Hot Water Boilers and Controls

Why Condensing Boilers are “Different”

Long Island Chapter, ASHRAE
H.W. Boilers and Controls

- Major types of boilers
  - Advantages and disadvantages
  - Resistance to thermal shock
  - Firetube vs. Watertube
- Minimizing thermal shock
  - Piping arrangements
  - Control systems, boiler and building
  - Operations– $\Delta T$

- Boiler efficiency
  - Relevant factors
- Condensing boilers
  - How efficient are they?
  - Major types
  - Applications
- Piping arrangements
  - Primary-Secondary
  - Single Loop
  - Hybrid systems
- Control Systems
  - Conventional boilers
  - Condensing boilers
Hot Water Boiler Types

- Firebox
- Sectional Cast Iron
- Vertical Tubeless
- Scotch Marine
- Flexible Watertube
- Finned Copper Tube
- Condensing
- Industrial Watertube
Boiler Types NOT Recommended

- **Firebox**
  - Geometry makes uniform circulation difficult
  - Many right angle welds concentrate stress

- **Sectional Cast Iron**
  - Less efficient than other types
  - Larger units are easily damaged by thermal shock
  - Eutectic cast iron boilers are an exception
Thermal Shock

- Resistant boilers
  - Copper fin tube
  - Flexible Watertube boilers
  - Most condensing boilers
  - Eutectic cast iron boilers

- Shock prone boilers
  - Conventional Cast Iron
  - Scotch Marine
  - Firebox Boilers
Thermal Shock

Thermal Shock results from -
- rapid temperature changes in the boiler
- uneven temperature changes to boiler vessel
- parts of boiler expanding (or contracting) more rapidly than other parts
- rigidity in boiler construction
- continuous “flexing” of rigid parts
- can be caused by frequent cycling
- for example: shutting plant down at night

Thermal Shock results in -
- leaking tubes
- cracked tube sheets
- cracked sections in cast iron boilers
Causes of Thermal Shock

- Return of cold water to a hot boiler
  - system piping in building cools down overnight
  - boiler is kept hot
  - secondary pumps over pump the primary pumps

- Return of hot water to a cold boiler
  - cold boiler is started after being isolated from flow

- Failure to bring a cold boiler up to temp slowly
  - cold boiler should stay at low fire until up to temperature, at least for 30 minutes
Four pass water backed firetube
Firetube Hot Water Boiler Design
Scotch marine firetube boiler

- **Advantages**
  - Very efficient
  - Sizes up to 800 HP
  - Burn any fuel
  - Low waterside ΔP
  - Easy to clean
  - Easy to maintain
    - Replace or plug tubes
    - Clean tubes

- **Disadvantages**
  - Prone to thermal shock
    - Slow warm-up
    - Maintain temperature in standby boilers
  - Floor space requirements
    - Tube pull area
  - Must not condense
  - Typical 20 - 30°F ΔT limit

On many large projects, firetube hot water boilers are extremely efficient and reliable, but hydronic system and control system design must be adapted to the boilers needs.
Copper Fin Tube Boilers

• Fan assisted – sealed combustion
  • Low emissions
  • Medium efficiency -- 80 to 84%
  • Staged Combustion
• Atmospheric
  • Draft hood
  • Modulating combustion
• Return water temp down to 105°F
• Can be stacked two high to conserve floor space (no offset)
• From 122 MBH to 4000 MBH
• Condensing heat exchanger can be added

For Hydronic Heating and Domestic Hot Water

Indoor and Outdoor
Copper Finned Tube Heat Exchanger
Hydronic Systems for Fin Tube Boilers

- Generally use primary-secondary scheme
- Primary pump is supplied on the boiler
  - Primary pump sized to match the boiler requirements
    - Too much flow can cause erosion of boiler tubes
    - Too little flow can cause local overheating
- Boiler mounted pumps run with the boiler
  - Shut down when boiler is off line
- Secondary pumps run via BMS control
Finned Copper Tube Summary

**Pro**
- High efficiency
- Low standby losses
- Low cost
- No thermal shock
- Low water temperatures
- Sealed combustion
- Direct heating of DHW
- Simple to maintain
- Low cost
- Can offer Condensing Operation

**Con**
- Gas fired only
- Flow sensitive
  - Use primary-secondary systems
  - Excess flow – erosion
  - Low flow – scale formation
  - Must have flow to operate
- Beware of rated efficiencies
- Condensing versions use secondary heat exchangers
Flexible Watertube Boilers

