Hot Water Boilers and Controls

Why Condensing Boilers are “Different”

Presented Oct. 14, 2008
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– ΔT
- 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

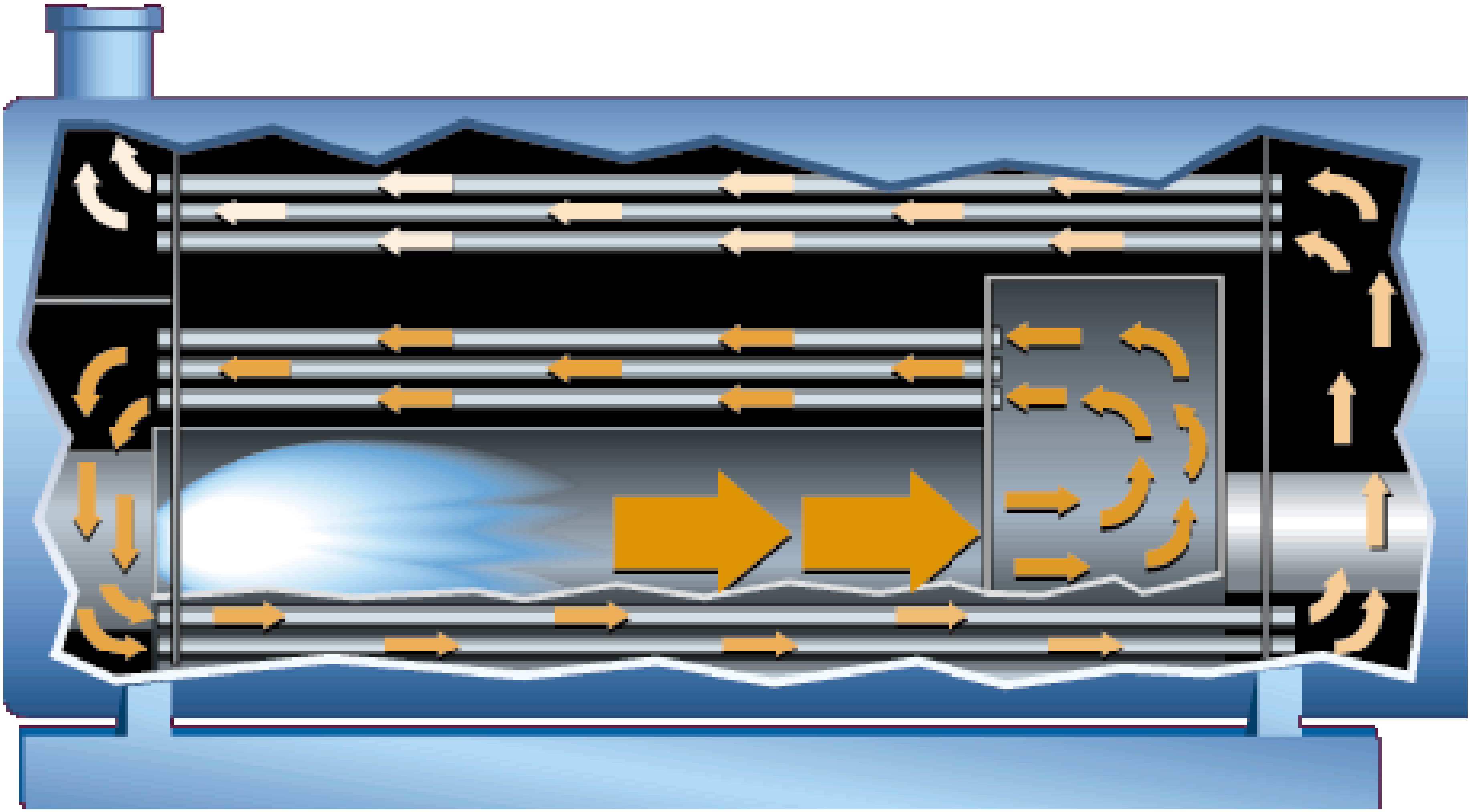
Thermal Shock

- 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

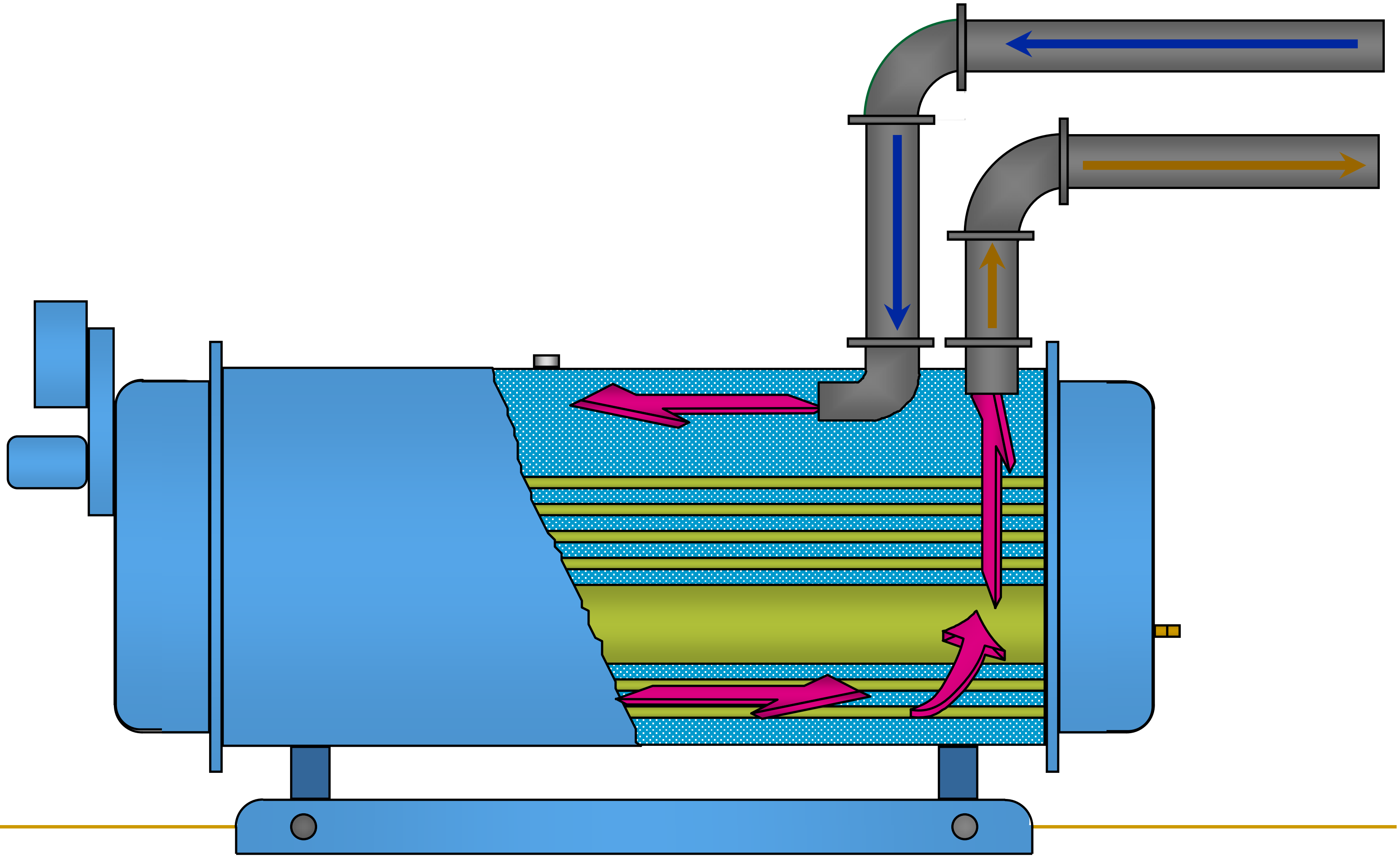
Causes of Thermal Shock

- 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 Δ P
  - 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 - 30ºF 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

