Optimizing Boiler Efficiency

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Why Are Efficient Boilers Desirable?

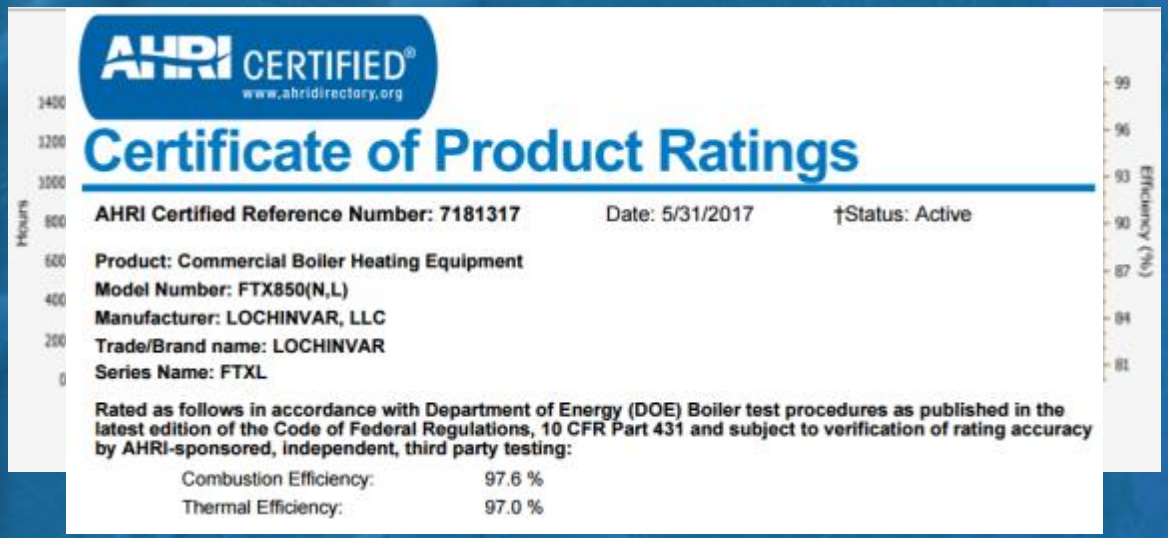
- Meet code requirements
- Reduce upfront equipment cost (incentives)
- Reduce operating expenses
- Reduce replacement equipment expenses
- Reduce footprint
- Provide greater control and monitoring
- Improve emissions
- Achieve specialty certifications (USGBC)
- Marketing

Measures of Efficiency

- AHRI / AFUE certified efficiencies
- Efficiency chart for different firing rates
- Turndown ratio

Defining Efficiency

- ENERGY STAR
  - < 300 MBH
  - ≥ 90% AFUE (gas)
- AHRI
  - AFUE
    - ASHRAE bin data
  - ≤ 300 MBH
  - BTS-2000
    - Steady state
    - Combustion / thermal efficiency



AHRI CERTIFIED®
www.ahridirectory.org

Certificate of Product Ratings

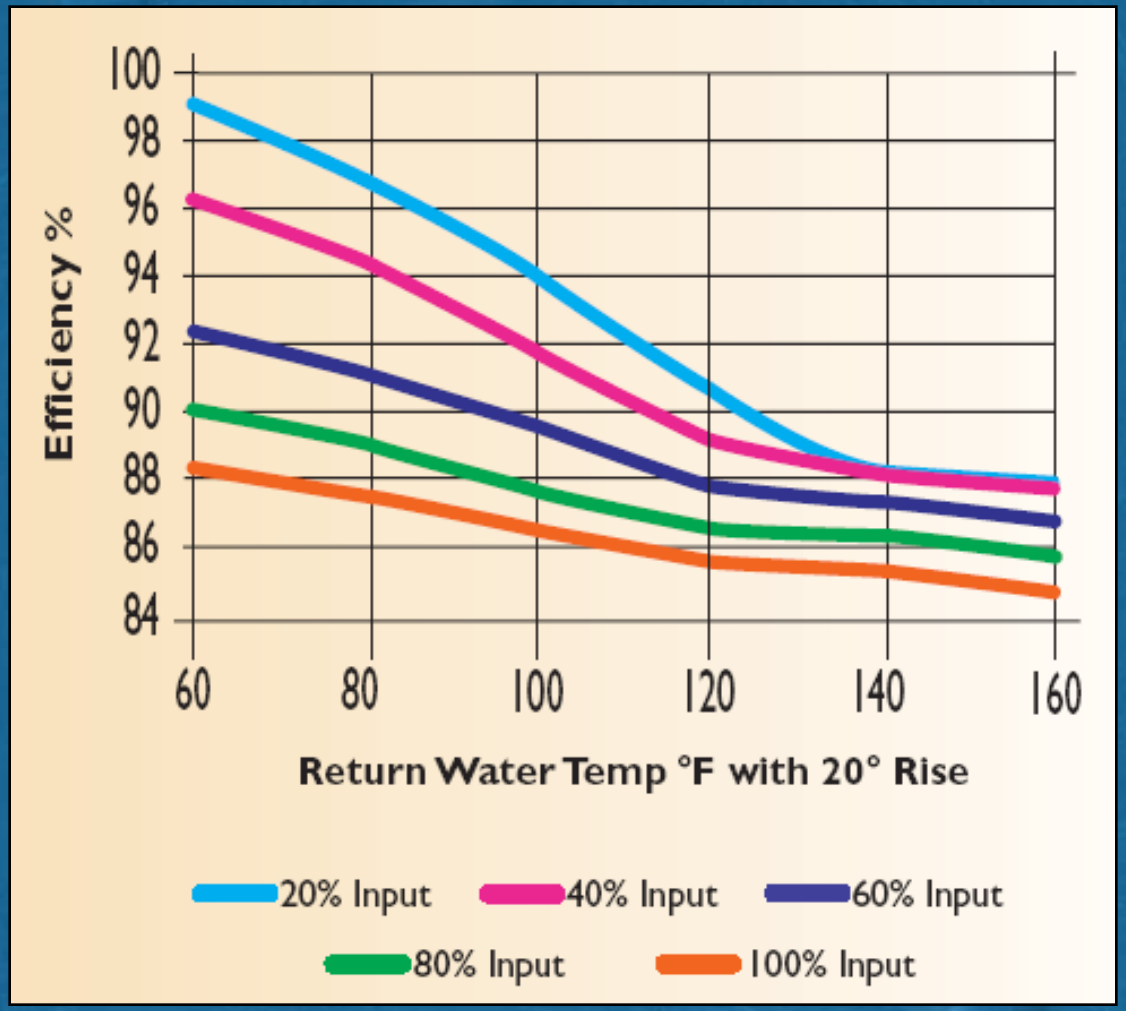
AHRI Certified Reference Number: 7181317 Date: 5/31/2017 †Status: Active

Product: Commercial Boiler Heating Equipment
Model Number: FTX850(N,L)
Manufacturer: LOCHINVAR, LLC
Trade/Brand name: LOCHINVAR
Series Name: FTXL

Rated as follows in accordance with Department of Energy (DOE) Boiler test procedures as published in the latest edition of the Code of Federal Regulations, 10 CFR Part 431 and subject to verification of rating accuracy by AHRI-sponsored, independent, third party testing:

Combustion Efficiency:	97.6 %
Thermal Efficiency:	97.0 %

Efficiency vs. Firing Rate & RWT



Factors Not Considered

- Excess air levels
- Blower's electrical energy
- Pumping energy
- Pre / post-purge losses (cycling)
- Real-world losses
  - Fouling, blocked condensate, etc.

What Matters

- Specifier needs a tool for comparison
- Specifier needs to design a system for the boiler to perform as intended
- Contractor needs to install equipment per engineer's and manufacturer's instructions
- Owner needs to maintain equipment & system for the boiler to perform as intended

High Turndown Ratio

Advantages

- Limits thermal cycling
- Saves wear-and-tear on burner components
- Stabilizes loop temperature
- Increases efficiency for commonly oversized boiler plants
- Priced equally to standard 5:1 TDR boilers
- No different maintenance requirements than standard 5:1 TDR boilers

Disadvantages

- Increases components and complexity
- More sensitive to combustion tuning
- May affect dew point temperature of products of combustion (low-fire)

The Importance of Proper Combustion

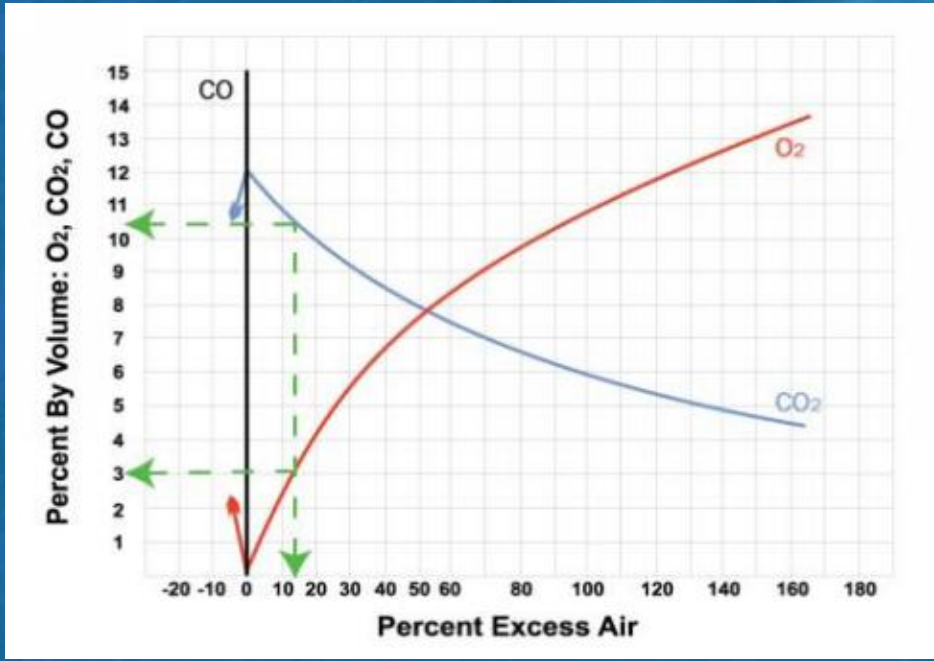
- Air = 21% O_2 & 79% N_2 (by volume)

$$CH_4 + 2\,(O_2 + 3.76\,N_2) \rightarrow CO_2 + 2\,H_2O + 7.52\,N_2$$

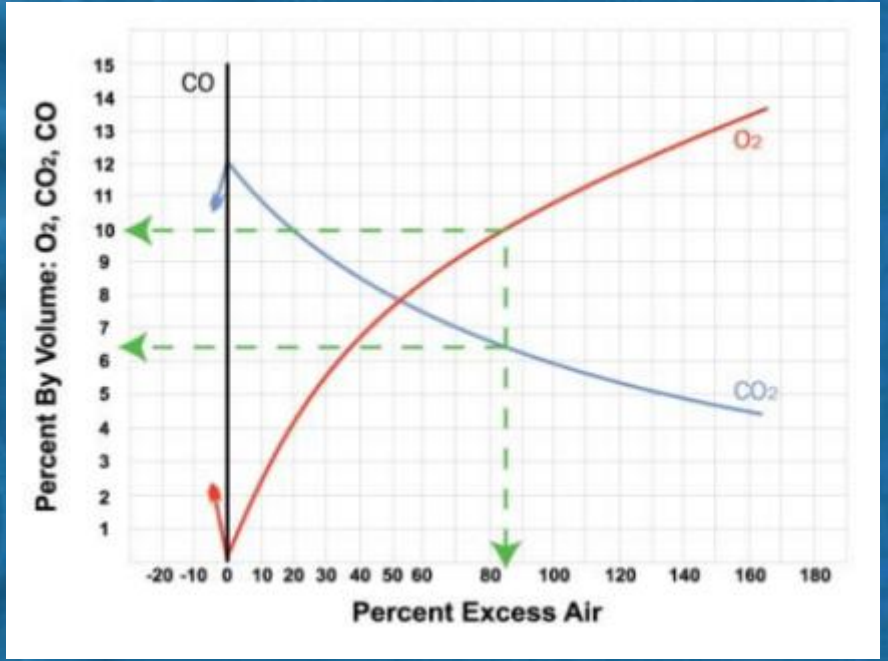
- 1 ft^3 methane (natural gas) burns completely with 9.52 ft^3 air (stoichiometric ratio)
- 2-3% excess O_2 (10-15% excess air is desirable)