- Small footprint
  - 143 HP unit is 47.5”w by 160” long by 86” high
  - 34” tube pull to each side
- Can be field erected
  - no welding or tube rolling
  - build in one week
- Guaranteed against Thermal Shock
- Requires a minimum flow
Flextube Boilers

- Water in the Tubes/Exhaust Gases Pass Around the Tubes
- Up to 12 MMBtu/hr Input
- Multiple Passes
- Hot Water/Low Pressure Steam Boilers - High Resistance to Thermal Stress
- Heating Applications
Industrial Watertube Boilers

Used for low, medium and high temperature hot water and high pressure steam
Sizes from 15 to 100 million BTU/hr
Tubes are tangent allowing for individual expansion and contraction

PLAN VIEW
Boiler Water Flow versus ΔT

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<th>Boiler Output (x1000) BTU/HR</th>
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A brief discussion of boiler efficiency

- Boiler efficiency depends on many factors
  - Boiler design
  - Percent load (firing rate)
  - Fuel being fired
  - Temperature of fluid (water or steam) in boiler

- Always try to obtain efficiency guaranties:
  - Based on fuel being fired
  - Based on actual design water temperatures

- Don’t believe everything you read
Boilers are really heat exchangers

- The lower the stack temperature the higher the efficiency
- The lower the fluid temperature the lower the stack temperature
- Heat recovery exchangers can be used to recover energy in flue gasses
- Scotch Marine boilers are extremely efficient heat exchangers
- Conventional boilers capture sensible heat
- Condensing boilers capture sensible AND latent heat
Efficiency by Losses

- Fuel energy in = heat energy out
- Energy leaves in hot water (or steam) or as a loss
- Efficiency = 100% minus losses
- Greatest loss is stack loss (100% minus stack loss = “Combustion Efficiency”)
  - Typically 15% to 20% including latent and sensible heat
  - With natural gas, 10% of energy in fuel is lost as latent heat of vaporization
  - With fuel oil, 4% of energy in fuel is lost as latent heat
  - Remainder of stack loss is sensible heat
  - Sensible heat loss increases with excess air

- Second greatest loss is radiation loss
  - Typically ½ to 3% of energy input at maximum load
  - Radiation loss is a constant BTU loss, not a constant %

- Typically other losses from boilers are insignificant.
One ft$^3$ natural gas yields two ft$^3$ water vapor.

Two ft$^3$ water vapor condenses to one ounce water.

About 9% of the BTU content in each ft$^3$ natural gas burned leaves the stack as latent heat of vaporization in this water vapor.

By condensing this water and lowering the stack temperature, 98% efficiency can be reached. Some heat pump supplement boilers can achieve this.

A 1 million BTU/hr boiler will produce 6 gallons/hr liquid water when fully condensing.

This water will only condense at gas temp <135°F.

No manufacturer’s boiler can take full advantage of typical 160 to 180°F hydronic applications.
Cautions !!!!!!!!!!!!!!

- Any boiler can be a condensing boiler
  - Just return water cooler than 130°F
  - Water will condense somewhere in the boiler
- Conventional boilers will be damaged
  - By corrosion or failed refractory from condensation
  - By sooting due to blocked fins (copper fin tube)
- Condensing boilers are special
  - They can handle flue gas condensate safely
  - They can also run at non-condensing temperatures
- Condensing boilers need special flue material
  - AL29-4C or PVC (316L is used in Europe)
Types of Condensing Boilers

- **Firetube – high water volume**
  - Can be used in variable flow single loop systems
  - Forgiving of low or no water flow
  - Examples are Pulse, Benchmark, Vantage
  - The higher the water volume, the lower the flow can be with boiler firing

- **Watertube – low water volume**
  - Must be used in primary – secondary systems
  - Require a minimum water flow through boiler
  - Examples are Wall mounted European design, Copper Fin, Aluminum heat exchanger design
Examples of firetube condensing boilers
Vertical Extended Surface Firetube

- High water volume
- Tubes have internal “fins”
- Full condensing Operation
- High water volume
- No minimum water flow
- No minimum water temperature
- Efficiency up to 98%
- Sealed Combustion available
- Screen type low NOx burner
Extended Heating Surface Tubes

- Stainless steel tubes
- Alloy finned inserts
  - Exceptional heat transfer
- Down fired
- Efficiencies up to 98%
- Extremely quiet
Efficiency as a function of percent firing rate and return temperature
Pulse Boilers