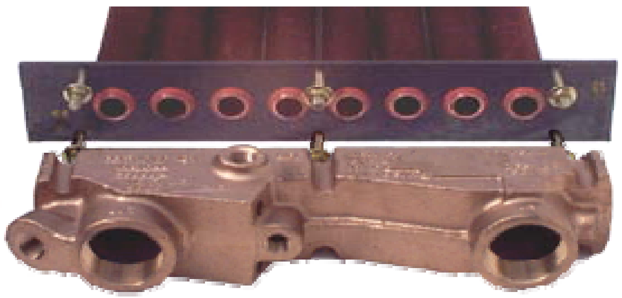
Copper Fin Tube Boilers

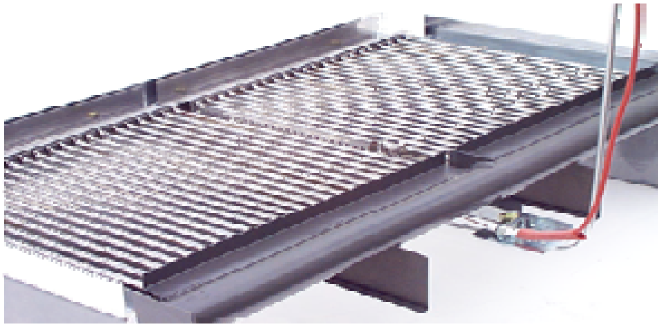
For Hydronic Heating and Domestic Hot Water