Combustion Comparison

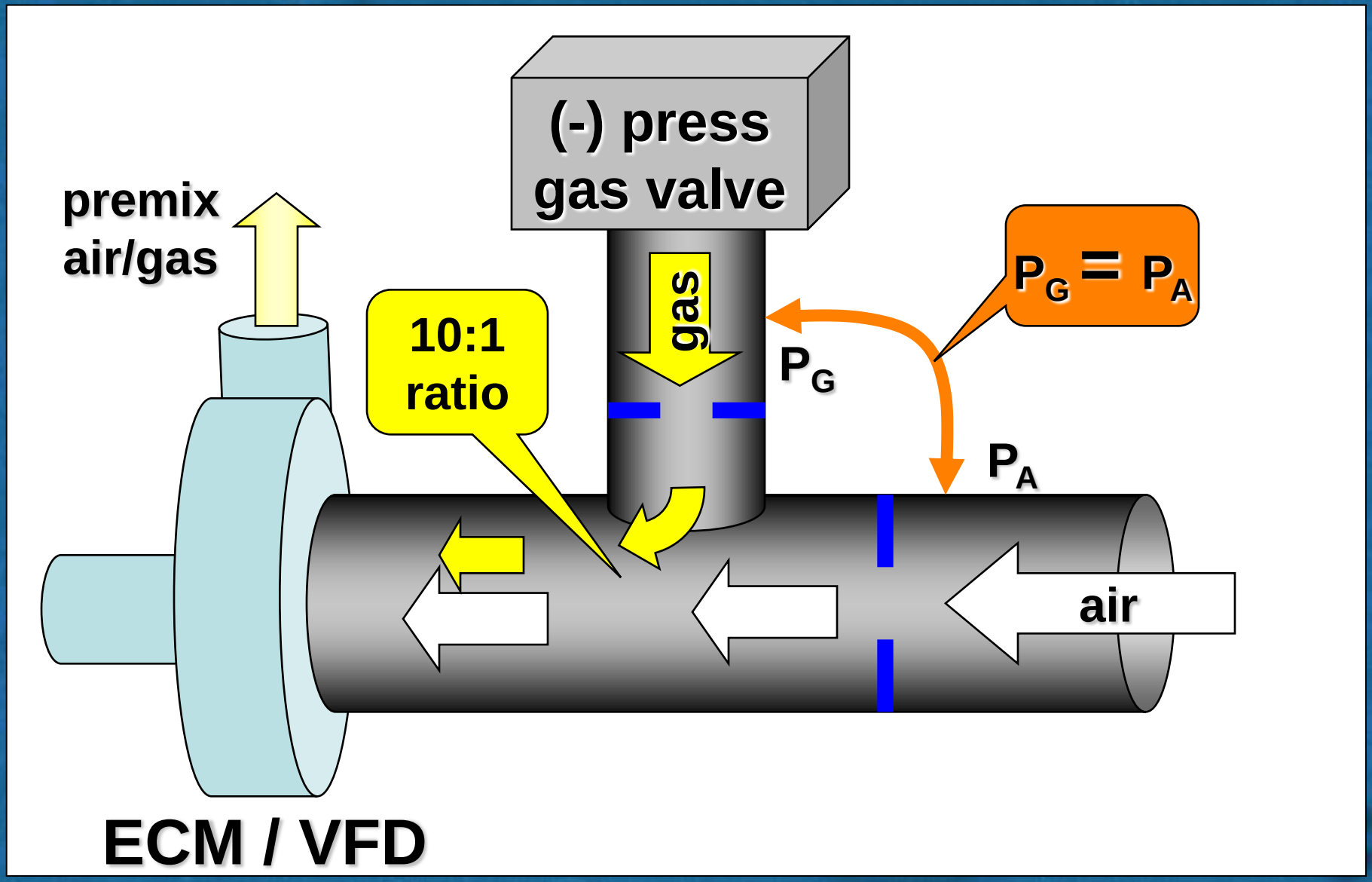
Ideal Combustion



Poor Combustion



Air-Fuel Coupled

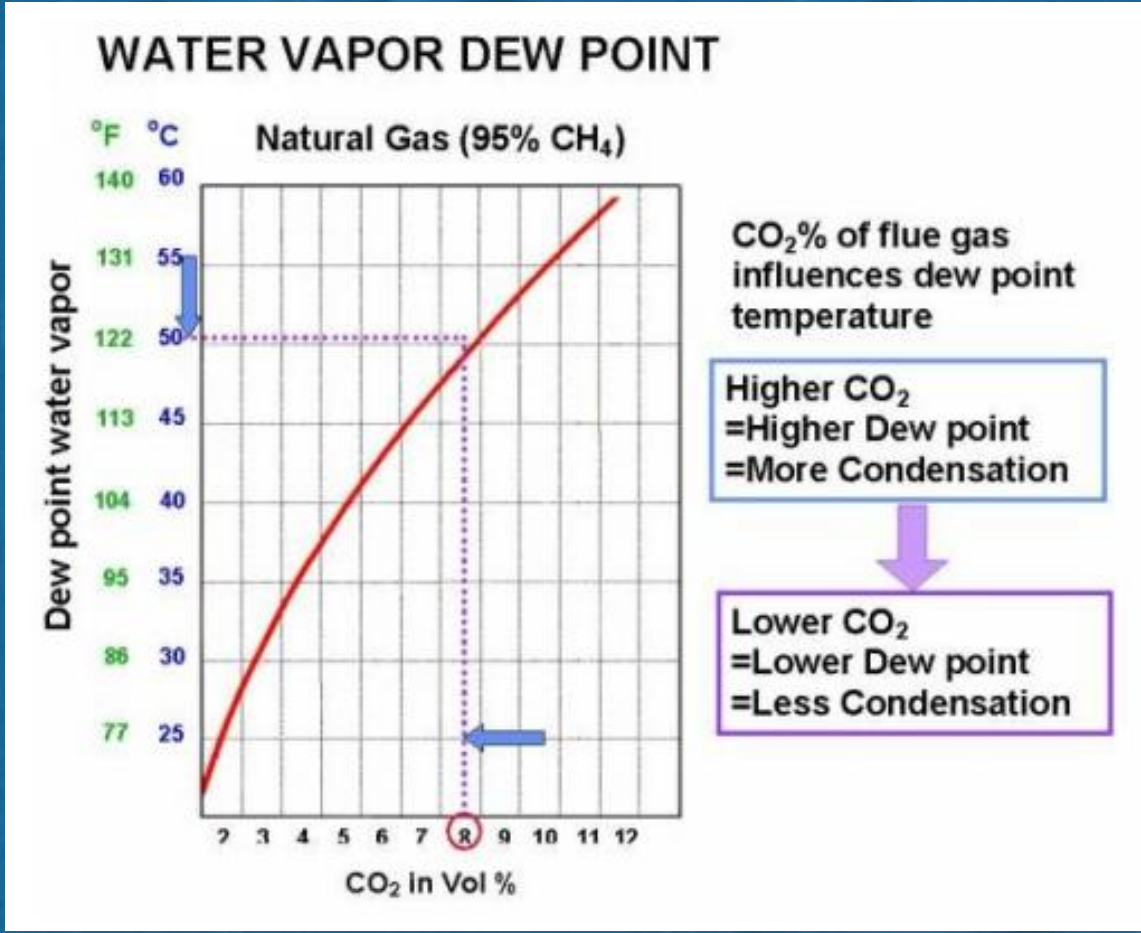


Problems with Unbalanced Excess Air

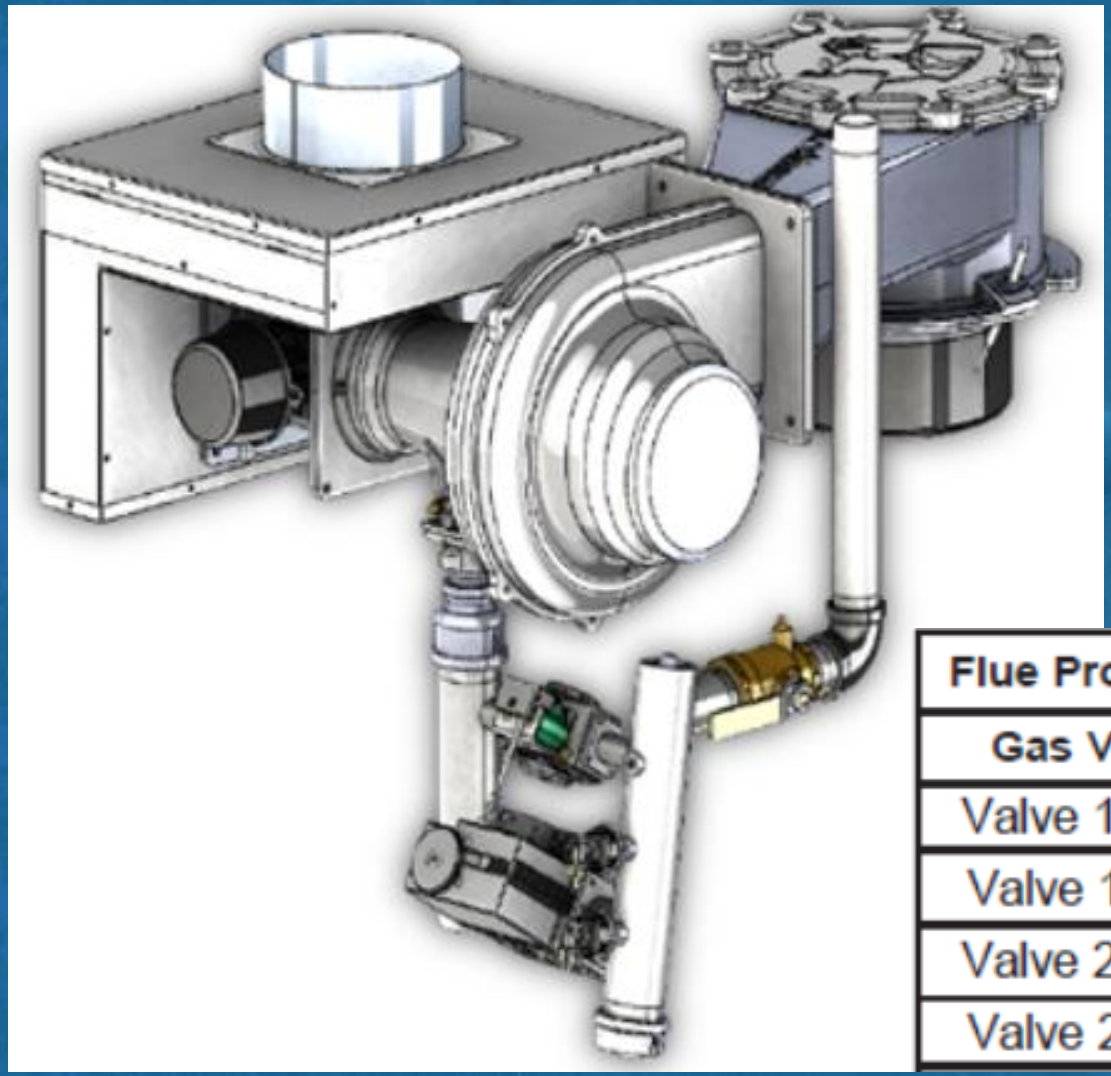
- Smoky exhaust
- Yellow flame
- Flame / ignition failures
- Sooty boiler HX surface
- More CO and/or NO_x production
- Rumbling noise
- Dilutes flue gas → lowering its heat transfer temperature → increases sensible flue gas loss → decreases combustion efficiency
- Reduction in CO_2 will affect the dew point of the water vapor in the products of combustion

Dew Point Shift

- The efficiency gains from higher turndown can be trumped by a dew point shift



Controlling Excess Air



Flue Products	Natural Gas	
Gas Valve	CO_2 (%)	O_2 (%)
Valve 1 High	9.2	4.6
Valve 1 Low	9.0	4.9
Valve 2 High	9.3	4.4
Valve 2 Low	8.7	5.5

Combustion with Fan Assist

Natural Gas

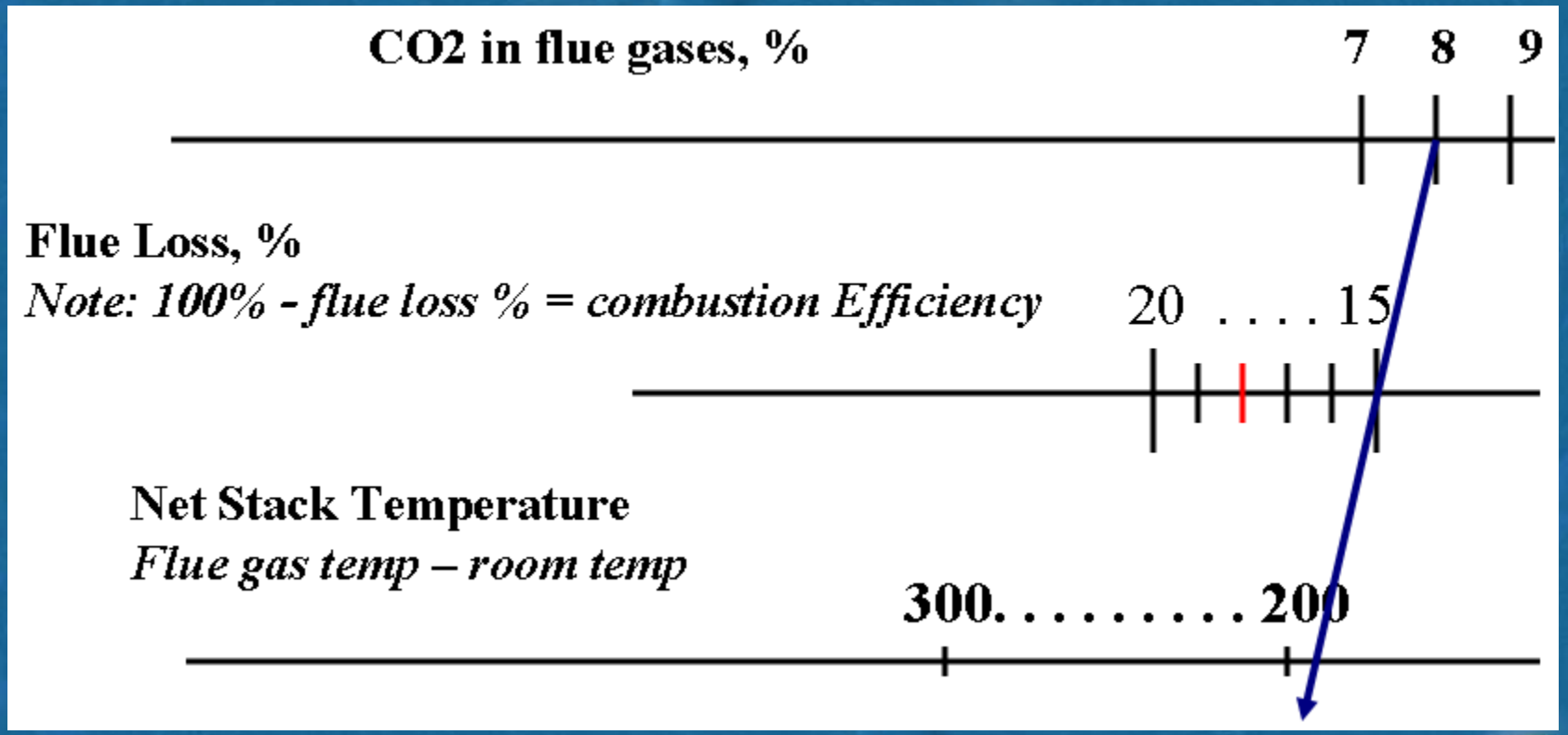
- Combustion Efficiency Control

Combustion Efficiency for Natural Gas						
Excess %		Combustion Efficiency				
		Flue gas temperature less combustion air temp, °F				
Air	Oxygen	200	300	400	500	600
9.5	2.0	85.4	83.1	80.8	78.4	76.0
15.0	3.0	85.2	82.8	80.4	77.9	75.4
28.1	5.0	84.7	82.1	79.5	76.7	74.0
44.9	7.0	84.1	81.2	78.2	75.2	72.1
81.6	10.0	82.8	79.3	75.6	71.9	68.2

Excess air changes with temperature and barometric pressure

Effects of Excess Air

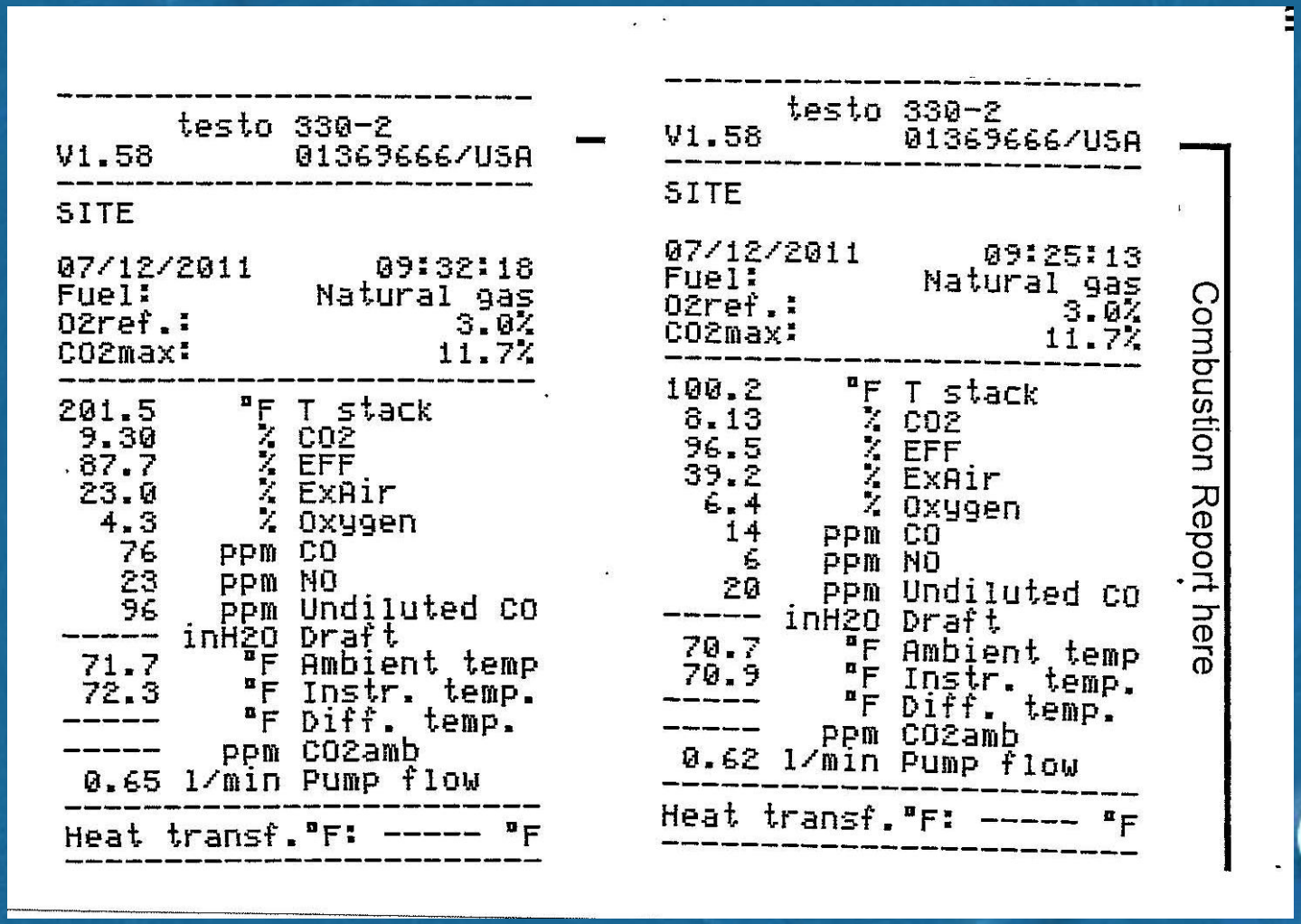
AGA Nomograph



Boiler Start-Up & Tuning

- Factory Authorized Company
- Accurate Flue-Gas Analyzer
- Simple Adjustment for CO_2 Control
  - High & low-fire
- Combustion Report Printout

Test Reports



testo 330-2
V1.58 01369666/USA

SITE

07/12/2011 09:32:18
Fuel: Natural gas
O2ref.: 3.0%
CO2max: 11.7%

201.5	°F	T stack
9.30	%	CO2
87.7	%	EFF
23.0	%	ExAir
4.3	%	Oxygen
76	ppm	CO
23	ppm	NO
96	ppm	Undiluted CO
-----	inH2O	Draft
71.7	°F	Ambient temp
72.3	°F	Instr. temp.
-----	°F	Diff. temp.
-----	ppm	CO2amb
0.65	l/min	Pump flow

