Condensing Boilers in Primary Variable Flow Piping Systems
Agenda

• Condensing Boilers vs. Non-Condensing Boilers
• High-Mass vs. Low-Mass Boilers
• Optimizing High-Mass Condensing Boilers
  – Operating Temperature and Input
  – Primary Variable Systems for High Mass Boilers
  – Matching System Flow to Boiler Turndown
• Hybrid Systems
Primary/secondary loop with non-condensing boilers
- 180°F hydronic loop setpoints
- High return temperature needed to protect boiler from condensing and corrosion
- Primary/secondary pumping
- Calculate “design day” load, select one large boiler, put in a second boiler for redundancy
• **What is a condensing boiler?**
  – Boiler that extracts latent heat of vaporization (13% of energy content of natural gas) from flue gas and transfers it into the water source
  – Materials of construction to prevent corrosion as condensate is slightly acidic – 4 – 6 pH
Condensing Boilers: Different Boiler Designs

- Firetube SS
- Watertube SS
- Cast Aluminum
- Cast Iron
- Copper-Fin w/ Secondary HX
Advantages of Condensing Boilers

• Higher efficiencies (with proper operating conditions)
• Most designs offer no minimum return temperature
• Corrosion resistant
• More resistance to thermal shock or stress
• Potential for greater longevity and reliability
• Modular design provides better system turndown and redundancy
Specific operating conditions are necessary for a condensing boiler to operate at optimal efficiencies:

- **Water temperature (set point, return water)**
  - Lower water temperatures allow flue gases to condense
  - Flue gas temperature is directly related to return water temperature

- **Firing rate (modulation)**
  - Lower firing rate increases flue gas residence time in the heat exchanger meaning more heating surface relative to BTU input
Efficiency Curve for Condensing Boilers

- Most efficient at lowest possible return water temperature
- Efficiencies above 87-88% only possible if return water temperatures are below the flue gas dew point
- Dew point = 127°F for natural gas combustion
Efficiency Curve for Condensing Boilers

- Inverse relationship between firing rate and efficiency
- More efficient to run more boilers at lower firing rates
High Mass vs. Low Mass

- Refers to mass of heat exchanger, and also water volume
- High Mass = More than 50 gallons per MMBTU
- Low Mass = Less than 25 Gallons per MMBTU
High Mass vs. Low Mass: Pros & Cons

- **High Mass (3,640 lbs, 126 gal.)***
  - **Advantages**
    - Primary variable system
    - More tolerant of low or no flow
    - Low water side pressure drop
    - Greater delta T (up to 100°F for condensing boilers)
    - Resistance to water quality
    - Less cycling
    - Longer life expectancy
  - **Disadvantages**
    - Higher initial equipment cost
    - Larger footprint
    - Heavier

- **Low Mass (1,250 lbs, 13.2 gal.)***
  - **Advantages**
    - Lower initial equipment cost
    - Smaller footprint
  - **Disadvantages**
    - Primary/secondary system
    - High minimum flow requirements
    - High water side pressure drop
    - Smaller delta T (max. 30-35°F)
    - Minimum pressure requirements
    - Sensitivity to water quality
    - More frequent cycling
    - Often needs buffering
    - More maintenance
    - Shorter life expectancy

*Comparison of high-mass and low-mass 2,500 MBH boilers*
Traditional Primary/Secondary System

- Supply
  - Secondary pumps (variable speed)
  - Decoupler
- Buffer Tank
- Primary pump
- Boiler 1
- Boiler 2
- Boiler 3

Return
Traditional Primary/Secondary System

- Decouples or “hydraulically separates” the primary (*boiler*) and secondary (*system*) loops
  - Closely spaced tees or a mixing manifold
- Prevents flow in one circuit from interfering with another
  - Example: As zone valves open, close, or modulate, and as system pumps vary speed, the boiler loop is not impacted.
Primary Variable Flow

Return

Supply

Primary pumps (variable speed)

Boiler 1

Boiler Isolation valve

Boiler 2

Boiler Isolation valve

Boiler 3

Boiler Isolation valve
Benefits of Primary Variable Systems

Benefits of high mass boilers utilizing primary variable systems include:

• Less piping, no dedicated primary pump or buffer tank
• Increased overall system efficiency.
  – Save electrical energy required to run dedicated primary pump.
  – None of the efficiency penalties as related to fixed primary flow
    • No blending of primary and secondary loops (results in elevated return water temperatures)
    • Large mass allows modularity and lower firing rates
System Comparison: 100% Design Load

- Primary-Secondary: 100% Design Load = 6000 MBH
System Comparison: 100% Design Load

- Primary Variable: 100% Design Load = 6000 MBH
System Comparison: 100% Design Load