Indoor and Outdoor

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

Copper Finned Tube Heat Exchanger





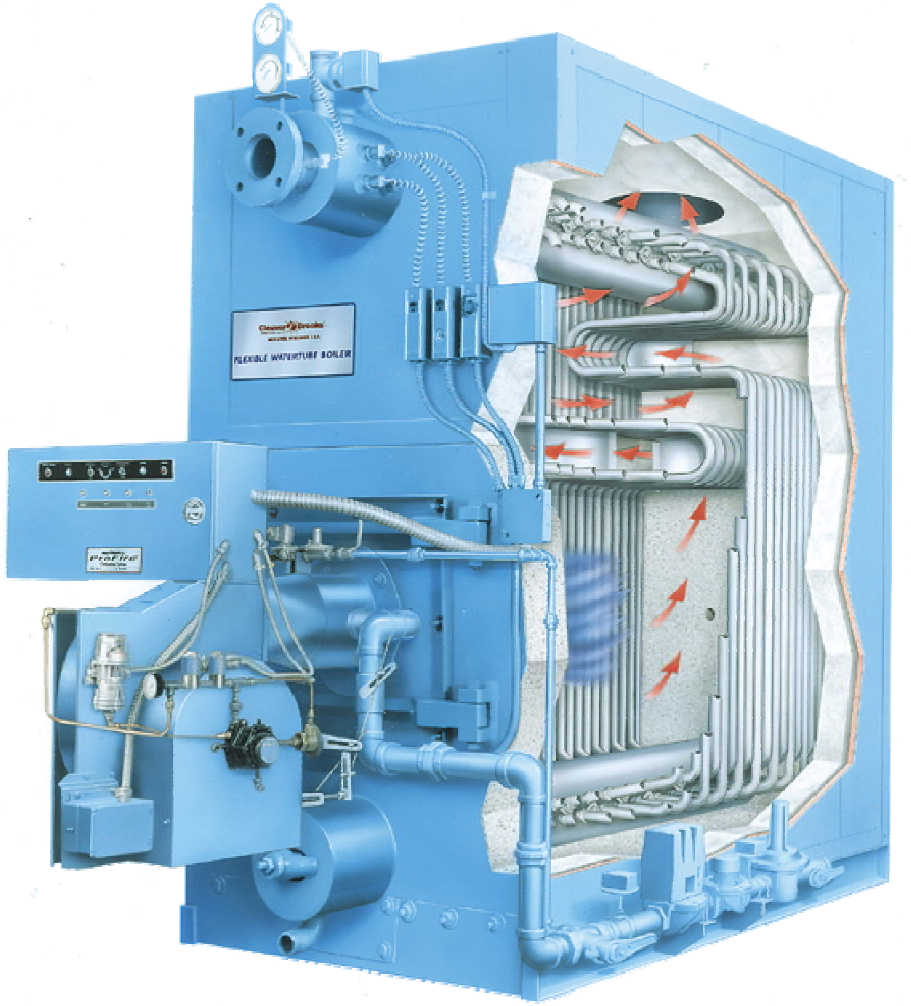
Hydronic Systems for Fin Tube Boilers

- 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

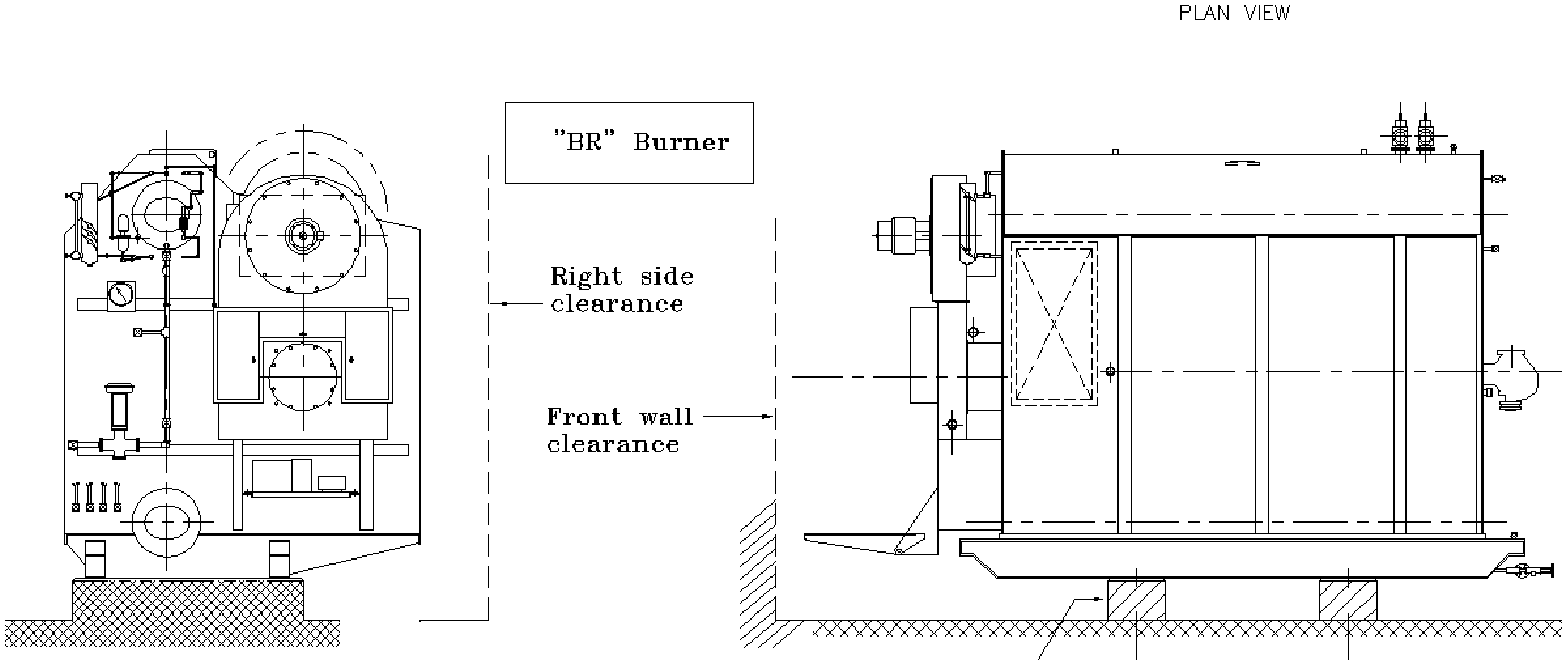
- Water in the Tubes/Exhaust Gases Pass Around the Tubes
- Up to 12 MMBtu/hr Input
- Multiple Passes
- Hot Water/Low Pressure Steam Boilers - High Resistance to Thermal Stress
- Heating Applications

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



Boiler Water Flow versus ΔT

Boiler HP	Boiler Output (x1000) BTU/HR	SYSTEM TEMPERATURE DROP - DEGREES F									
		10	**20**	30	40	50	60	70	80	90	100
		MAXIMUM CIRCULATION RATE - GPM									
15	500	100	50	33	25	20	17	14	12	11	10
20	670	134	67	45	33	27	22	19	17	15	13
30	1005	200	100	67	50	40	33	29	25	22	20
40	1340	268	134	89	67	54	45	38	33	30	27
50	1675	335	168	112	84	67	56	48	42	37	33
60	2010	402	201	134	101	80	67	58	50	45	40
70	2345	470	235	157	118	94	78	67	59	52	47
80	2680	536	268	179	134	107	90	77	67	60	54
100	3350	670	**335**	223	168	134	112	96	84	75	67
125	4185	836	418	279	209	168	140	120	105	93	84
150	5025	1005	503	335	251	201	168	144	126	112	100
200	6695	1340	670	447	335	268	224	192	168	149	134
250	8370	1675	838	558	419	335	280	240	210	186	167
300	10045	2010	1005	670	503	402	335	287	251	223	201
350	11720	2350	1175	784	587	470	392	336	294	261	236
400	13400	2680	1340	895	670	535	447	383	335	298	268
500	16740	3350	1675	1120	838	670	558	479	419	372	335
600	20080	4020	2010	1340	1005	805	670	575	502	448	402
700	23450	4690	2345	1565	1175	940	785	670	585	520	470
800	26780	5360	2680	1785	1340	1075	895	765	670	595	535

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.

Condensing Boilers

- 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 <135ºF
- **No manufacturer's boiler can take full advantage of typical 160 to 180F 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