Heat transf.°F: ----- °F

testo 330-2
V1.58 01369666/USA

SITE

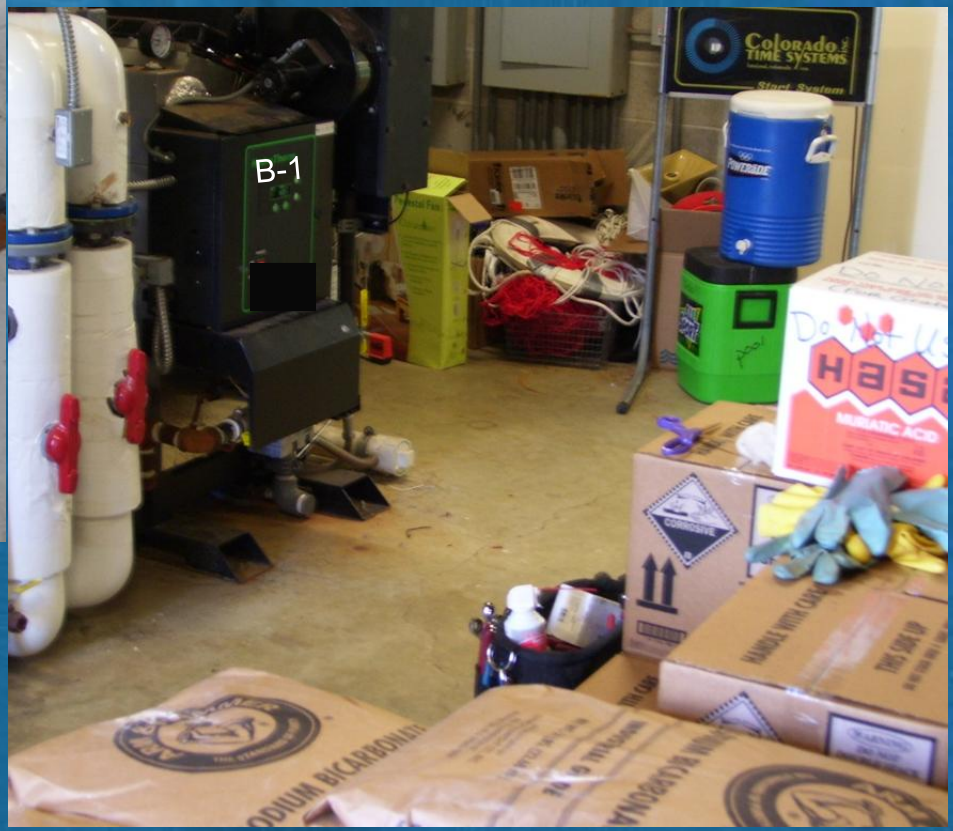
07/12/2011 09:25:13
Fuel: Natural gas
O2ref.: 3.0%
CO2max: 11.7%

100.2	°F	T stack
8.13	%	CO2
96.5	%	EFF
39.2	%	ExAir
6.4	%	Oxygen
14	ppm	CO
6	ppm	NO
20	ppm	Undiluted CO
-----	inH2O	Draft
70.7	°F	Ambient temp
70.9	°F	Instr. temp.
-----	°F	Diff. temp.
-----	ppm	CO2amb
0.62	l/min	Pump flow

Heat transf.°F: ----- °F

Combustion Report here

Heat Exchanger Surface (Air Side)



Heat Exchanger Surface (Air Side)

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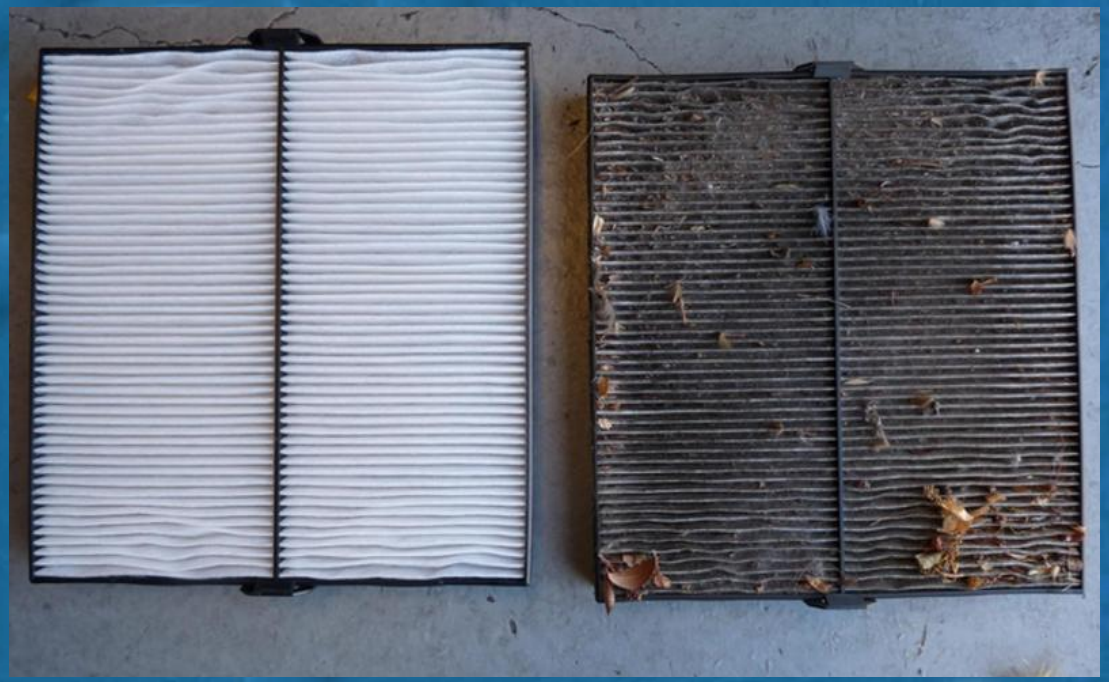
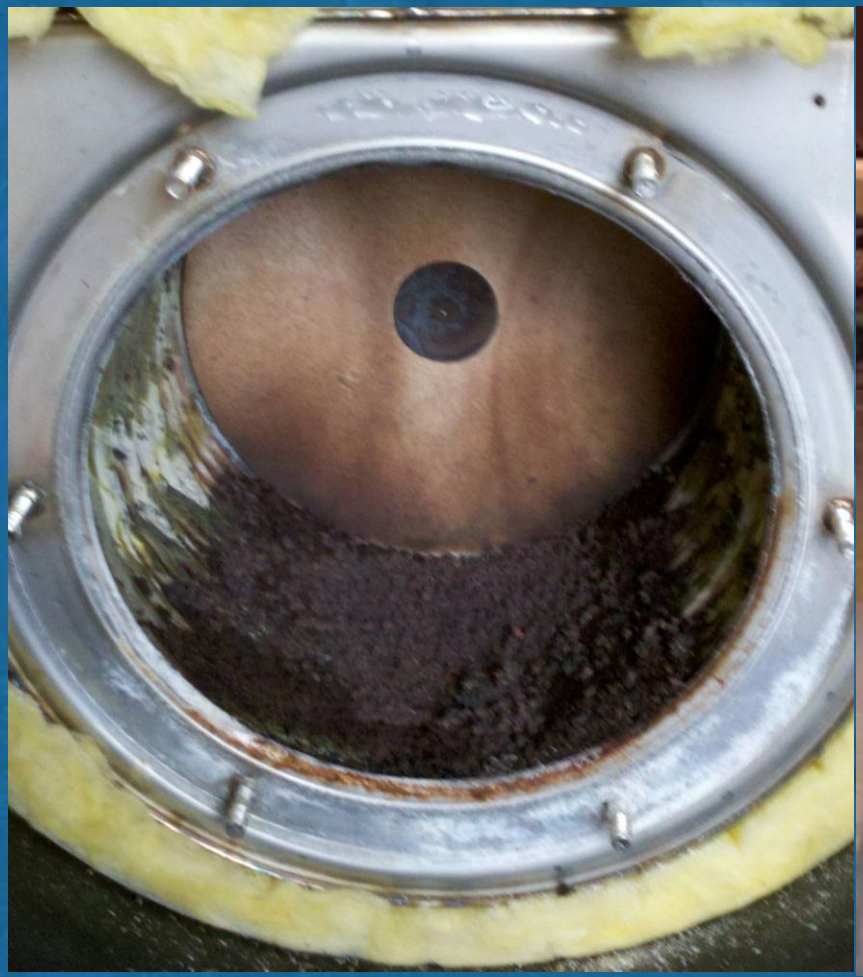


Heat Exchanger Surface (Air Side)



What You Can Do

- Ensure your RWT is cold enough to condense
- Follow manufacturer's guidelines for checking combustion & maintenance
  - Use a good analyzer
  - Ensure tech is familiar with equipment
- Clean boiler's air filter & burner
- Change out condensate neutralizer chips
- Use chemical-free combustion air
- Follow manufacturer's venting guidelines

The System "Pressure Band"

P_2 Upper pressure limit

Relief valve setting

Allowable Pressure Range

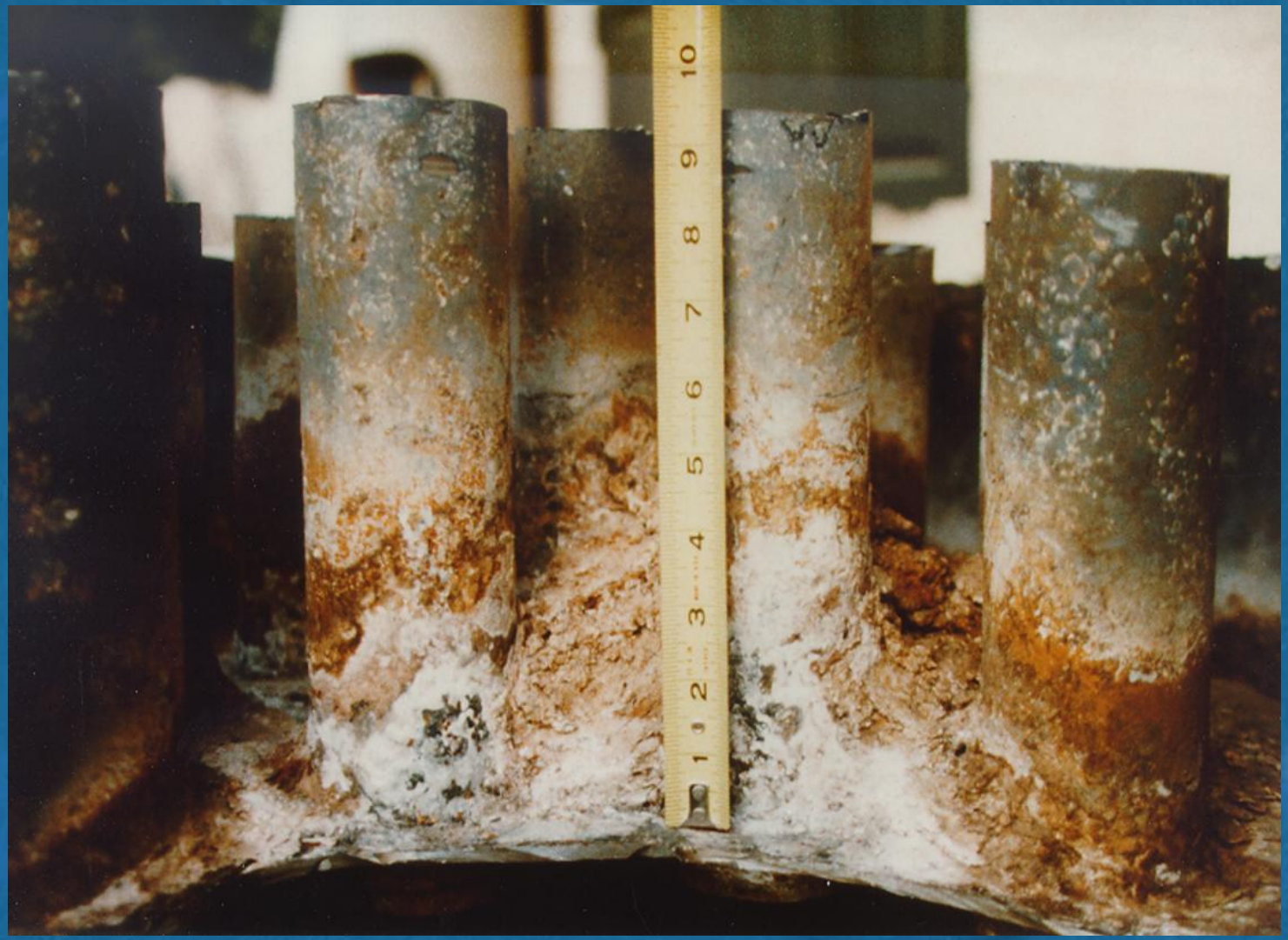
P_1 Lower pressure limit

Fill pressure setting

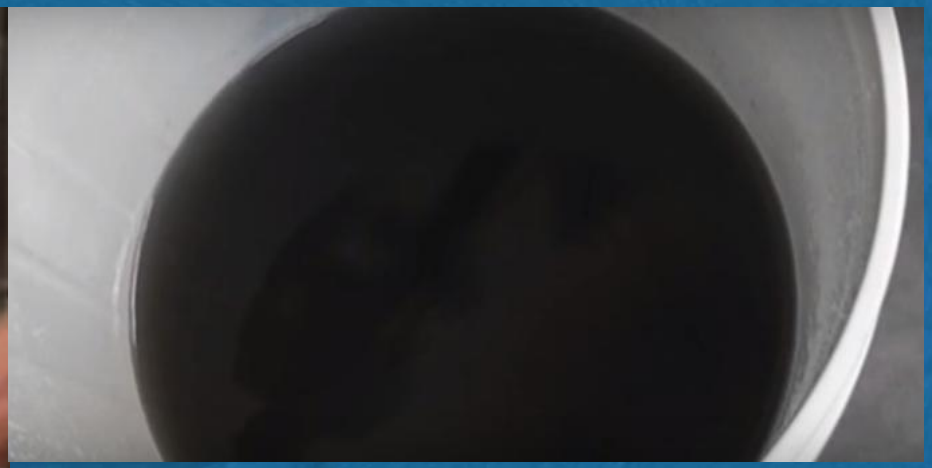
Excessive Makeup Water

- Causes:
  - Is the expansion tank undersized?
  - Where is the expansion tank relative to the pump? Boiler relative to pump?
  - What's the expansion tank's air charge?
  - Is there a leak in the system?
  - Is the fill valve isolated?
  - What's the boiler's relief valve set point?