- Use fuel energy to pull in combustion air
  - No combustion air blower motor (except for start)
- High water volume design
- Require vibration isolation on mount and piping
- Special designs available for low emitted noise
- Extremely compact
Internals of Pulse Boilers

- Is not sensitive to water flow
- Uses very little electrical energy – 0.25 amps, 120V
Pulse Boiler internal construction
Benchmark Series
Low mass firetube design
Oil as a back-up fuel

- NYC does not allow use of propane
  - Most condensing boilers also burn propane
  - Many designs allow for automatic switch to propane
- Very few condensing boilers can burn oil
- #2 oil is used as a back-up in some designs
  - Boiler is prevented from condensing when on oil
  - Water temperature is automatically raised
Dual Vessel Condensing Boiler
Dual Fuel Capable

- Fully condensing on gas
- Burns #2 oil as backup
- Sizes 2, 3 and 4 million BTU
Cut away view of dual fuel condensing boiler
Compact watertube condensing boiler
Compact watertube condensing boiler

Premix Burner

316L SS Heat Exchanger

Hydro-Formed water-tubes
Efficiency of European design boiler

- Very low electrical consumption
- Extremely efficient heat exchanger
  - Flue gas temperature is 20ºF above inlet water
- Compact
- 316L heat exchanger allows one unit to be applied for hydronic or domestic hot water
Condensing boilers – Special concerns

- Flue gasses will condense in flue piping
  - Need constant pitch TOWARD boiler
  - Need drain sections

- Condensate is acidic
  - Neutralize with limestone chips
  - Use trap to keep flue gasses out of neutralizer and out of boiler room

- Follow manufacturers instructions for venting
  - Watch differential between comb. air and exhaust.

- Follow NYC codes for spacing and size limitations
  - Sidewall venting limited to 350,000 Btu input
  - Minimum spacing between vents
  - No venting into shaft-ways or small courtyards or over sidewalks
Hot Water System Design

- Allow room for expansion of water
- Provide constant flow through primary loop
  - Past all temperature sensors
  - Through flow sensitive boilers
- Purge all air from system
- Balance flow through operating boilers
- Prevent thermal shock damage to boilers
- Prevent steaming - maintain water pressure
- Keep water inlet and outlet temperatures within design limits
Three Good HW Operating Practices

- **Maintain Water Quality**
  - Periodic water analysis to see when treatment is needed
  - Monitor make-up water flow into system

- **A planned preventative maintenance program.**
  - Burner, Controls, Pressure Vessel, Refractory and circulating pumps and control valves
Hot Water Boiler Summary

- Provide continuous circulation through the boiler
- Prevent hot or cold shock
- Prevent frequent cycling
- Balance the flow through boilers
- Provide proper over-pressure
- Provide water treatment
- Check for leaks – loss of water treatment
Sequencing multiple conventional boilers

- Keep as few boilers on line as possible
- Warm-up of cold boilers
- Keep water temperatures above 140°F
- Keep warm for stand-by boilers
- Maintain flow through operating boilers
- Cool-down period for boilers shutting down
- Minimizing $\Delta T$ on operating boilers
- Isolating boiler water temperature from building system temperature
- Control strategy depends on piping arrangement
Basic two boiler system for conventional boilers

Constant and Equal Flow Through Both Boilers

With two boilers on line
Load is shared
Boiler $\Delta T$ is same as Header $\Delta T$

With one boiler on line
Water at return temp leaves #2
$\Delta T$ of #1 must double to maintain same Header $\Delta T$

Boiler Return Temperature
Boiler Outlet Header Temperature

Primary Pumps set Boiler Flow

Secondary Pumps set Building System Flow

Boiler 1

Boiler 2

Water to and from Building System Could be 1000’s of Gallons stored in piping
Constant Flow System Notes

- Works fine for two boiler systems
- Temperature blending is a problem with 3
- Matches flow to load
- Allows one pump to be 100% spare
- Need to keep primary pumping rate high enough compared to building loop pumping rate to keep boiler return temperature above manufacturers minimum with cold water returning from building loop.
Three Firetube Boiler System
Arranged for Full Automation

This system shows motorized isolation valves (a) to allow flow to be directed to operating boilers only. Flow control valves (b) are shown bypassing the on-off valves to make certain that there is some flow through the boiler to keep vessel hot. Blend pumps (c) serve to equalize the temperature within the boiler when in “keep warm” mode. Typically the lead pump (d) would run continuously, and would support the lead boiler. The first lag pump (e) would start and stop with the first lag boiler. A signal from boiler return temperature could be used to cut back on the building pumping rate if the return water temperature fell below the minimum (150 degF for CB firetube boilers). Manual shutoff valves (f) would isolate a boiler from the loop for “cold standby” duty.
Primary Loop, Constant Differential