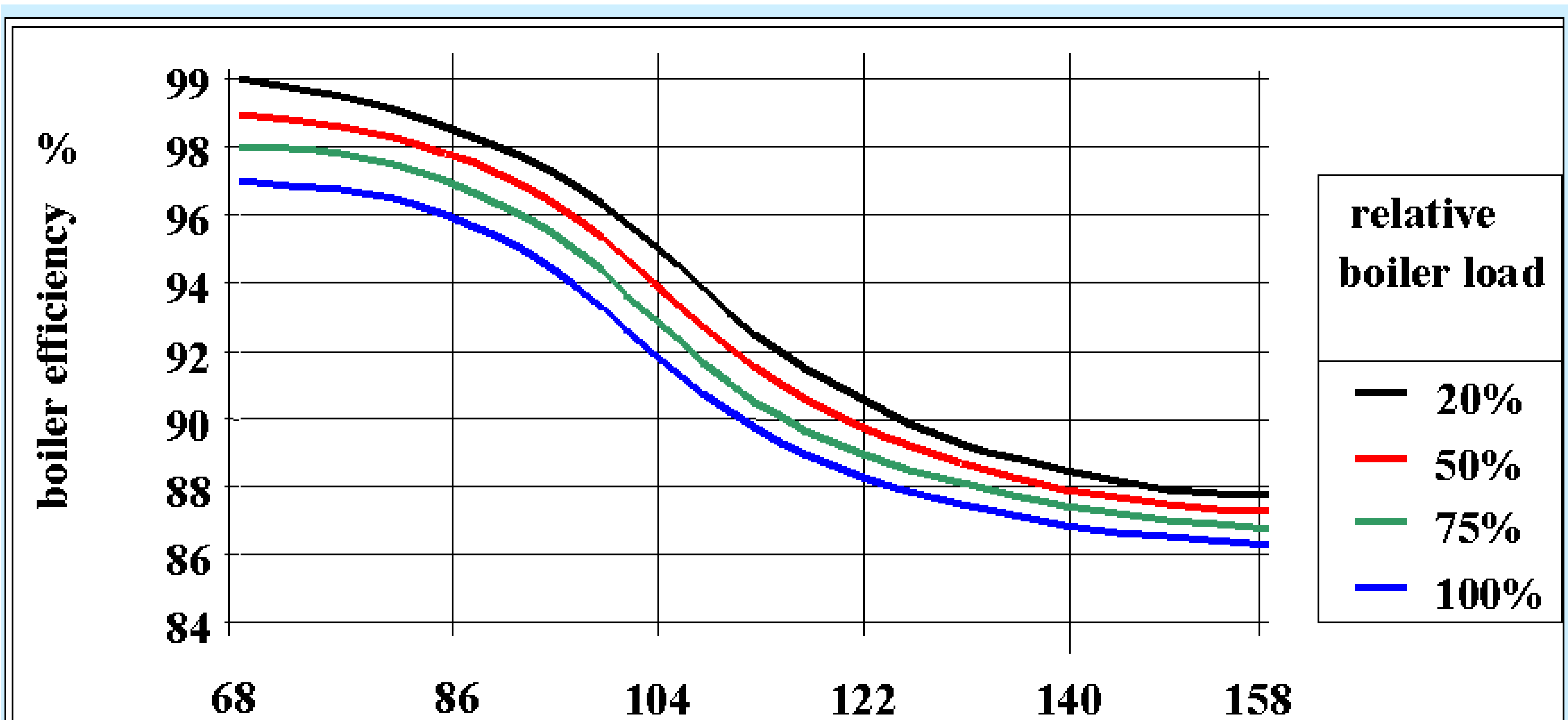
Vertical Extended Surface Firetube

- 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



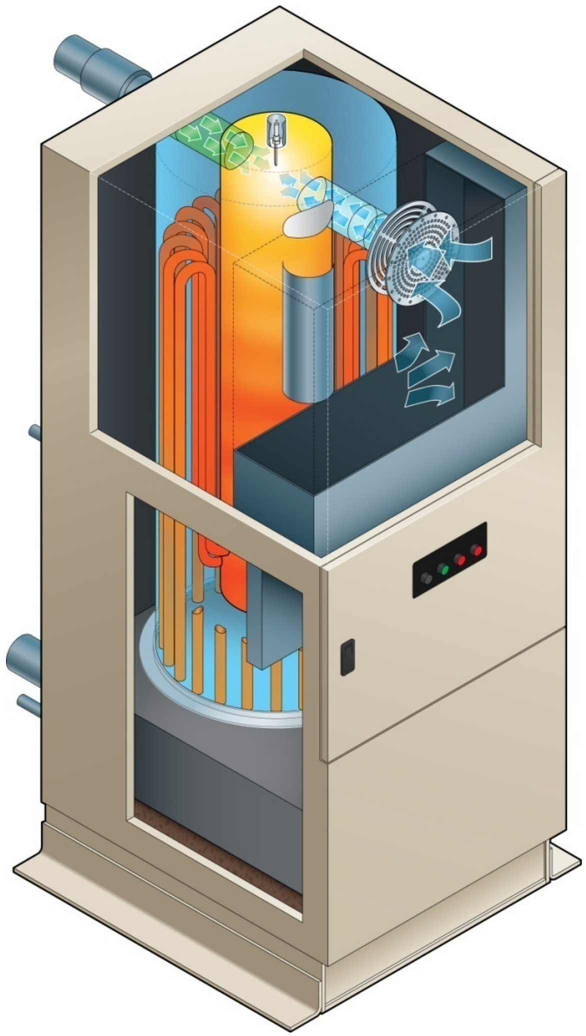
Pulse Boilers

- 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

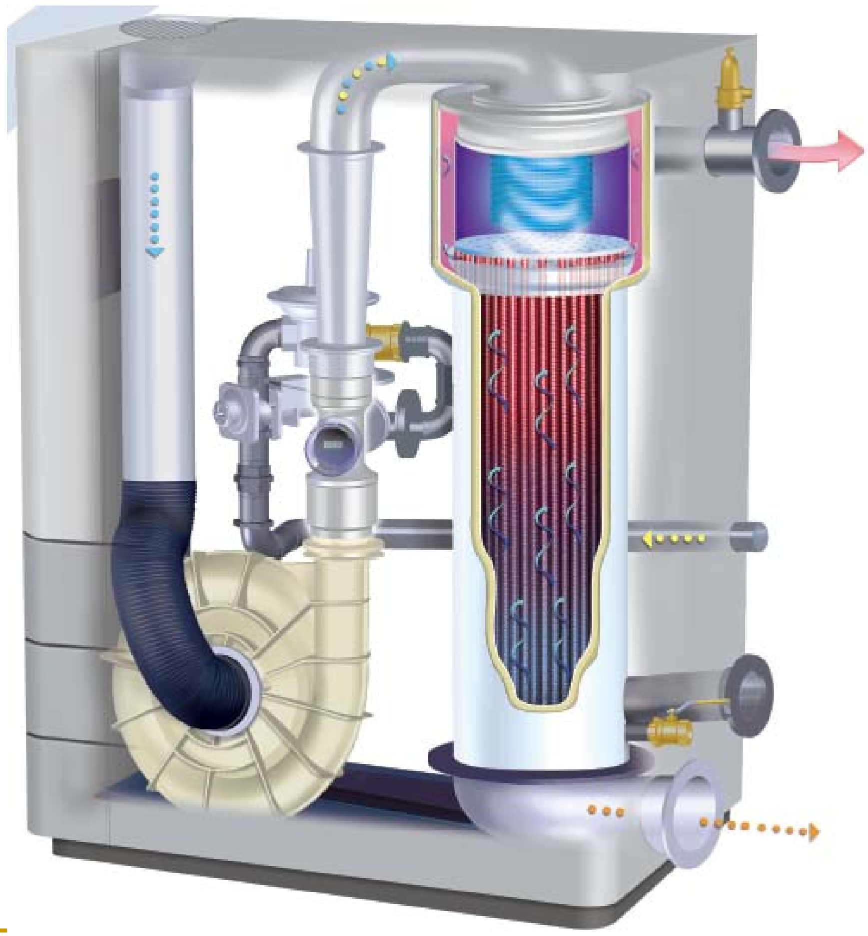