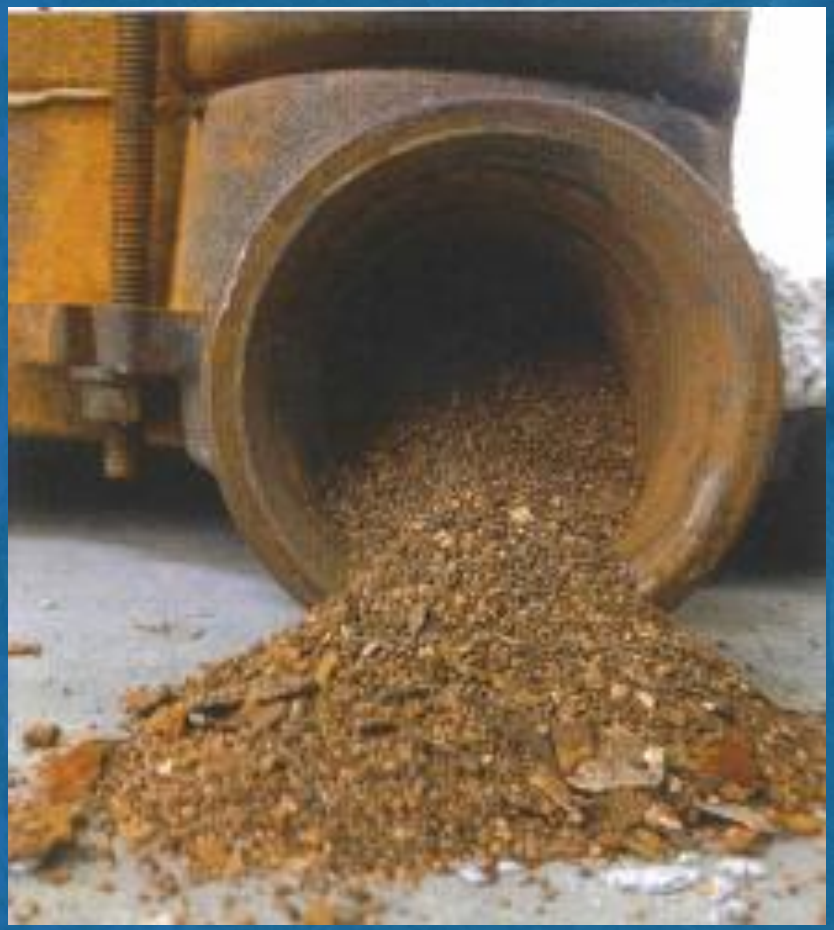
Heat Exchanger Surface (Wet Side)



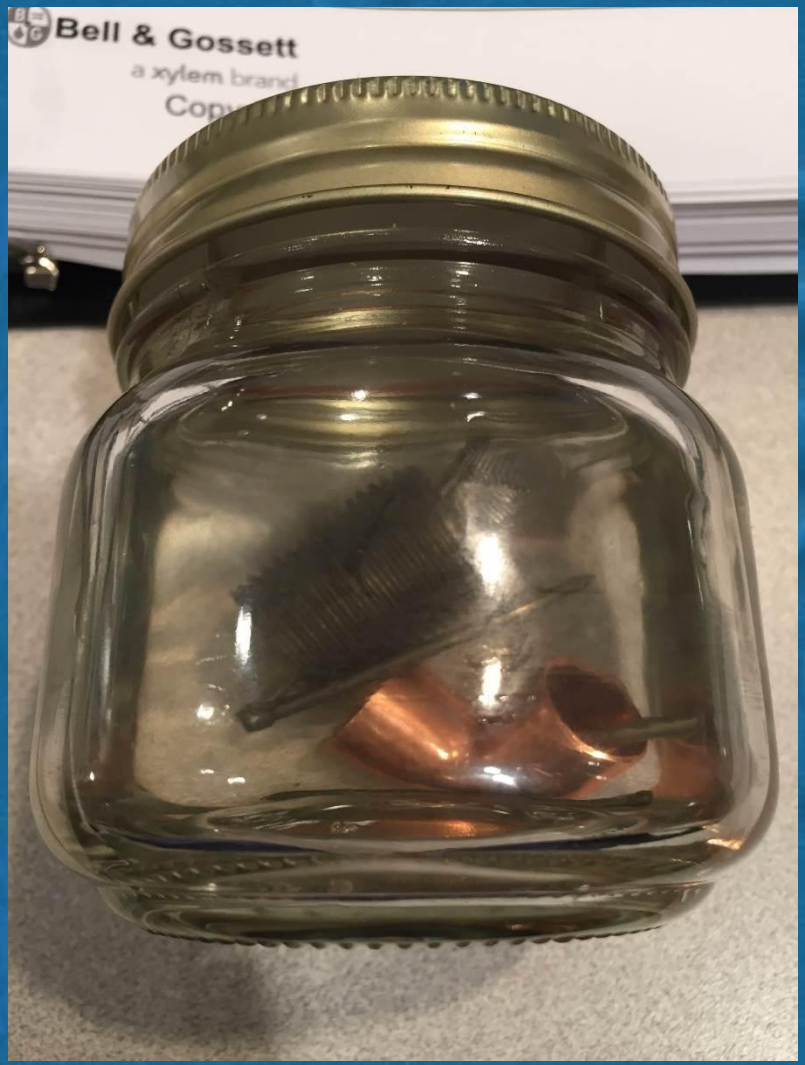
Magnetite

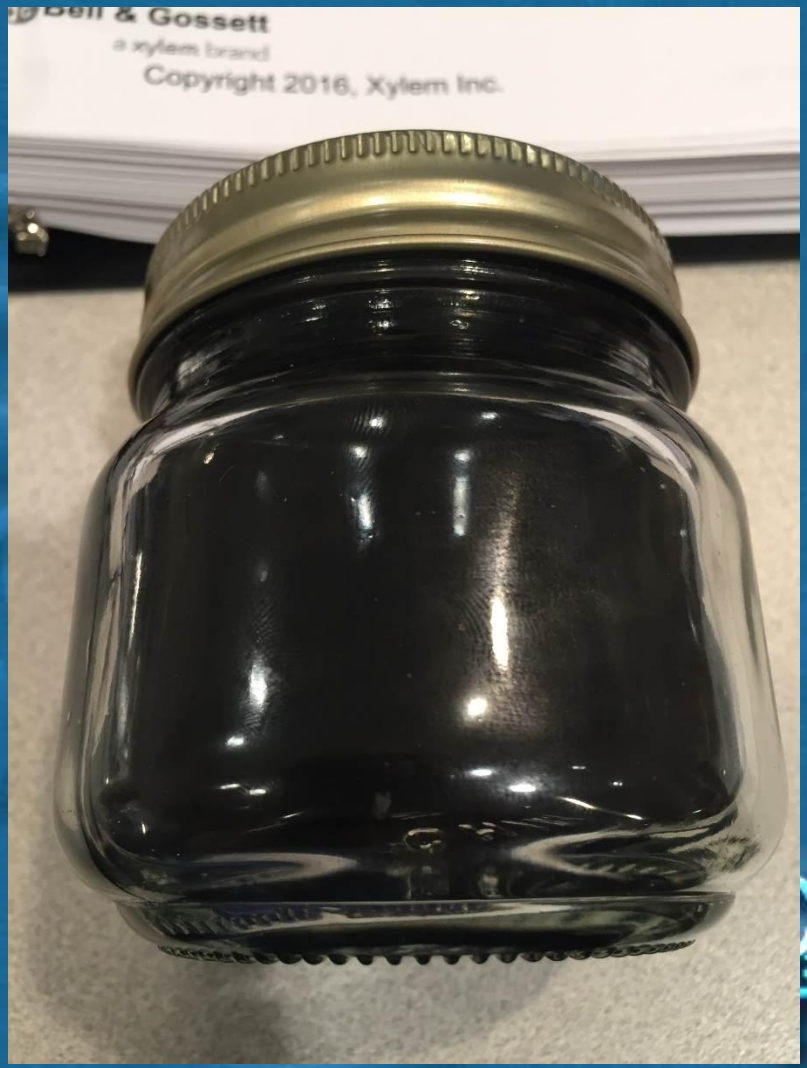


Heat Exchanger Surface (Wet Side)



Heat Exchanger Surface (Wet Side)





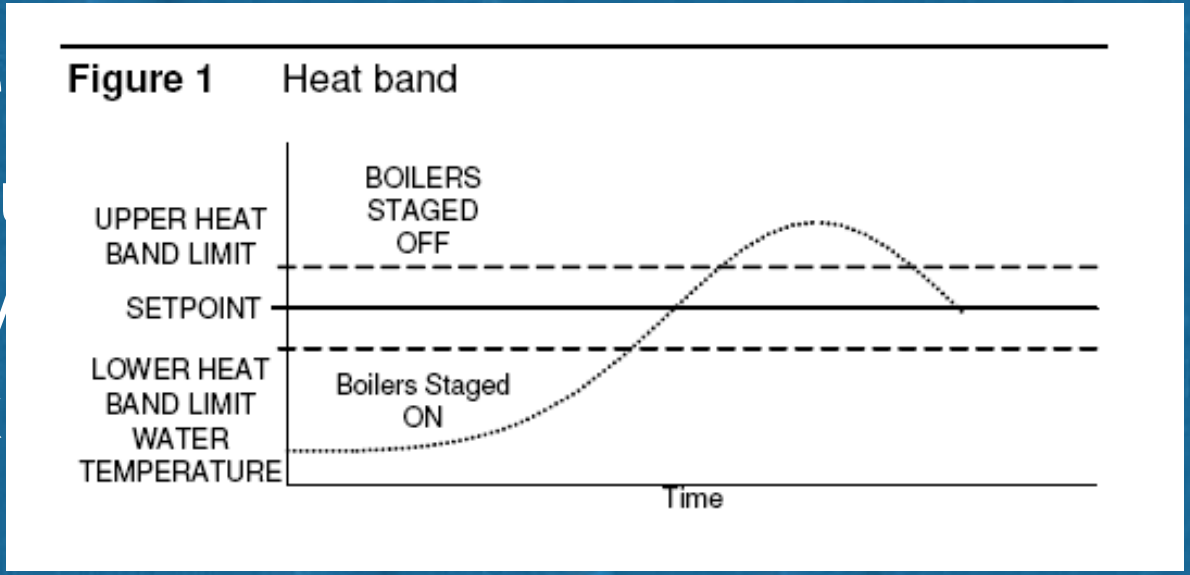
ECM Circulators

What You Can Do

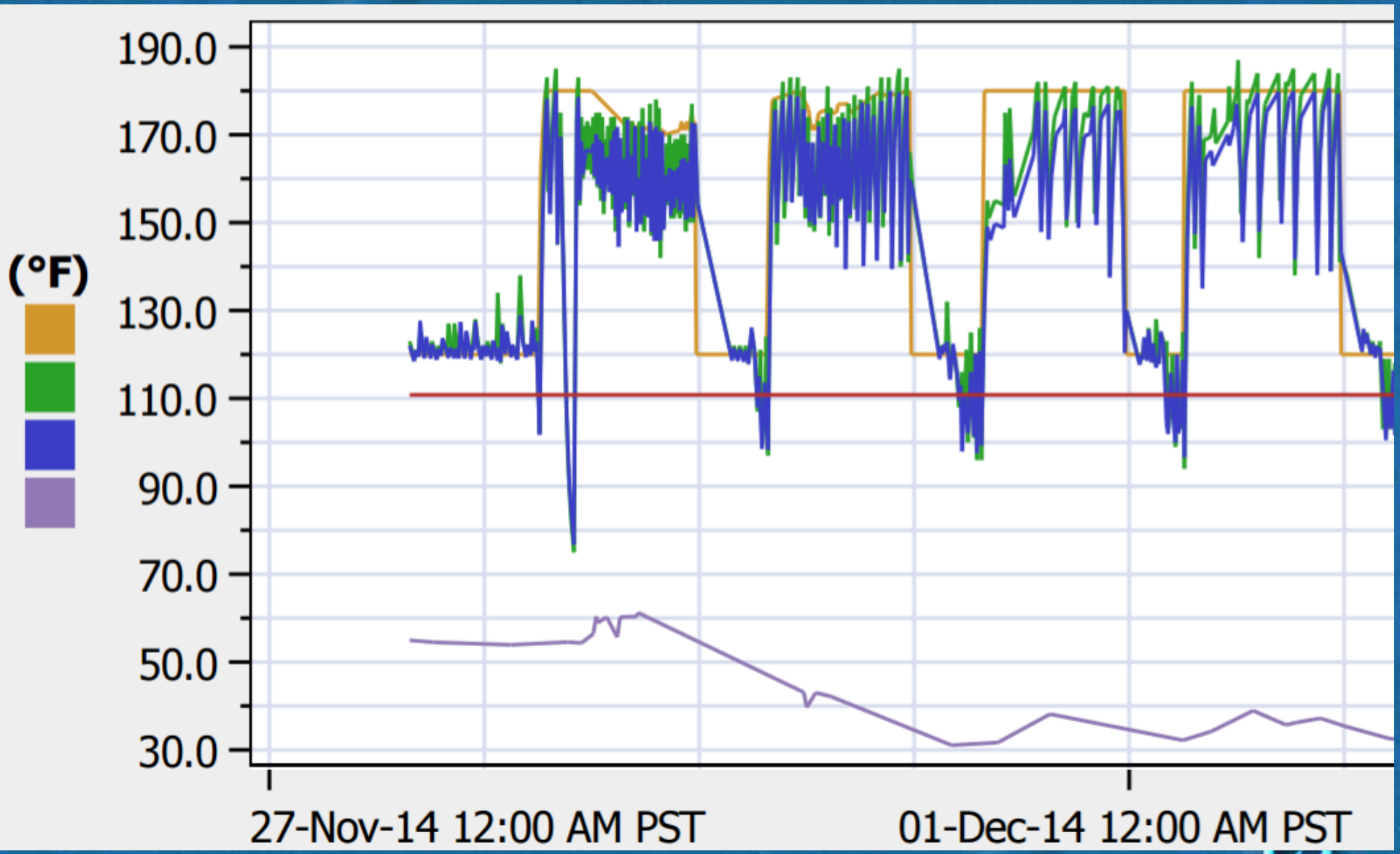
- Follow manufacturer's guidelines for draining & flushing heat exchanger
- Maintain water chemistry
- Air / dirt separators
- Strainers or bag filters
- Magnetic separation
- Clean and / or blowdown your filtration devices!

Effects of Proper Controls

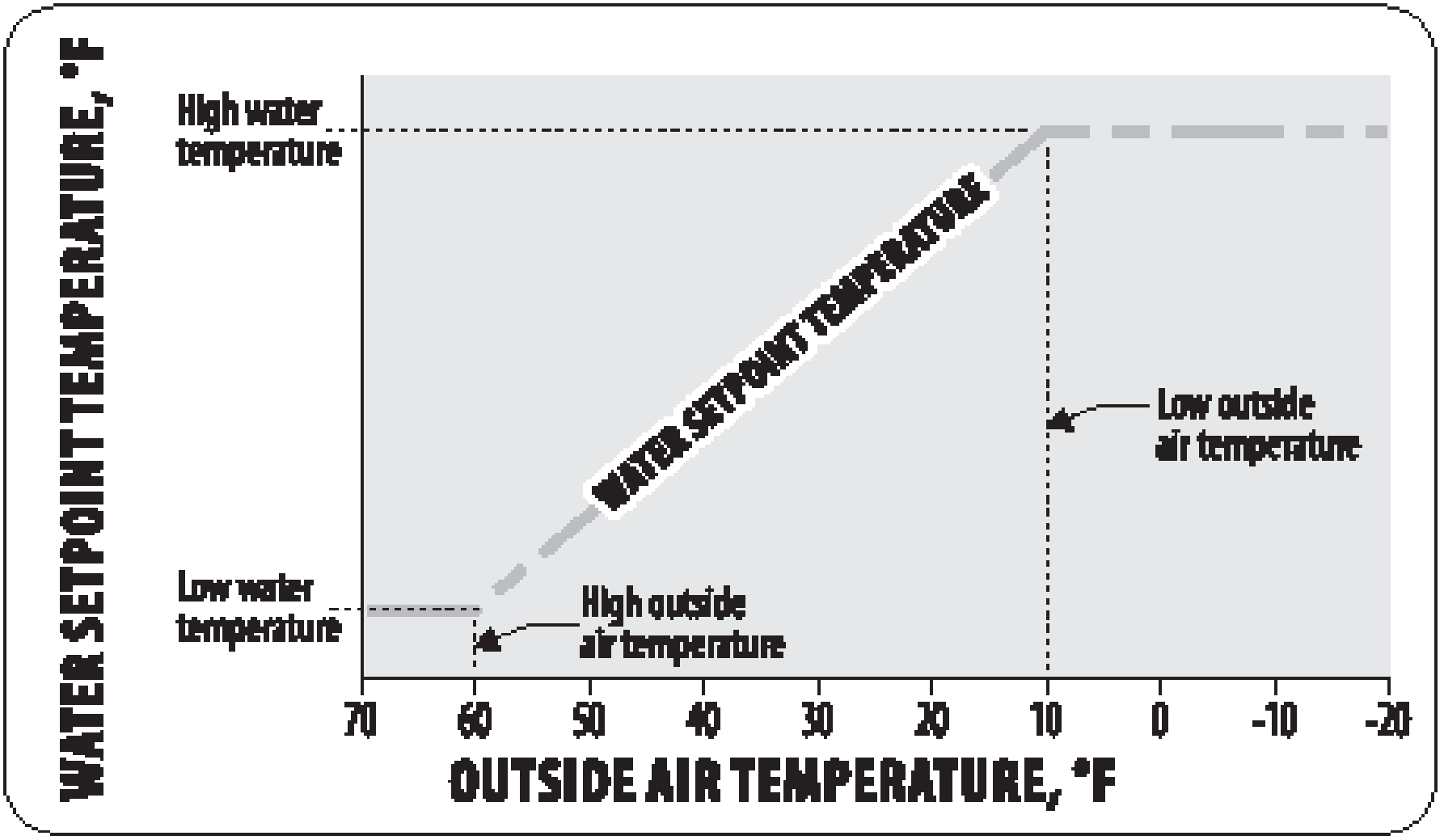
- Prope
  - Redu
  - Prov
  - Max



- Most useful control settings
  - Boiler bandwidth
  - Delay timers
  - Modulation clamp
  - Staging


(°F)
190.0
170.0
150.0
130.0
110.0
90.0
70.0
50.0
30.0
27-Nov-14 12:00 AM PST
01-Dec-14 12:00 AM PST