Control Functions
- Boiler: Sequencing with Parallel Modulation
- Balancing Valve Splits Flow thru Down Bus
- Supply Temperature Outdoor Reset
- Time/Date Supply Temp. Setback Schedule
- Pump Sequencing per Boiler Load

Piping Layout Disadvantages
- Can’t use VFD on Primary Pump to save kW
- Can’t Warm-up Boiler Off-Line
- Long Return Pipe can Send a Cold Slug of Water into the Boiler Every Morning as Load Increases. Potential Thermal Shock
- dP at End of Loop Drops as Load Increases

3 Hot Water Birs, Primary Loop, Header pumps, Variable Flow Loads, Bypass Valve

Plant Wide Controller (PWC)

Outside Air Temp (OAT)

Control Functions

Piping Layout Disadvantages

3 Hot Water Birs

Primary Loop Pumps

Self-Contained Differential Pressure Regulator

Modulating Temperature Control Valves

Boilers

Semi-Constant Flow to Boilers (via Bypass Regulator)

Variable Flow Heating Loads
Single Hot Water Loop, Blend Valves

**PWC Application Note:**

- 3 Hot Water Blrs. 220 F. Primary Loop, Boiler pumps. 3 Way Blend Valves. Constant Flow Loads

**Control Functions**
- Boiler: Sequencing with Parallel Modulation
- Blend Valve Prevents Thermal Shock
- Blend Valve Allows Off-Line Warm-Up
- High Boiler Outlet Temp cuts back Firing Rate to prevent tripping Boiler
- Supply Temperature Outdoor Reset
- Time/Date Supply Temp. Setback Schedule
- Pump Sequencing per Boiler Load

**Piping Layout Disadvantages**
- Can’t use VFD on Primary Pump to save kW
- No Scare Pumps
- If Pump Fails, Boiler is Down until Repaired
Primary Secondary Loops

3 Hot Water Birs, 220 F. Primary Header pumps. Secondary Header VFD Pumps, Blend Pumps

Control Functions
- Boiler:
  - Sequencing with Parallel Modulation
  - Balancing Valve Stops Flow thru Down Birs
  - Bal. Valve 10% open during Warm-Up
  - (Blend Pump Provides Flow for Warm-Up)
  - High Boiler Outlet Temp cuts back Firing Rate to prevent tripping Boiler
  - Supply Temperature Outdoor Reset
  - Time/Date Supply Temp. Setback Schedule
  - Distribution Pump Sequencing per Load
  - Dist. Pump VFD minimizes kW, and maximizes system delta T
  - Pump Speed: Zone dP over-rides Ref. Temp
  - Secondary Speed cuts back to prevent reverse flow thru cross-over pipe and cooling of Secondary
Sequencing multiple condensing boilers

- Keep as many boilers on line as possible
  - Condensing boilers are more efficient at low loads
  - More residence time allows for more condensation
- Modulate operating boilers in parallel
- Reduce or stop flow through standby boilers
- Maintain minimum flow through operating units
  - Common header temp sensor needs flow
  - Minimum flow depends on boiler design
Primary Secondary System with One Dedicated Pump per Boiler

Primary Pumps in Individual Boiler Leads

Secondary Taps Spaced as Close Together as Possible

Manifolded Secondary Pumps

Works well with watertube condensing boilers
Advantages of Individual Primary Pumps in Boiler Lead

- Flow through operating boilers is “constant”
  - Max $\Delta T$ at full fuel input remains constant
  - Boilers have flow for sufficient mixing

- No flow through boilers that are off line
  - No blending of cool water with heated water in common discharge header
  - $\Delta T$ of operating boilers is reduced

- Note: One pump must always run
  - So that there is flow past the header sensors
Modern control systems for multiple condensing boilers

- Generally furnished by boiler manufacturer
  - Most offer serial communications with individual boilers and with building automation systems

- Typical control functions:
  - Sequencing of boilers, pumps, and isolation valves
  - Full automation of entire primary loop
  - Building Management has control of secondary loop

The control sequence for multiple boilers is directly influenced by the way the system is piped. Consult your boiler vendor to make sure his control system matches your piping arrangement!
Thank you!