Internals of Pulse Boilers

- 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



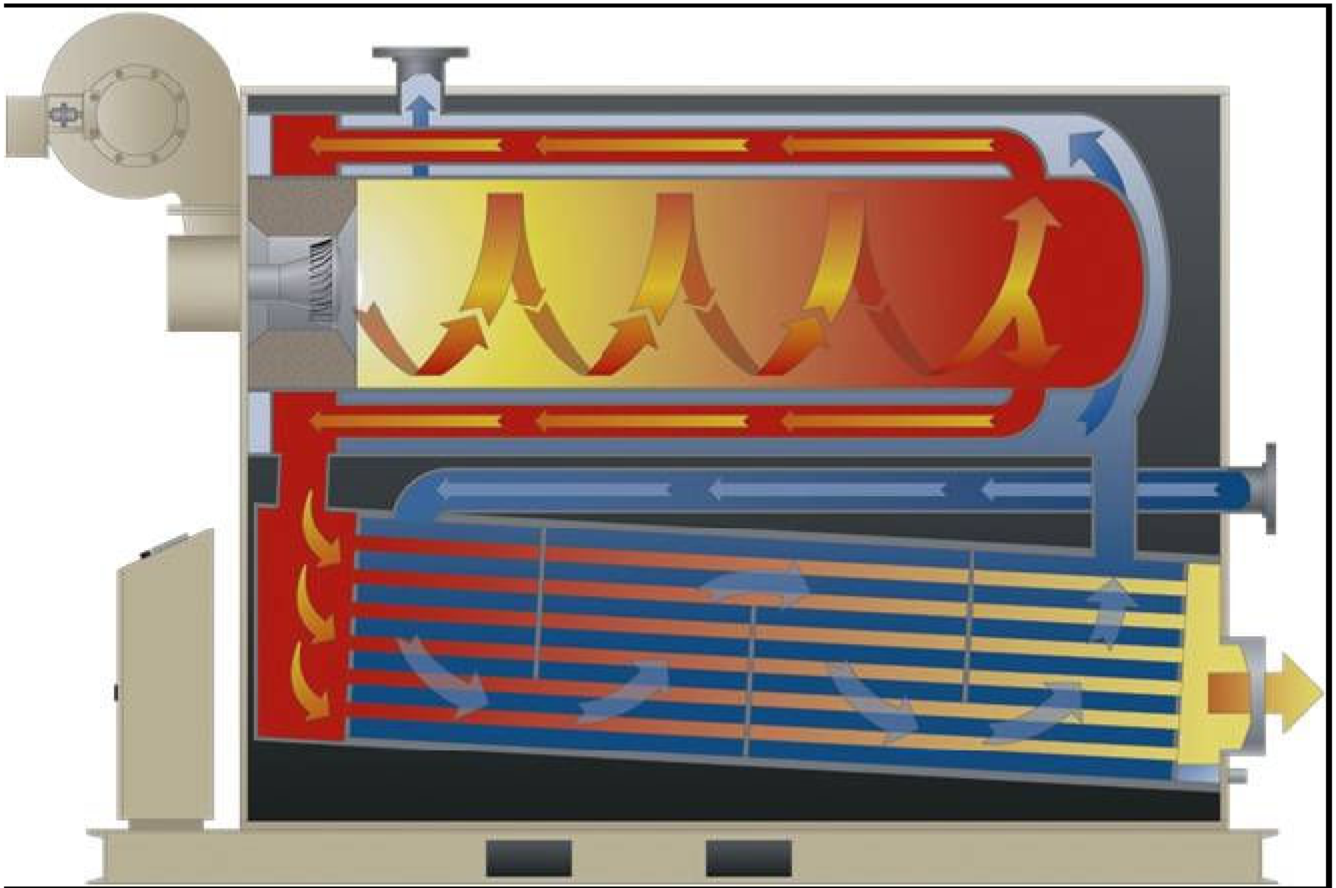
Oil as a back-up fuel

- 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

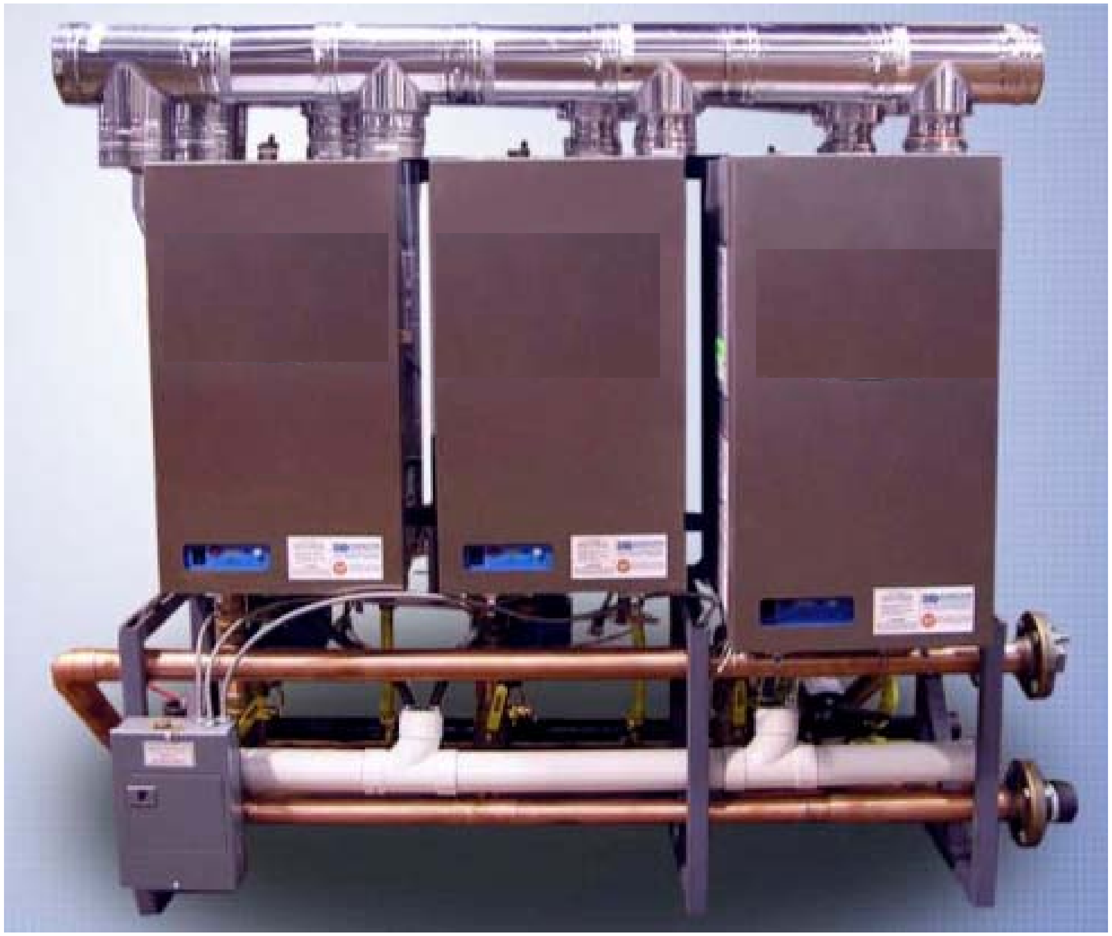
Dual Vessel Condensing Boiler Dual Fuel Capable