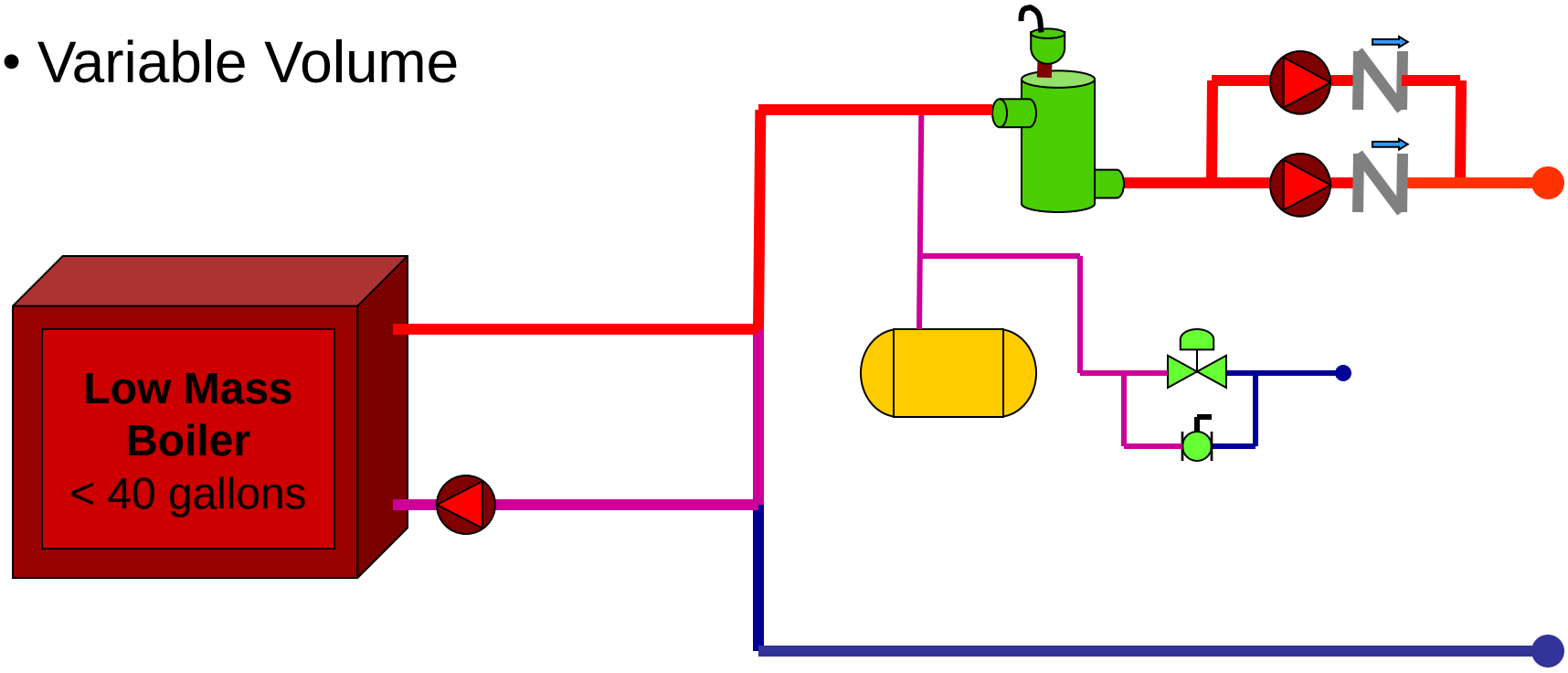
Outdoor Reset



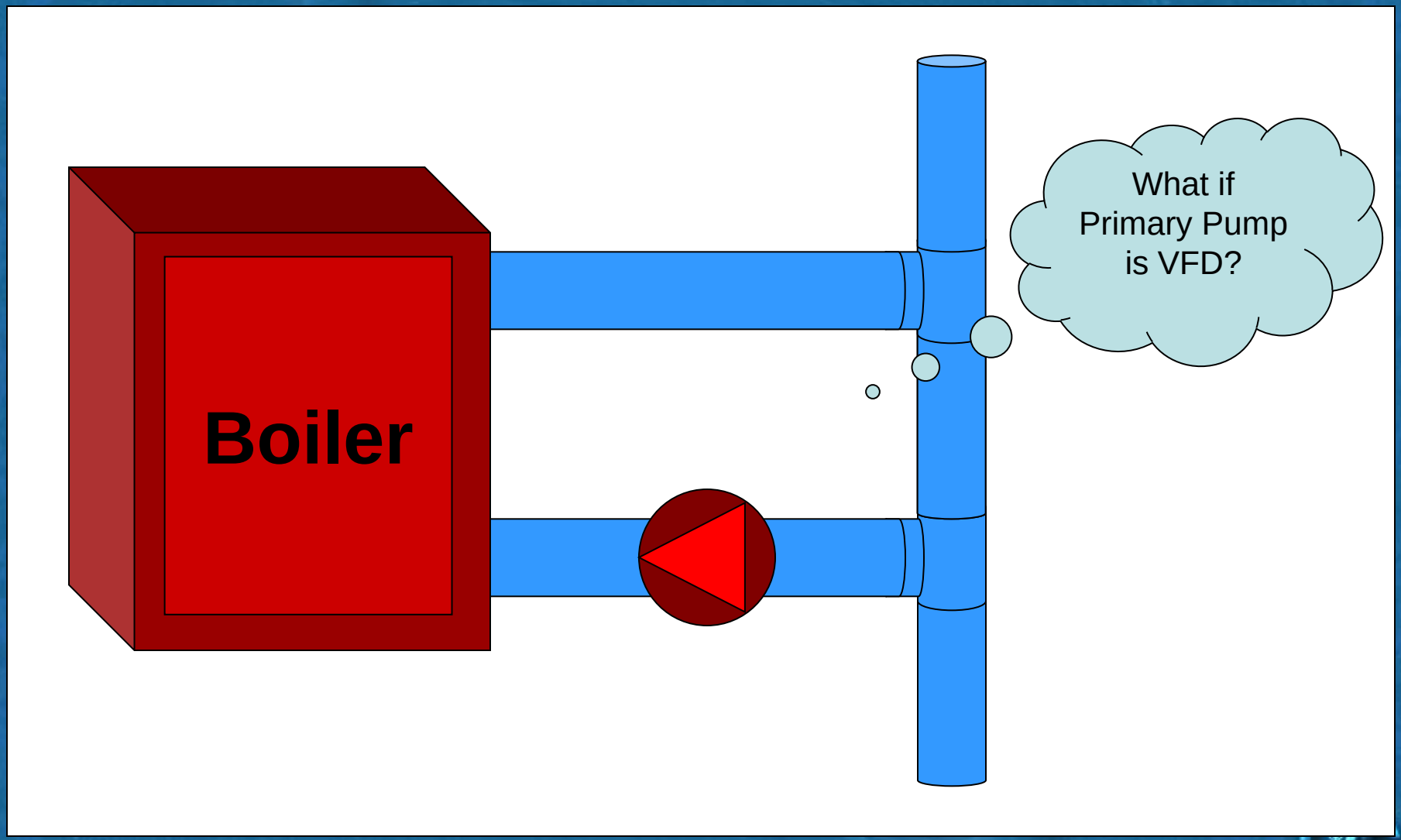
Low Mass Boiler

Primary / Secondary System

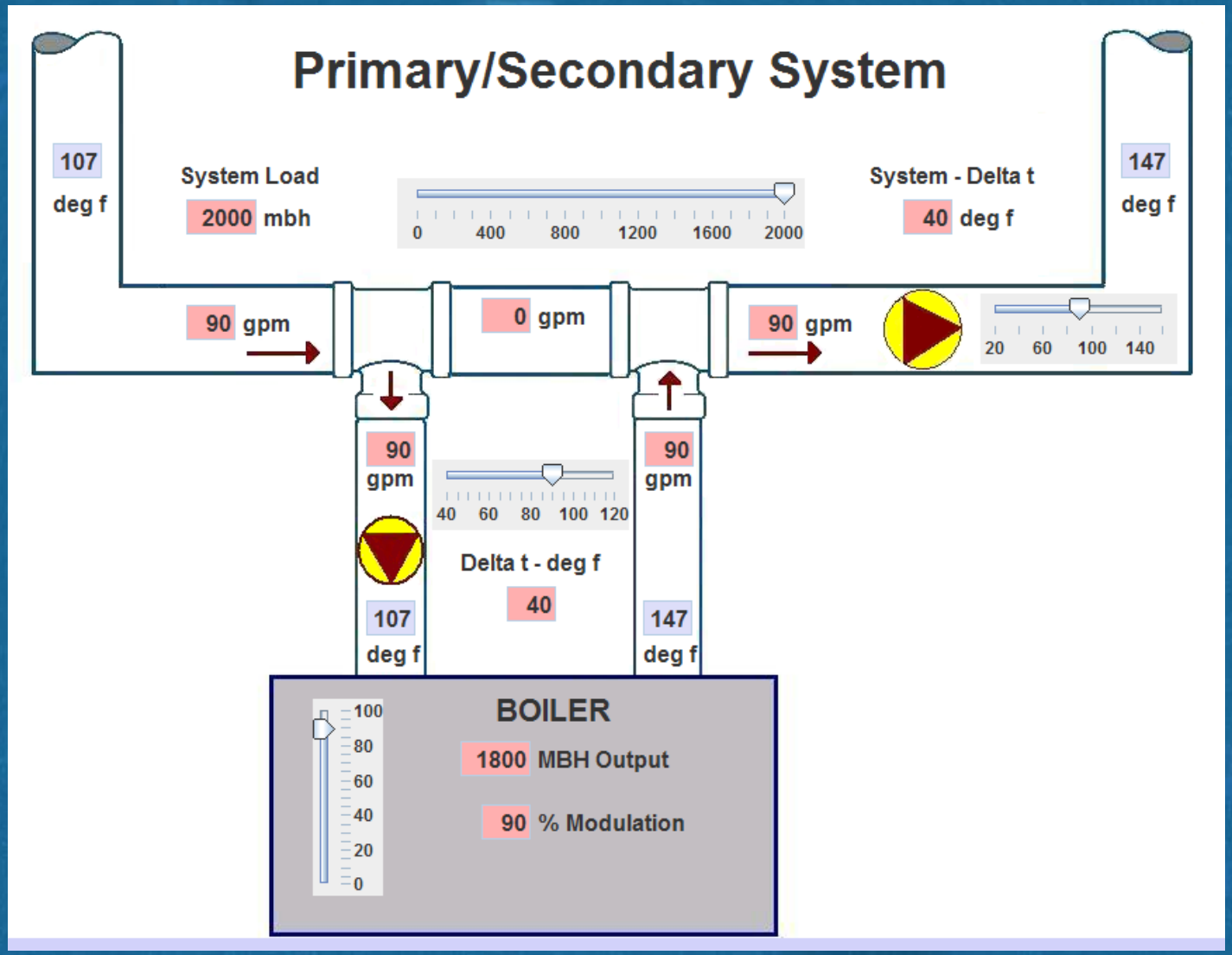
- Constant Volume
- Variable Volume



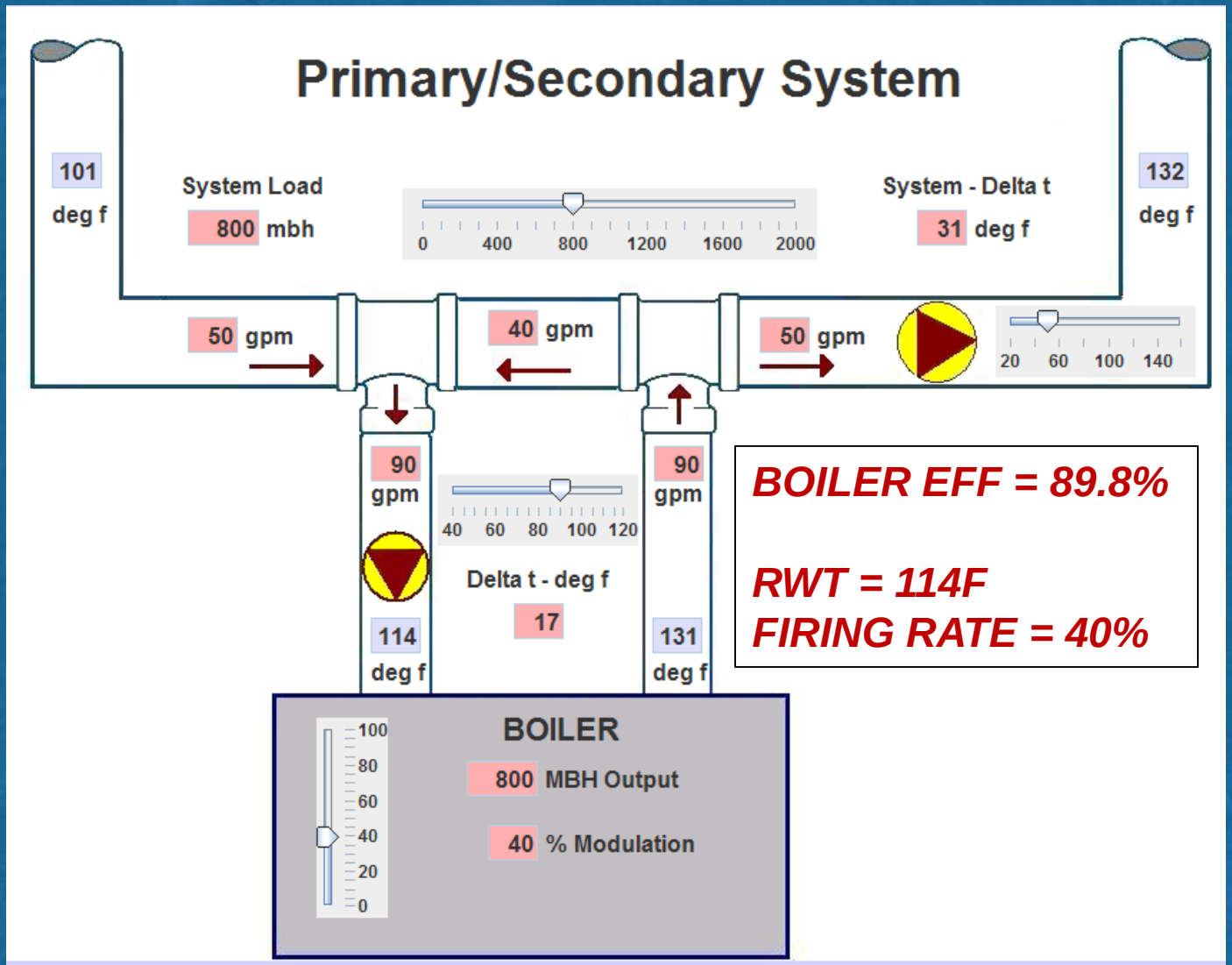
Primary Loop



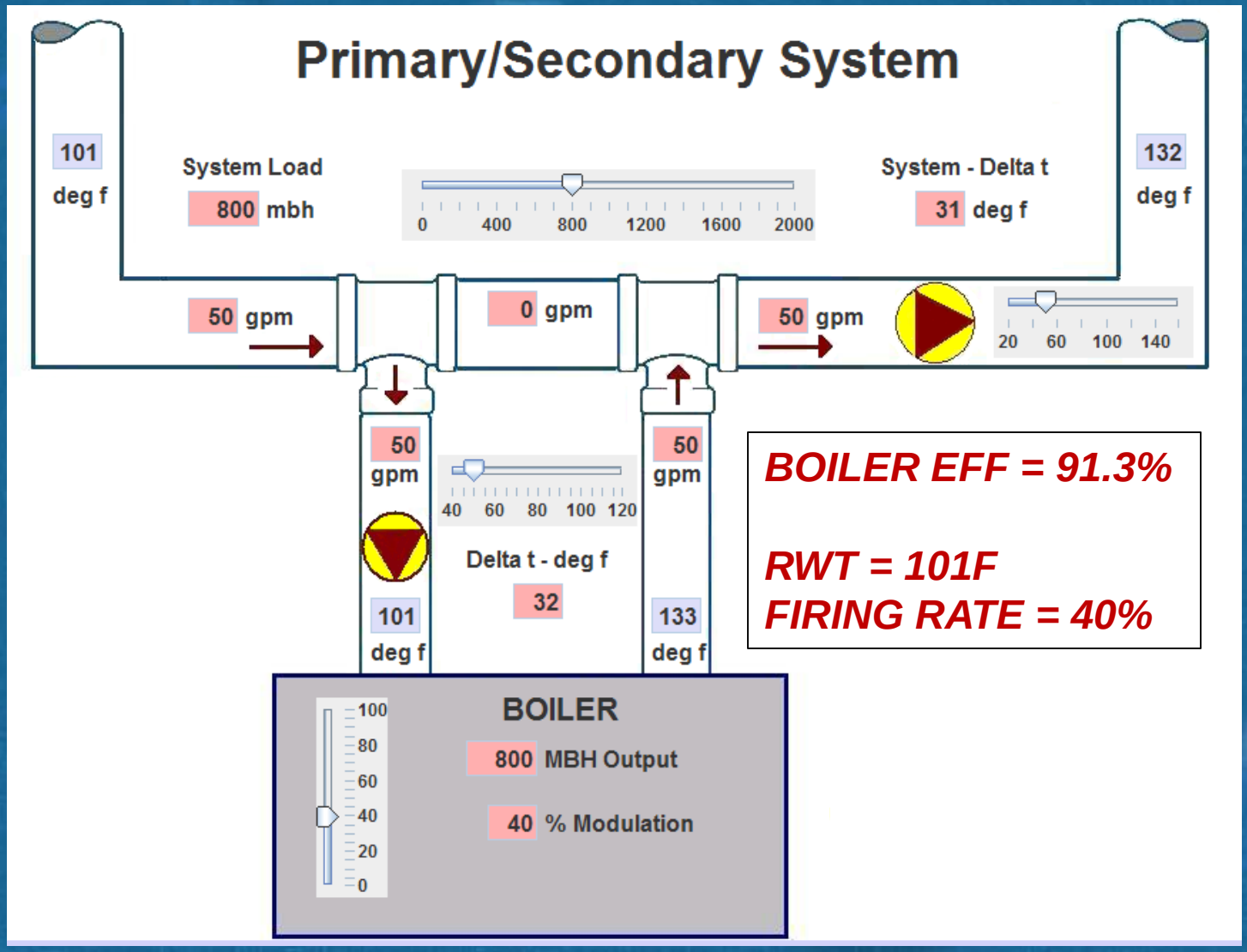
Constant Speed Primary Pump

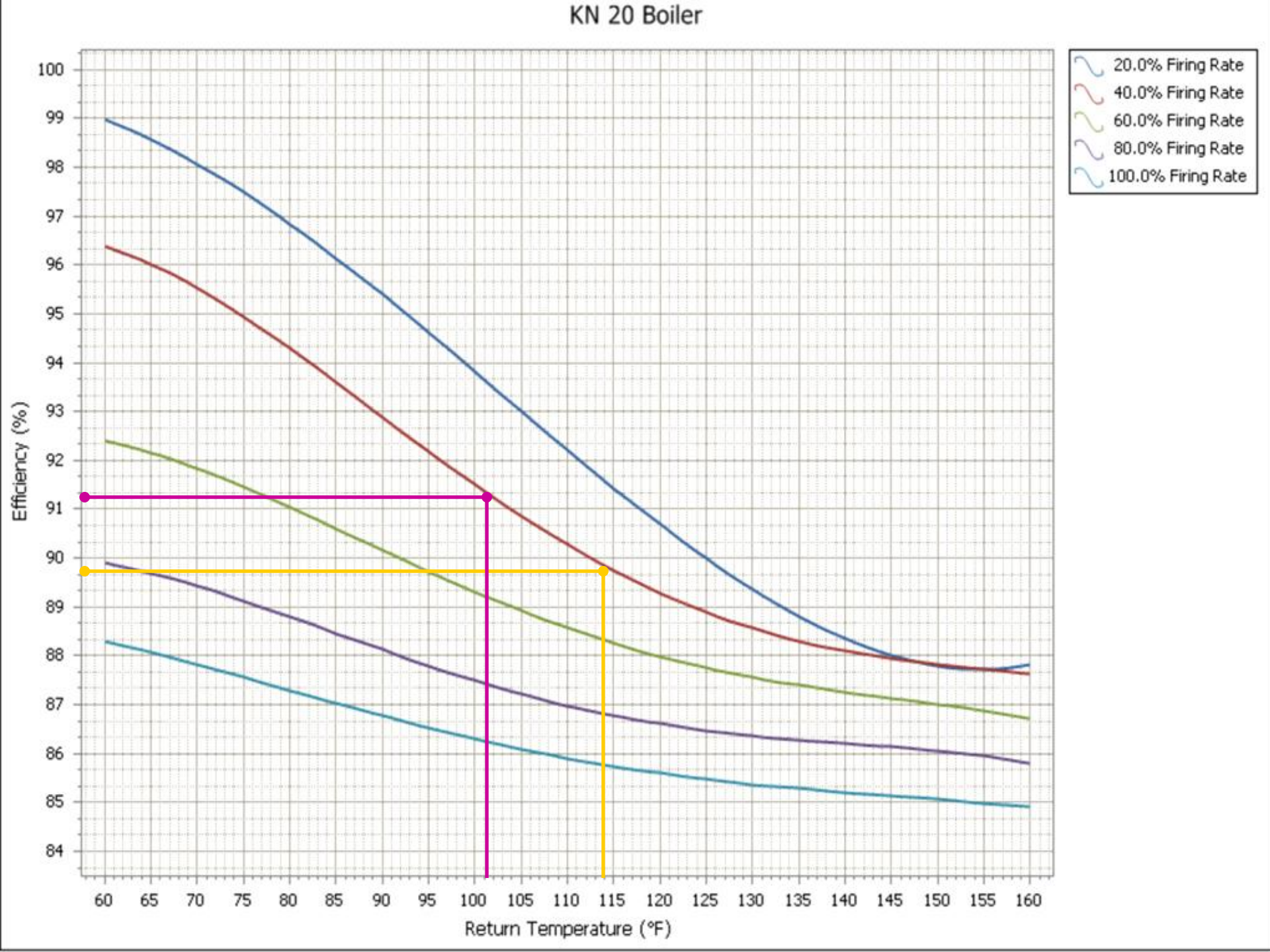


Constant Speed Primary Pump



Variable Speed Primary Pump




KN 20 Boiler
20.0% Firing Rate
40.0% Firing Rate
60.0% Firing Rate
80.0% Firing Rate
100.0% Firing Rate
Efficiency (%)
100
99
98
97
96
95
94
93
92
91
90
89
88
87
86
85
84
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
Return Temperature (°F)

Thermal Storage

Buffer Tank Sizing

V = Buffer tank volume (gal)
T = Boiler runtime (min)