**Primary-Secondary**
- Boiler Inlet Temperature: 120F
- Boiler Firing Rate: 100%
- Boiler Efficiency: 90%
- Boiler Input: 6700 MBH
- Pumping Energy: 10.5 HP

**Variable Flow Primary w/ High Mass Boilers**
- Boiler Inlet Temperature: 120F
- Boiler Firing Rate: 100%
- Boiler Efficiency: 90%
- Boiler Input: 6700 MBH
- Pumping Energy: 6.2 HP
System Comparison: 70% Part Load

- Primary-Secondary: 70% Part Load = 4200 MBH
System Comparison: 70% Part Load

- Primary Variable: 70% Part Load = 4200 MBH
System Comparison: 70% Part Load

**Primary-Secondary**
- Boiler Inlet Temperature: 130°F
- Boiler Firing Rate: 75%
- Boiler Efficiency: 88%
- Boiler Input: 4775 MBH
- Pumping Energy: 6.6 HP

**Variable Flow Primary w/High Mass Boilers**
- Boiler Inlet Temperature: 120°F
- Boiler Firing Rate: 70%
- Boiler Efficiency: 91%
- Boiler Input: 4600 MBH
- Pumping Energy: 2.1 HP
Impact of Higher Return Temp on Efficiency
Primary-Secondary: 50% Part Load w/ Outdoor Reset = 3000 MBH
System Comparison: 50% Part Load

- Primary Variable: 50% Part Load w/ Outdoor Reset = 3000 MBH
System Comparison: 50% Part Load

Primary-Secondary
- Boiler Inlet Temperature: 120F
- Boiler Firing Rate: 75%
- Boiler Efficiency: 90%
- Boiler Input: 3330 MBH
- Pumping Energy: 3.8 HP

Variable Flow Primary w/ High Mass Boilers
- Boiler Inlet Temperature: 110F
- Boiler Firing Rate: 50%
- Boiler Efficiency: 93%
- Boiler Input: 3225 MBH
- Pumping Energy: 0.8 HP
System Comparison: 50% Part Load

**Primary-Secondary w/ 3 boilers operating**

- Boiler Inlet Temperature: 137F
- Boiler Firing Rate: 55%
- Boiler Efficiency: 88%
- Boiler Input: 3400 MBH
- Pumping Energy: 5.3 HP

**Variable Flow Primary w/ High Mass Boilers**

- Boiler Inlet Temperature: 110F
- Boiler Firing Rate: 50%
- Boiler Efficiency: 93%
- Boiler Input: 3225 MBH
- Pumping Energy: 0.8 HP
• Boiler turndown of no benefit if it exceeds system turndown.
  – Plus, modular boiler configurations collectively have a higher turndown ratio

• Similarly, boiler minimum flow requirements limit ability to take advantage of high boiler turndown.
  – Once flow is at minimum, further turndown of boiler will force a lower delta T.
Example: High Turndown Boiler with Minimum Flow Requirement

- 1,000,000 BTU/HR input boiler
- Assume 92% efficiency, design delta T of 30°F
- Boiler has 20:1 turndown and minimum flow requirement of 25 gpm

**Formula**

\[ Q = C_p \times m \times \Delta T \]

**Design conditions at high fire:**

\[
920,000 = 8.34 \times 60 \times m \times 30
\]

\[ m = 61.3 \text{ gpm} \]

**Keeping delta T constant:**

\[
Q = 8.34 \times 60 \times 25 \times 30
\]

\[ Q = 375,300 \text{ BTU/HR} \]

Turndown ratio = 2.5:1

**Applying 20:1 turndown:**

\[
46,000 = 8.34 \times 60 \times 25 \times \Delta T
\]

\[ \Delta T \text{ is only } 3.7°F \]
Excess Air & Dew Point

- High turndown burners typically have high excess air at low firing rates
- Negative relationship between excess air and dew point
Hybrid systems allow for much better return on investment as well as flexibility on project size.

- Replace just a portion of the existing equipment.
- During daily or seasonal low load periods – shut down the primary boiler plant.
Condensing Boilers Sized Based on Shoulder Loads

Average monthly low temperature in January is 47°F.
*Design load requirements: 4,000,000 BTU/hr at 37°F
January is San Francisco’s coldest month.

At 47°F Outdoor Temperature, Loop Temperature = 135°F
Hybrid Retrofit: Primary Variable
Why Use a Hybrid System?

- **Savings for owners**
  - Initial costs
  - Operating costs
  - Reduce excessive fuel consumption
  - Take advantage of outdoor reset
- **Alternate fuel back-up (e.g., oil)**
- **Improve ambient comfort throughout the heating season**
- **Operate the system more efficiently through proper controls**
Thank you for your time!

Questions?