- 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

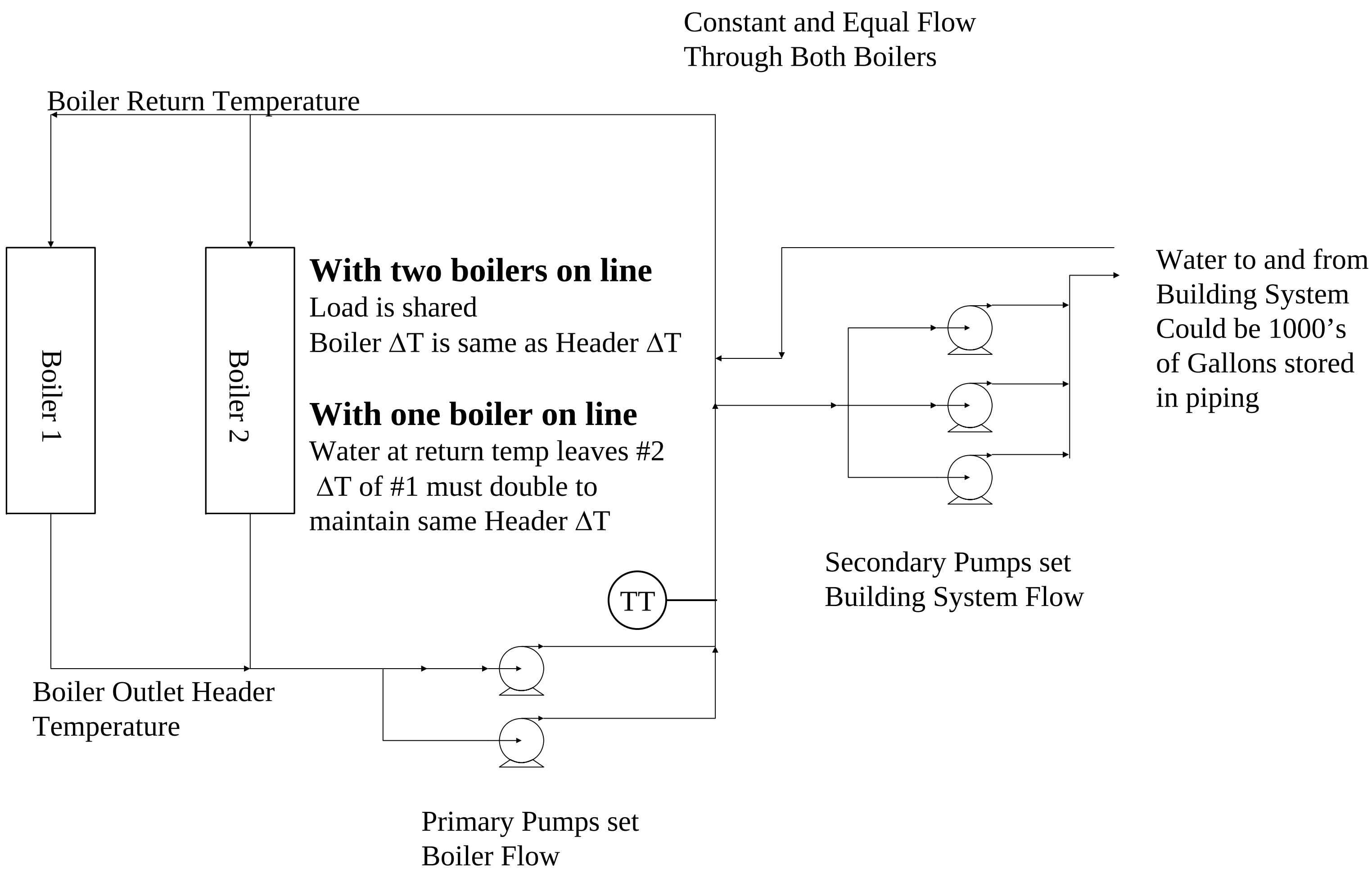
Hot Water Boiler Summary

- 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 140ºF
- Keep warm for stand-by boilers
- Maintain flow through operating boilers
- Cool-down period for boilers shutting down
- Minimizing ΔT on operating boilers
- Isolating boiler water temperature from building system temperature
- Control strategy depends on piping arrangement

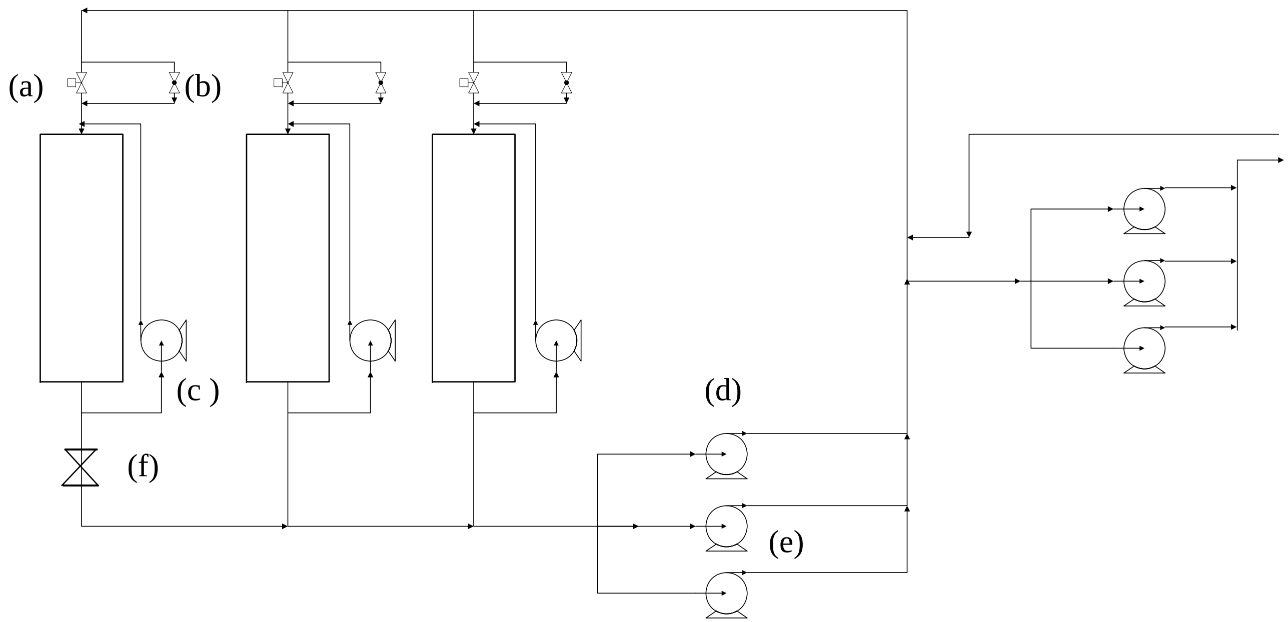
Basic two boiler system for conventional boilers



Constant Flow System Notes

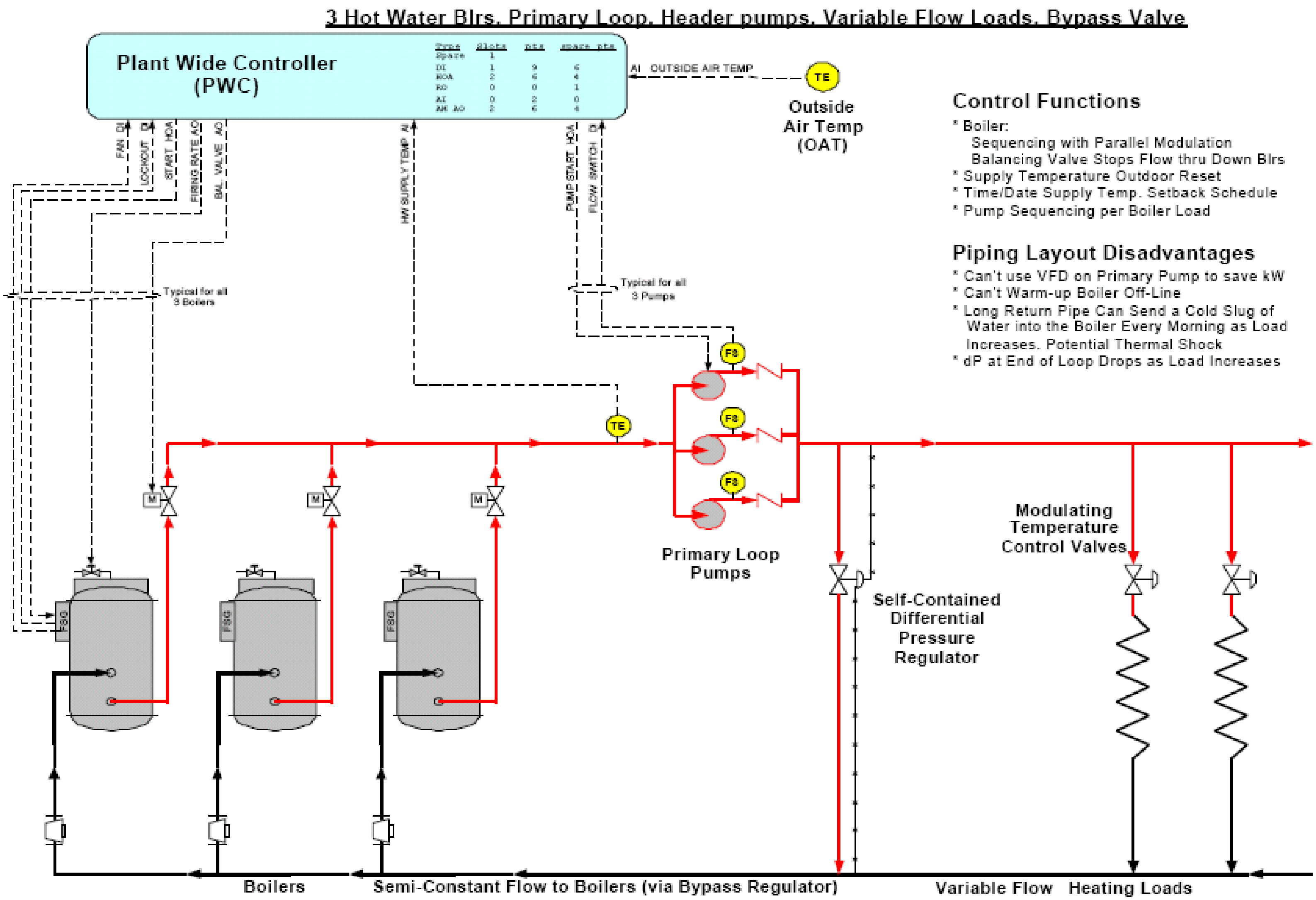
- Works fine for two boiler systems
- Temperature blending is a problem with 3
- Matches flow to load
- Allows one pump to be 100% spare
- Need to keep primary pumping rate high enough compared to building loop pumping rate to keep boiler return temperature above manufacturers minimum with cold water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