Q hs = Minimum heat output rate of boiler (BTU/hr)
Q load = Minimum expected load (BTU/hr)
ΔT = Boiler temperature bandwidth (°F)

Input	Volume	Min Flow	Max Flow
1500	94 Gallons	25gpm	350gpm
2000	111 Gallons	25gpm	350gpm
2500	161 Gallons	25gpm	350gpm
3000	181 Gallons	25gpm	350gpm
3500	215 Gallons	45gpm	350gpm
4000	382 Gallons	45gpm	350gpm
5000	483 Gallons	50gpm	350gpm

$$V = \frac{T \times (Q_{hs} - Q_{load})}{\Delta T \times 500}$$

$$111 = \frac{T \times (80{,}000 - 40{,}000)}{(140 - 120) \times 500}$$

T = 27.8 min.

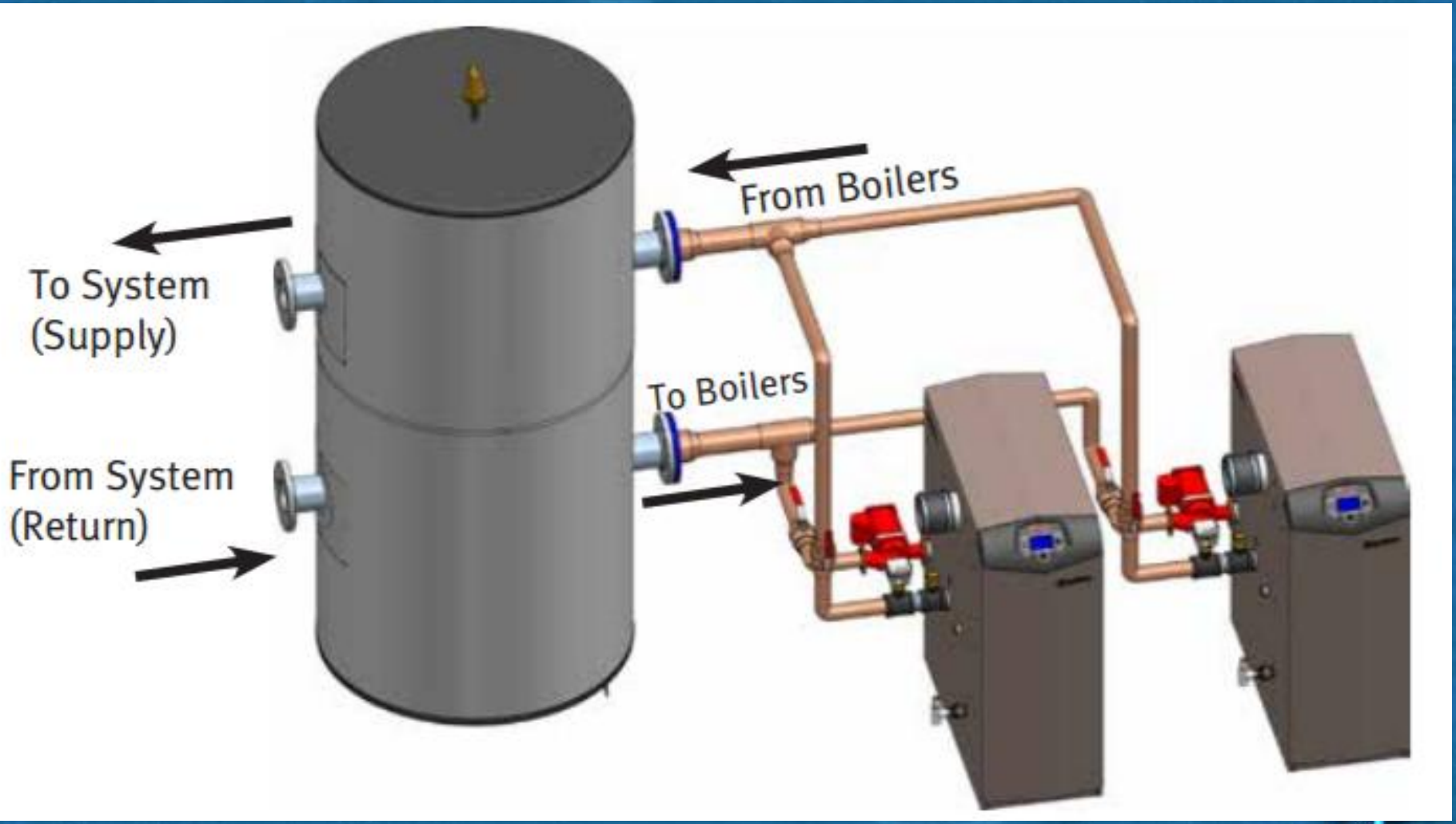
$$11 = \frac{T \times (80{,}000 - 40{,}000)}{(140 - 120) \times 500}$$

T = 2.8 min.

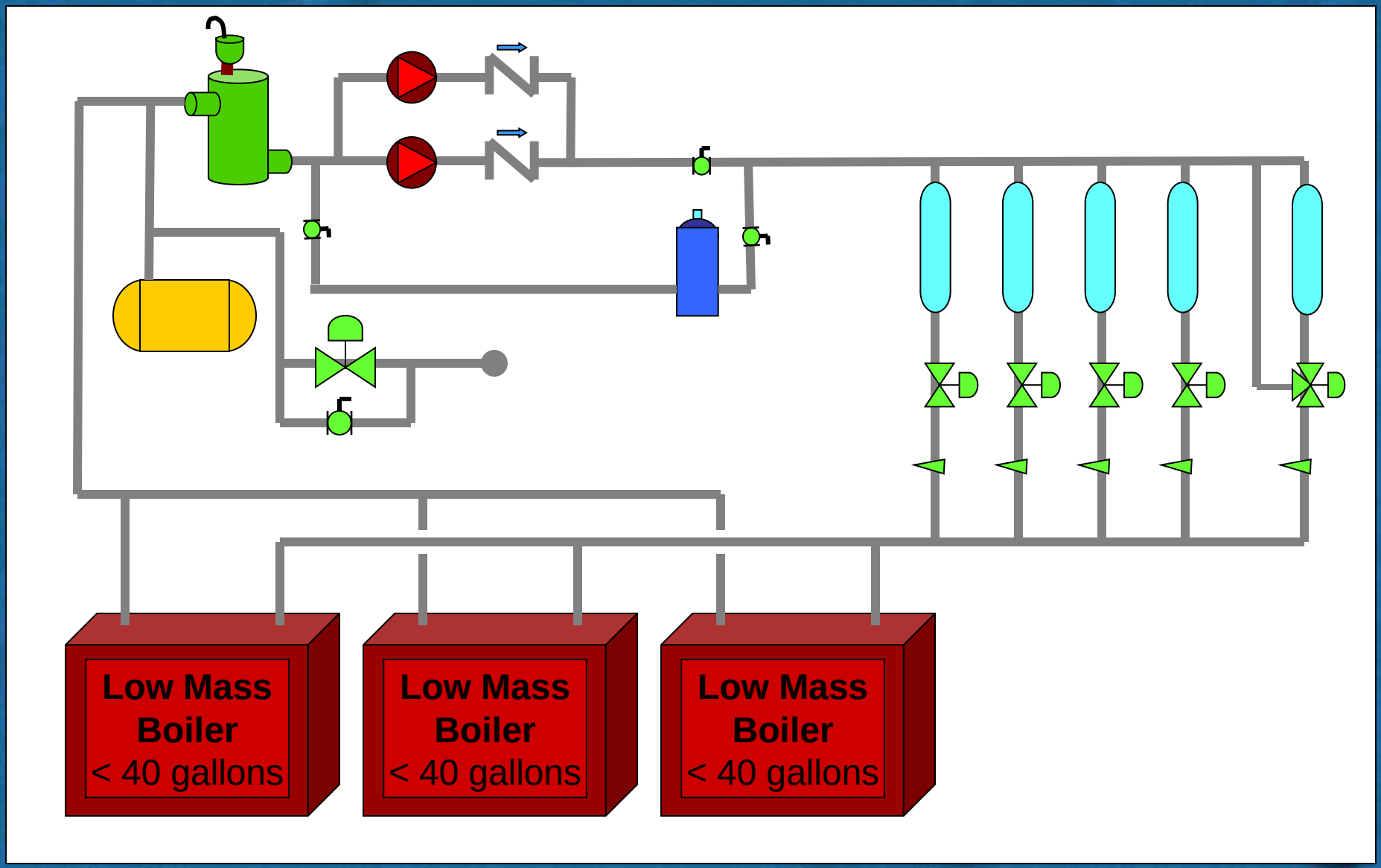
$$111 = \frac{T \times (120{,}000 - 40{,}000)}{(140 - 120) \times 500}$$

T = 13.9 min.

