings

Source: Dave Moser, PECI
Resources

- American Boiler Manufacturers Association (ABMA)
- Council of Industrial Boiler Owners
- DOE Operations and Maintenance (O&M) Best Practices Guide
- Equipment Manufacturers Web Sites

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