Three Firetube Boiler System Arranged for Full Automation

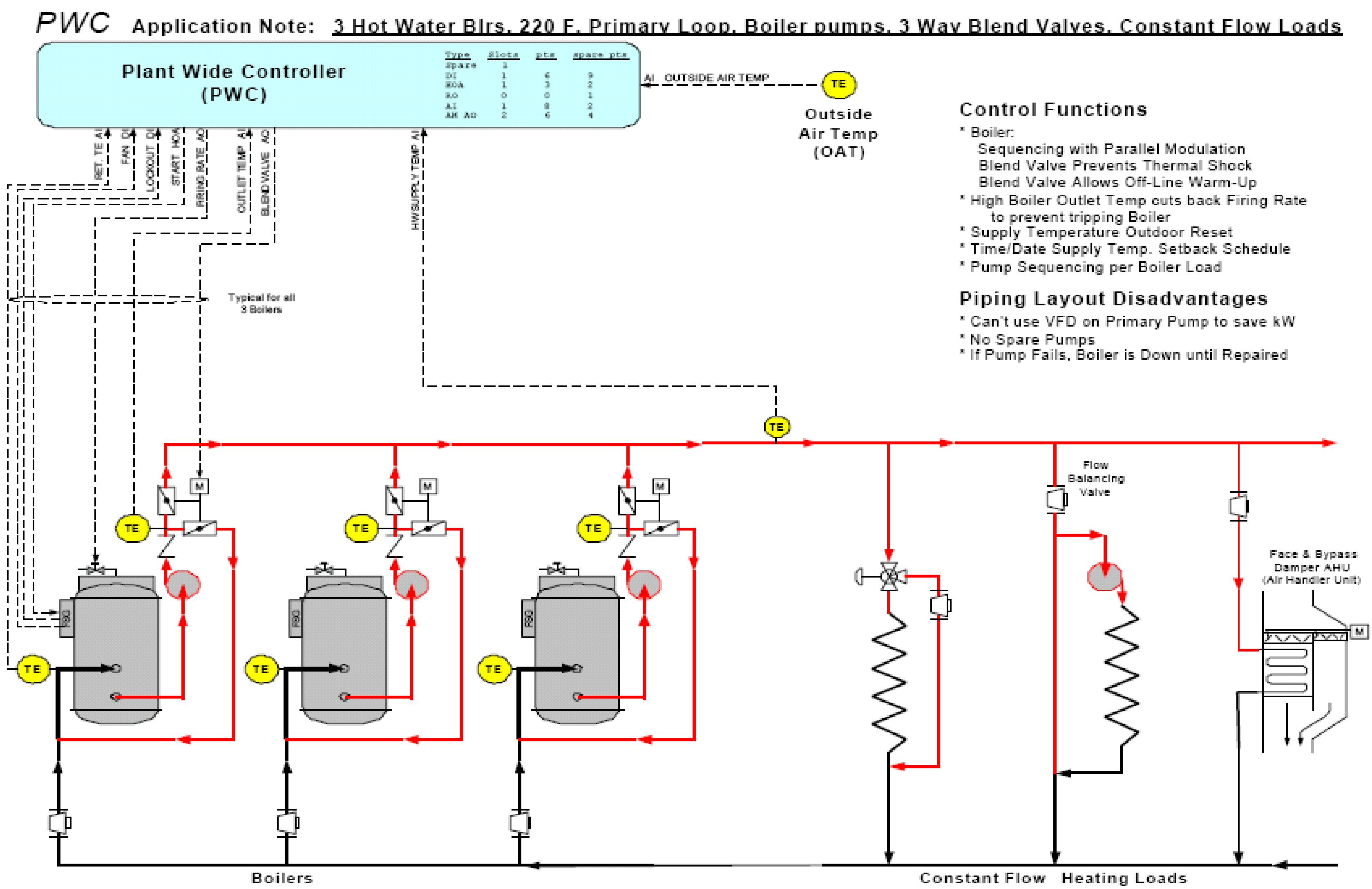


This system shows motorized isolation valves (a) to allow flow to be directed to operating boilers only. Flow control valves (b) are shown bypassing the on-off valves to make certain that there is some flow through the boiler to keep vessel hot. Blend pumps (c) serve to equalize the temperature within 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.