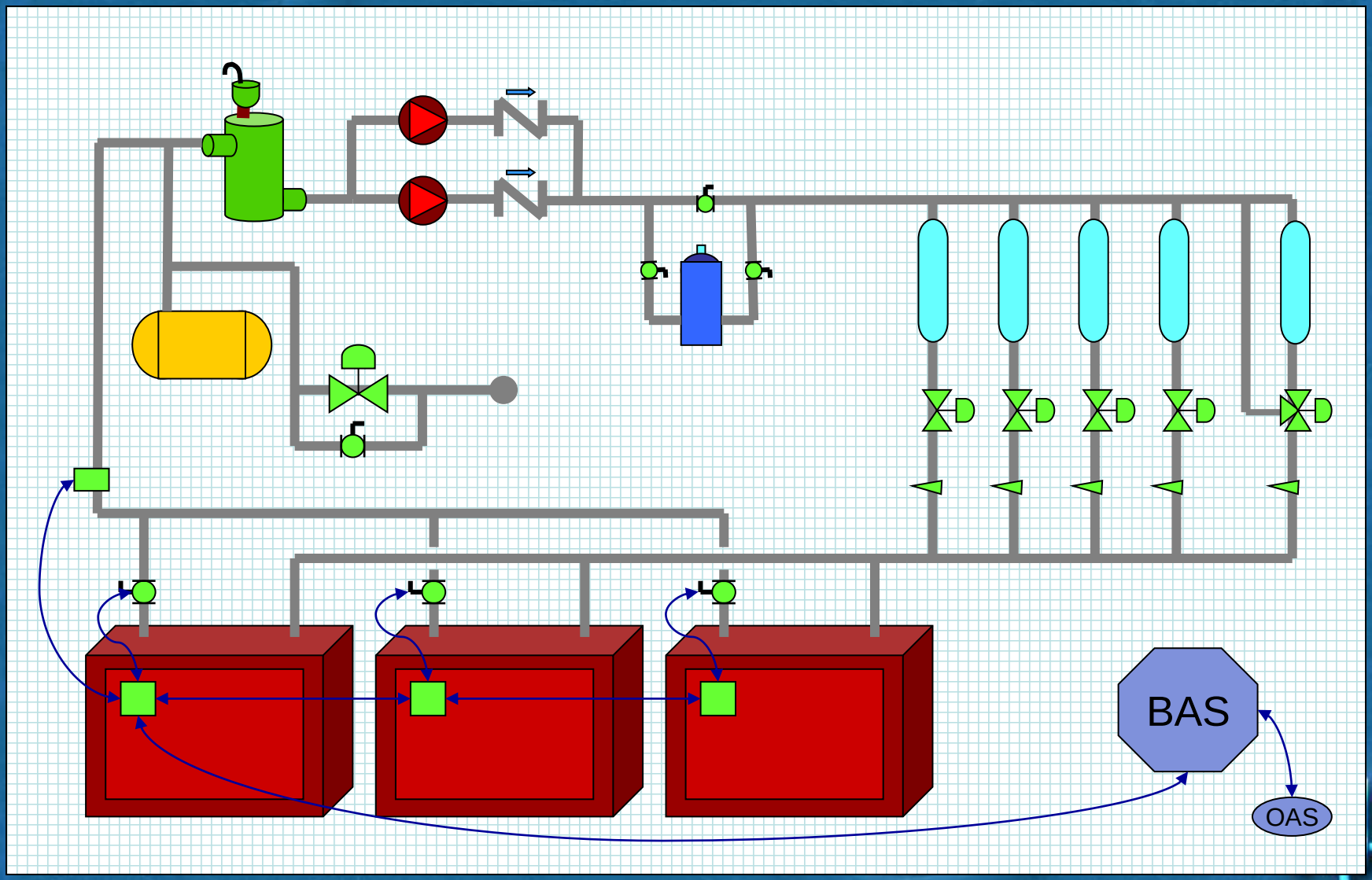
Buffer Tank


From Boilers
To System
(Supply)
To Boilers
From System
(Return)

