Boiler and Chiller Maintenance for Maximum Efficiency
Meet Your Panelists:

Mike Carter

Justin Kale
Provided by:

Northwest Regional Industrial Training Center:
(888) 720-6823
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      - Condenser-water entering and leaving temperatures
      - Chilled-water entering and leaving temperatures
      - Run times for automatic refrigerant purge units
  - Real-time monitoring
- Predictive maintenance

Source: www.sxc.hu
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  \(^{(water\text{-}to\text{-}steam \ energy)}\)
  - 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

#### Electric Boilers
- Available from 10 kW for the smaller units up to over 3,000 kW
- Often used in tandem with a gas-fired boiler in a fuel-switching strategy
- Replacement of an electric element bundle (13 to 18 year life) can range in price from $2,000 to $2,500 for a 75 kW to 100 kW electric boiler

#### Electrode Steam Boilers
- Operate at high voltages (12 kV or 24 kV)
- Submersible electrode boilers
  - Rely on immersed electrodes to conduct electricity through the boiler water
- High-velocity jet electrode boilers
  - In this design, the water jet (striking an electrode plate) is the resistance element
- Pros include lower installed capital cost, higher reliability, higher efficiency (99.5% at 100% output) and rapid response

Image source: Precision Boilers
Boiler Basics

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

Source: Wikipedia, Urquizo
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
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
Boiler Equipment Maintenance

- 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.
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>
<tr>
<td>200°F</td>
<td>600°F</td>
</tr>
<tr>
<td>85.4%</td>
<td>76.0%</td>
</tr>
<tr>
<td>84.7%</td>
<td>74.0%</td>
</tr>
<tr>
<td>82.8%</td>
<td>68.2%</td>
</tr>
</tbody>
</table>

- Efficiency improvements
  - 82.8% $\rightarrow$ 85.4% = 2.6%
  - 68.2% $\rightarrow$ 76.0% = 7.8%
Boiler Combustion Maintenance

- 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)
  
  \[
  \text{FLV} = \frac{\text{kW/ton efficiency rating}}{\text{COP}} = \frac{3.516}{\text{COP}} = \frac{12}{\text{EER}}
  \]

---

**FLV (kW/ton) | COP | EER**
---
0.6 | 5.9 | 20
0.75 | 4.7 | 16
1.0 | 3.5 | 12
1.5 | 2.3 | 8

---

**Load Point | Cap | DB °F | Weight Factor**
---
A | 100% | 95 | 2%
B | 75% | 81.5 | 61.7%
C | 50% | 68 | 23.8%
D | 25% | 65 | 12.5%
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
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
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

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

Source: LAKOS
Chiller Water-side Maintenance

- Clean debris and dirt from water tower condenser and unclog spray nozzles, especially in the spring.

- 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

- Check fan belt for proper tension and any belt wear or improper alignment.
- Check fan bearings and lubricate, if necessary.
- For gear drives, check oil level.
- Clean strainer
  - If atmosphere is extremely dirty, it may be necessary to clean strainer weekly.

Source: Virginia Department of Mines, Minerals, and Energy
Chiller Econo

- 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
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
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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