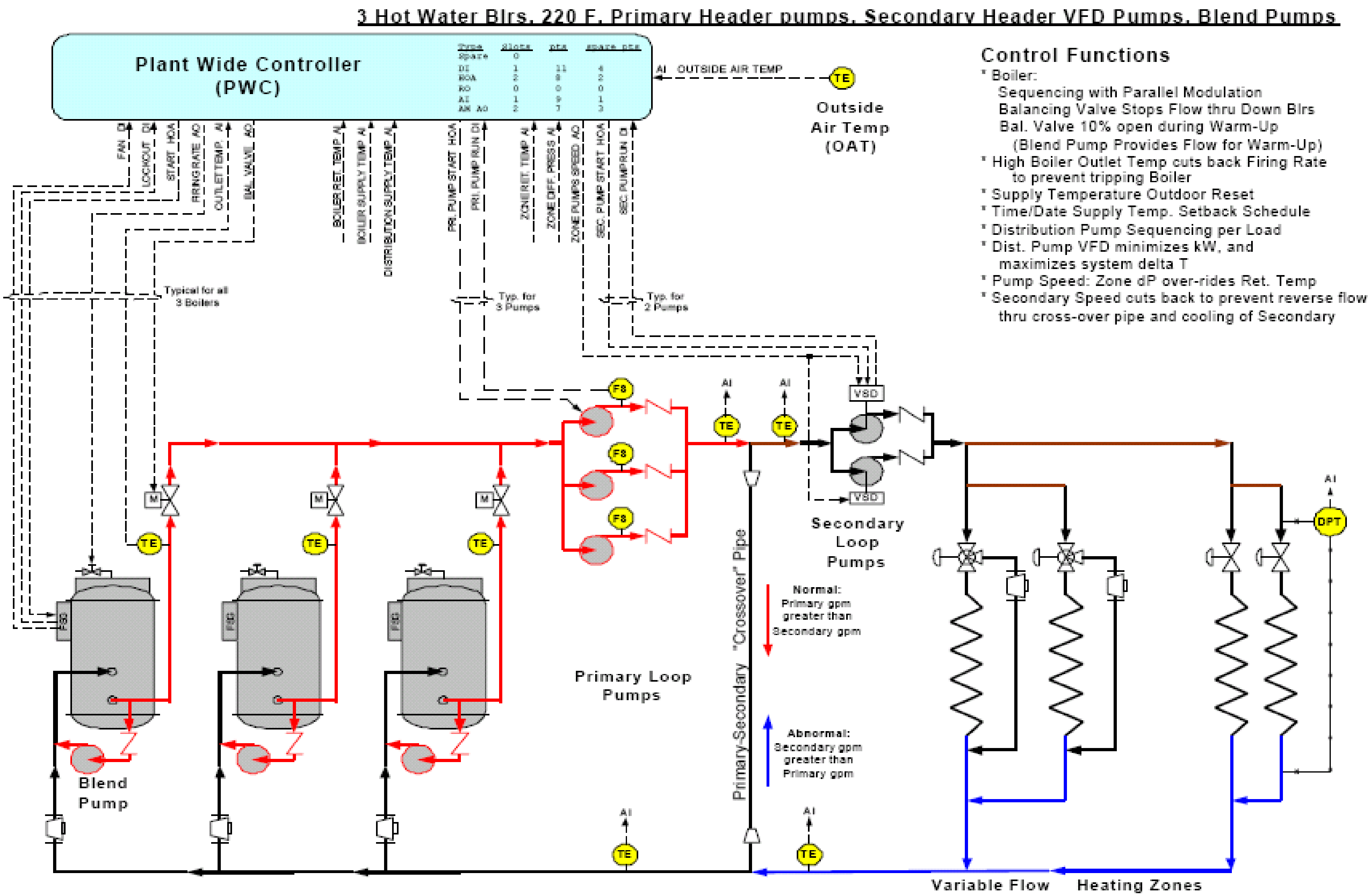
Primary Loop, Constant Differential



Single Hot Water Loop, Blend Valves



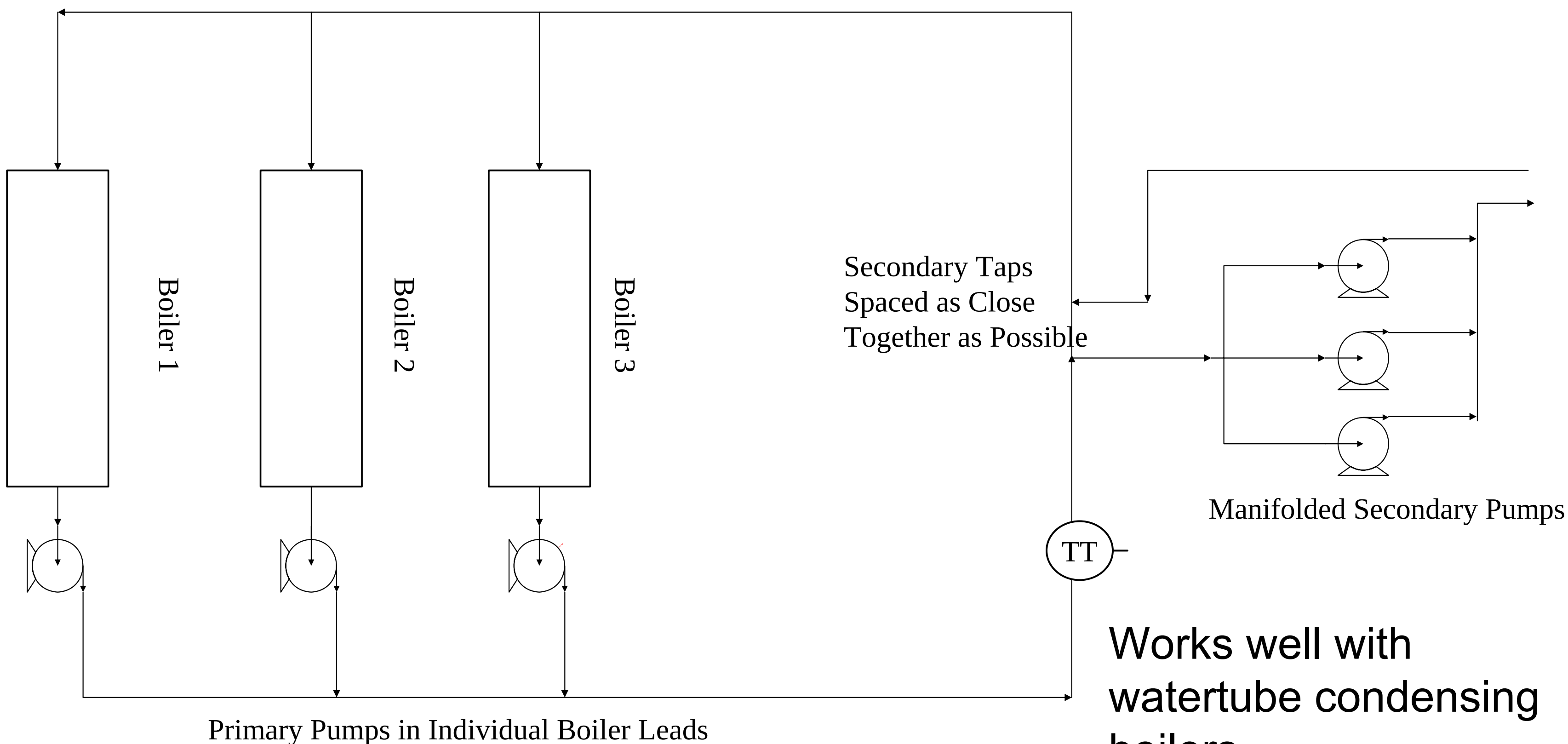
Primary Secondary Loops



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



Works well with watertube condensing boilers

Advantages of Individual Primary Pumps in Boiler Lead

- Flow through operating boilers is “constant”
  - Max Δ 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
  - Δ 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!