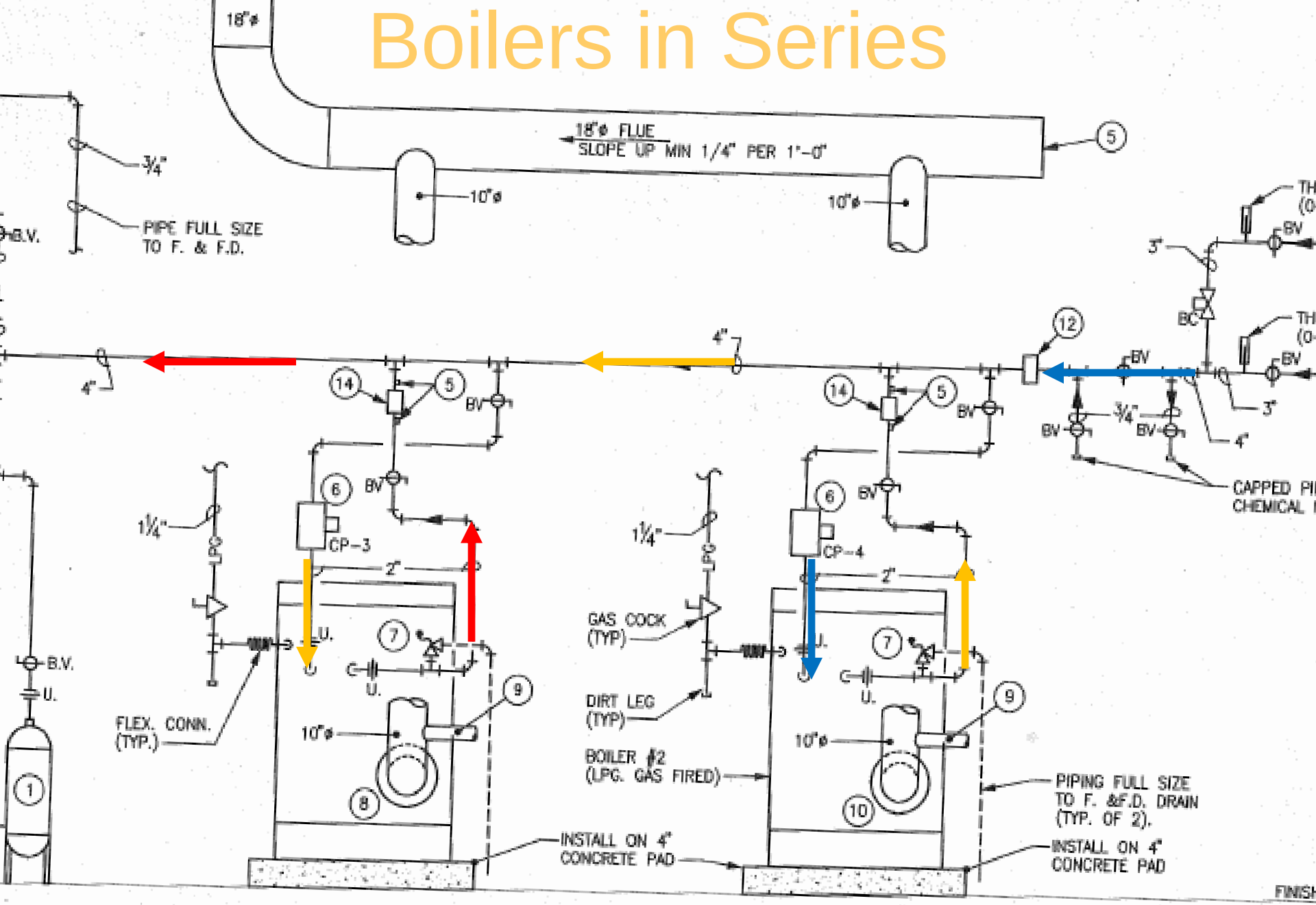
Blended Temperature



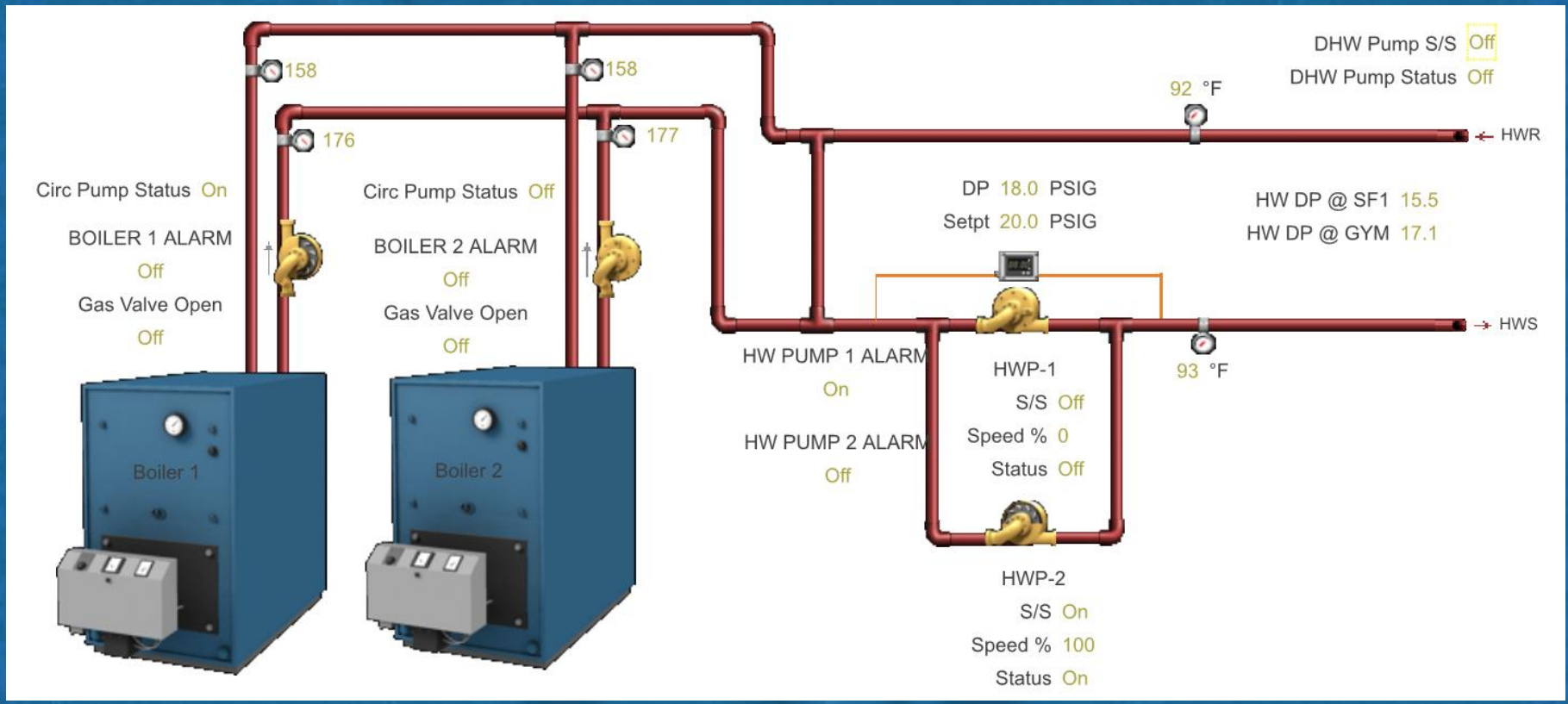
Motorized Isolation Valves



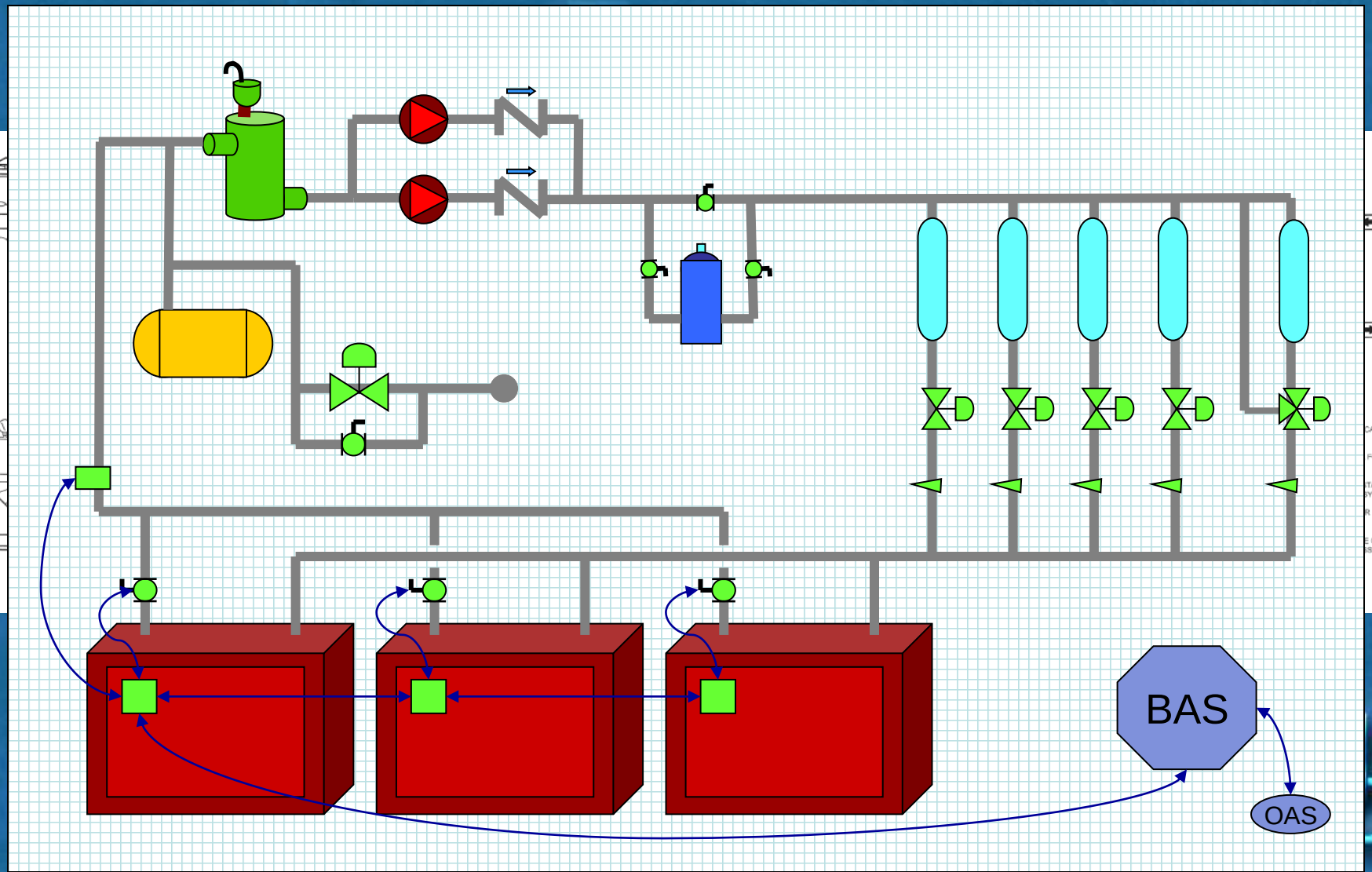
Boilers in Series



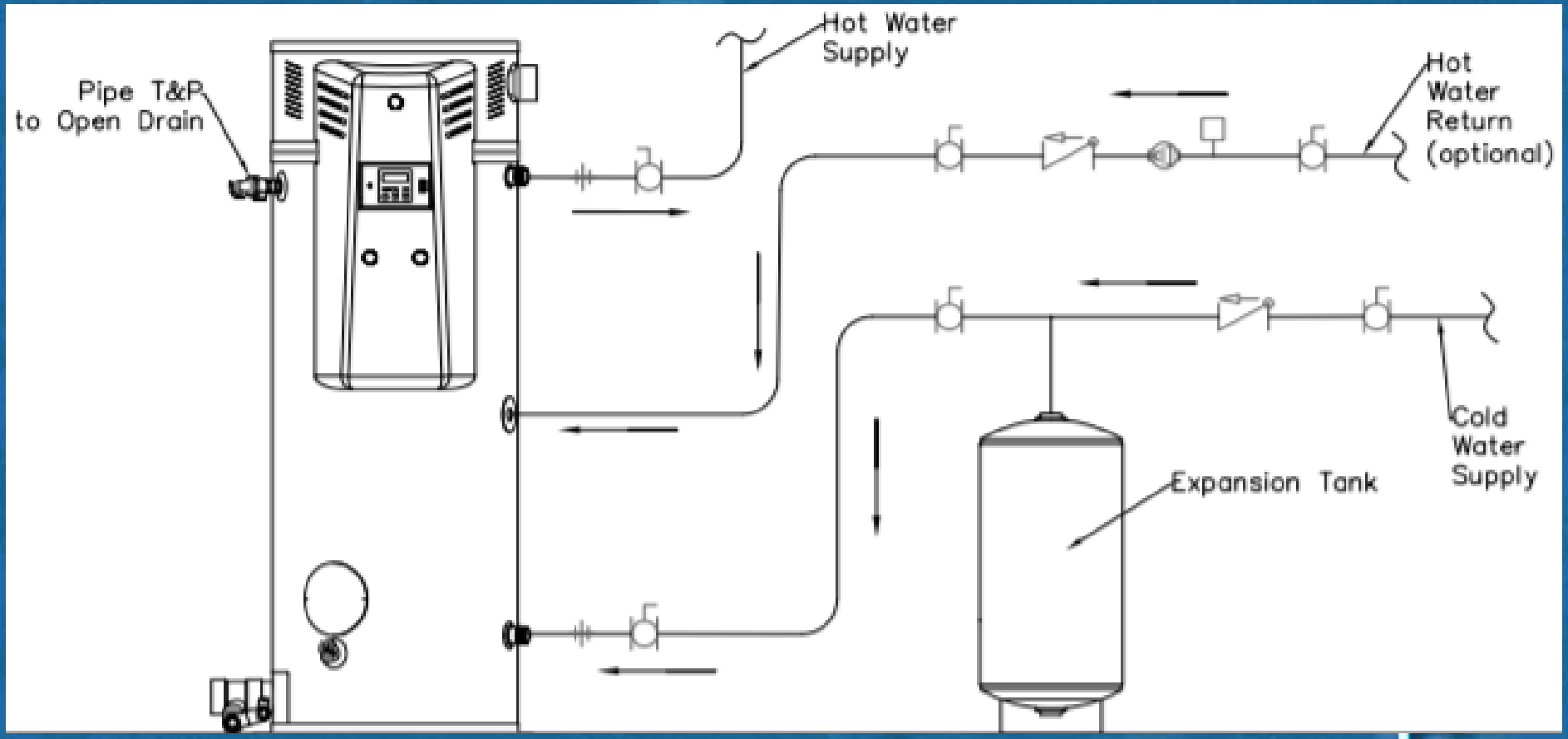
Header Sensor Location



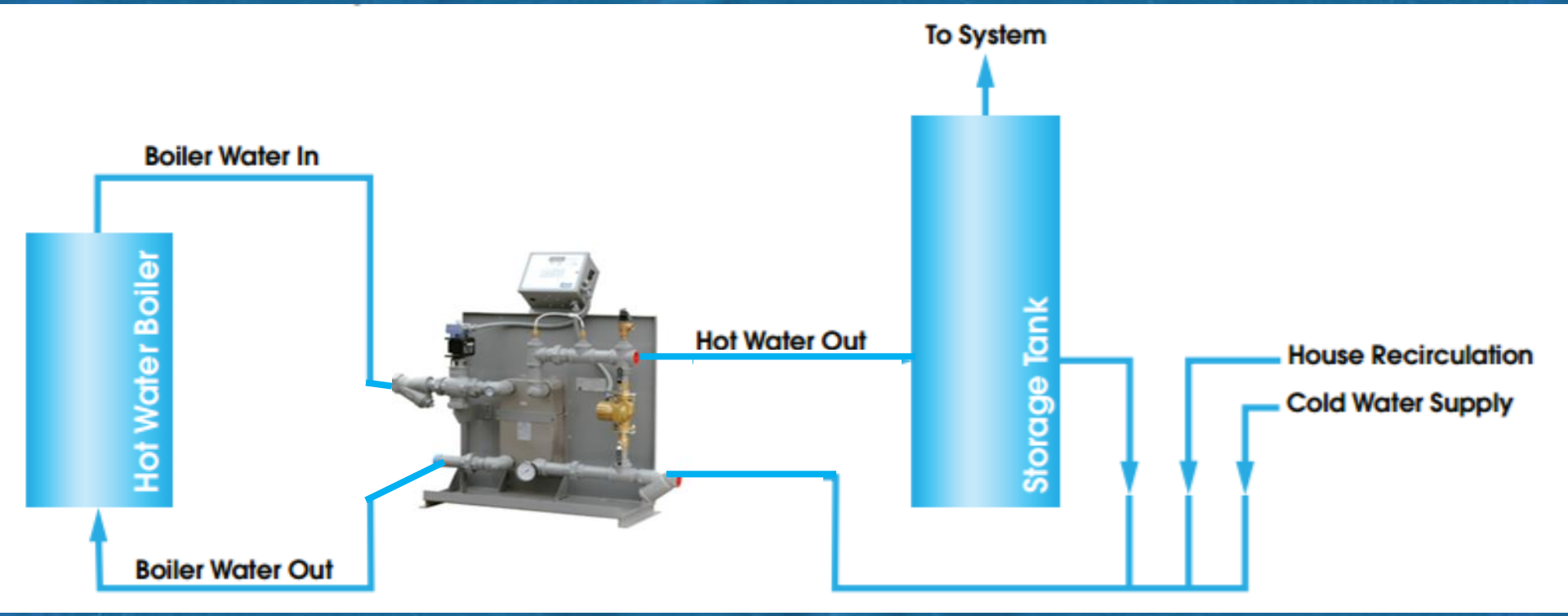
Boiler Minimum Flow Bypass Location



Dual Return Ports



Indirect Water Heating



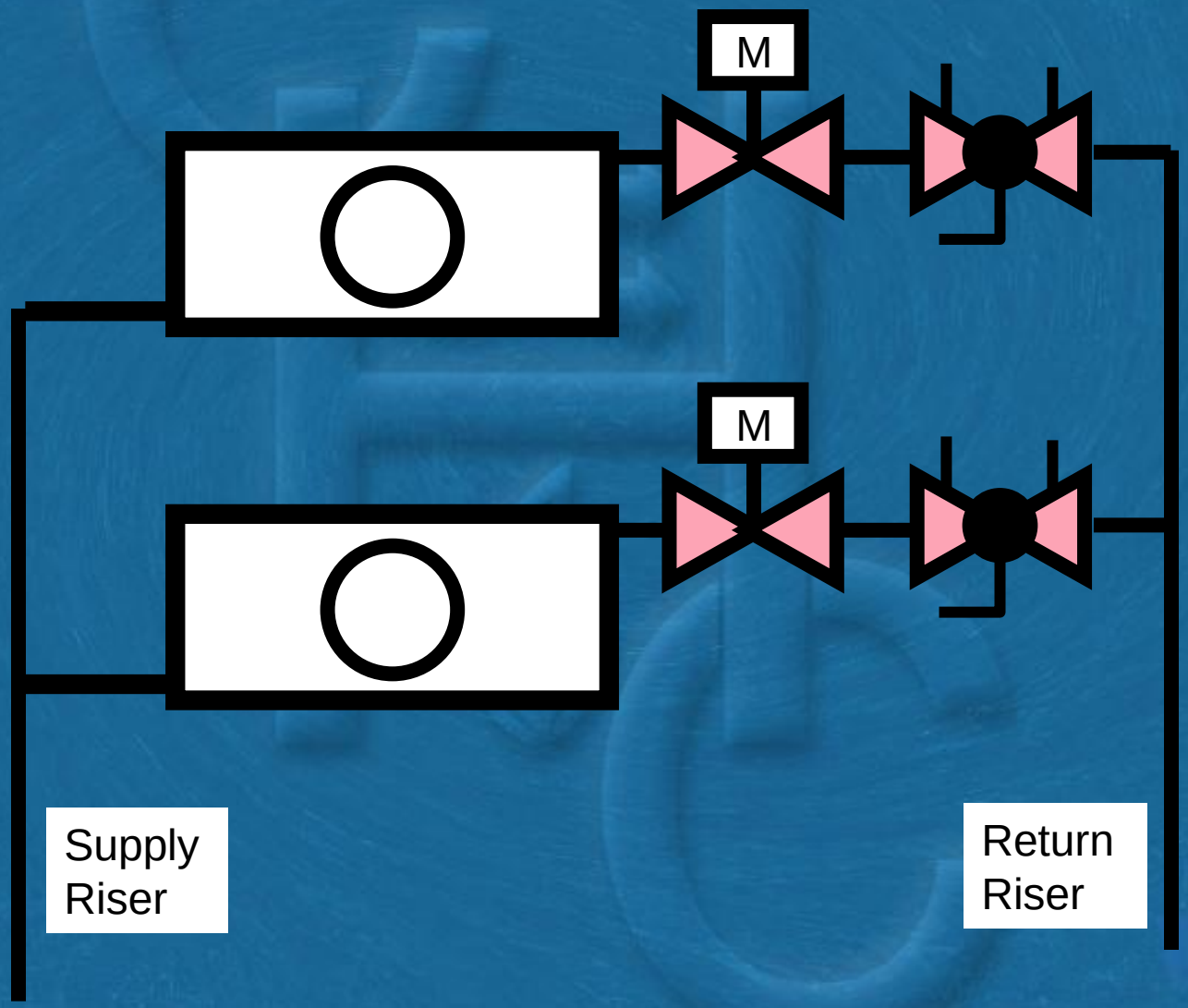
Low ΔT Syndrome

- Dirty coils
- Improperly sized coils
- Improperly sized control valves
- Control valve quality / rangeability

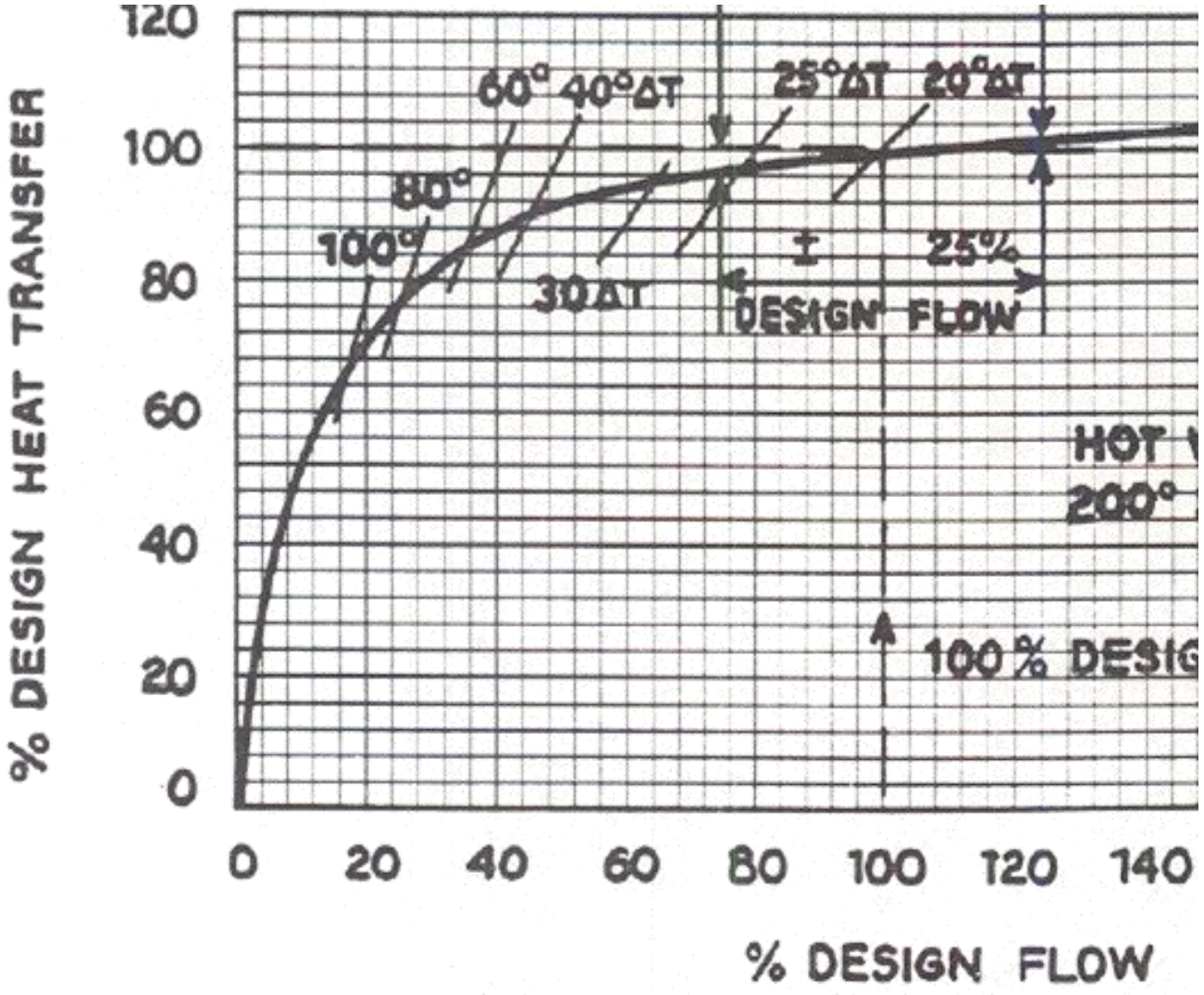
Two-Way Valve Control

- Variable Flow Through Coil
- Variable Flow Through System

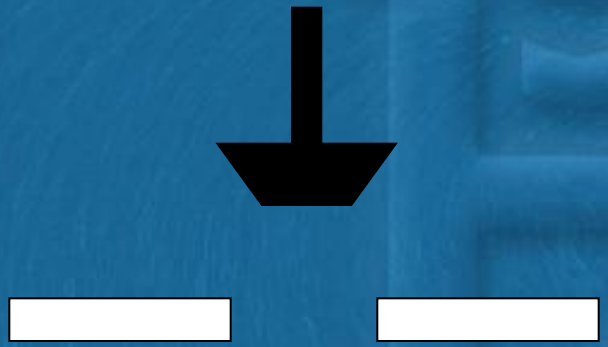
2-Way Valve Balance



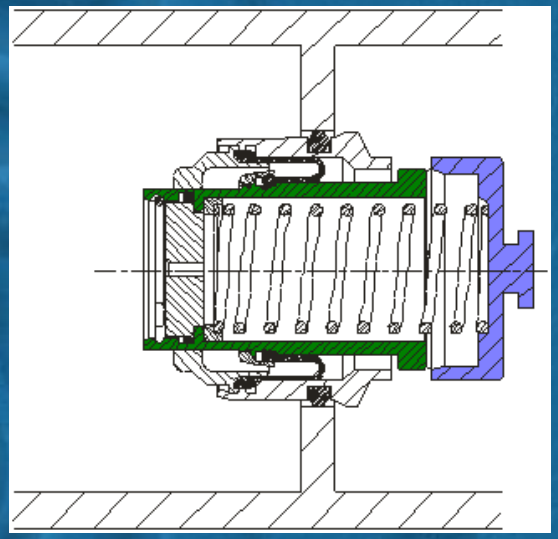
Heating Coil Characteristic Curve



2-Way Modulating Valve + Flow Limiter

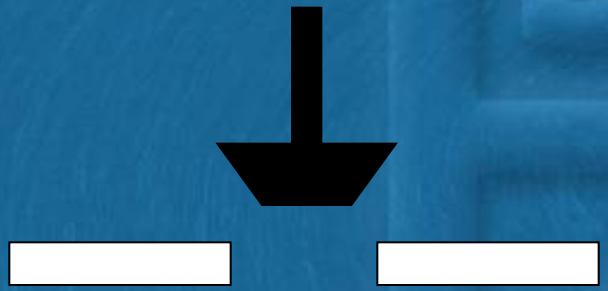


Control Valve

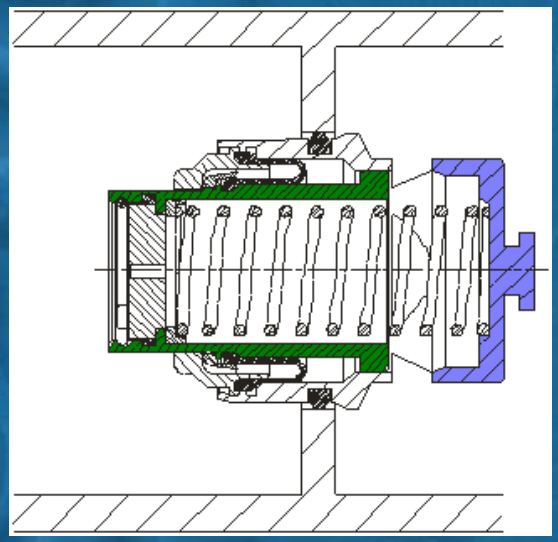


PI Flow Limiter

2-Way Modulating Valve + Flow Limiter

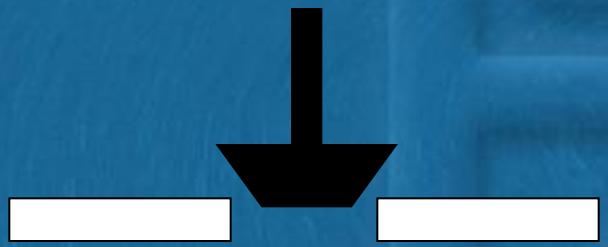


Control Valve

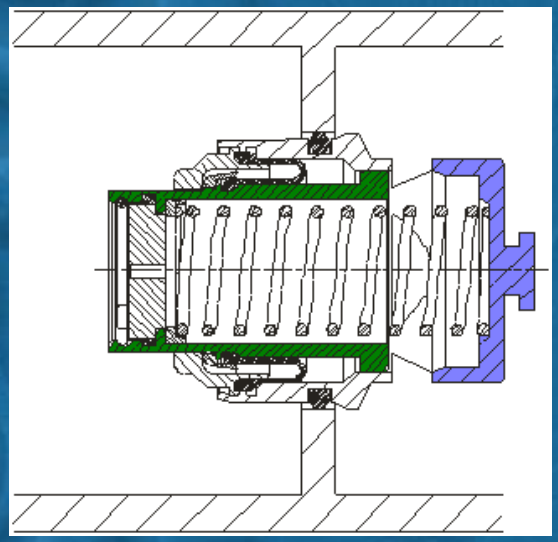


PI Flow Limiter

2-Way Modulating Valve + Flow Limiter

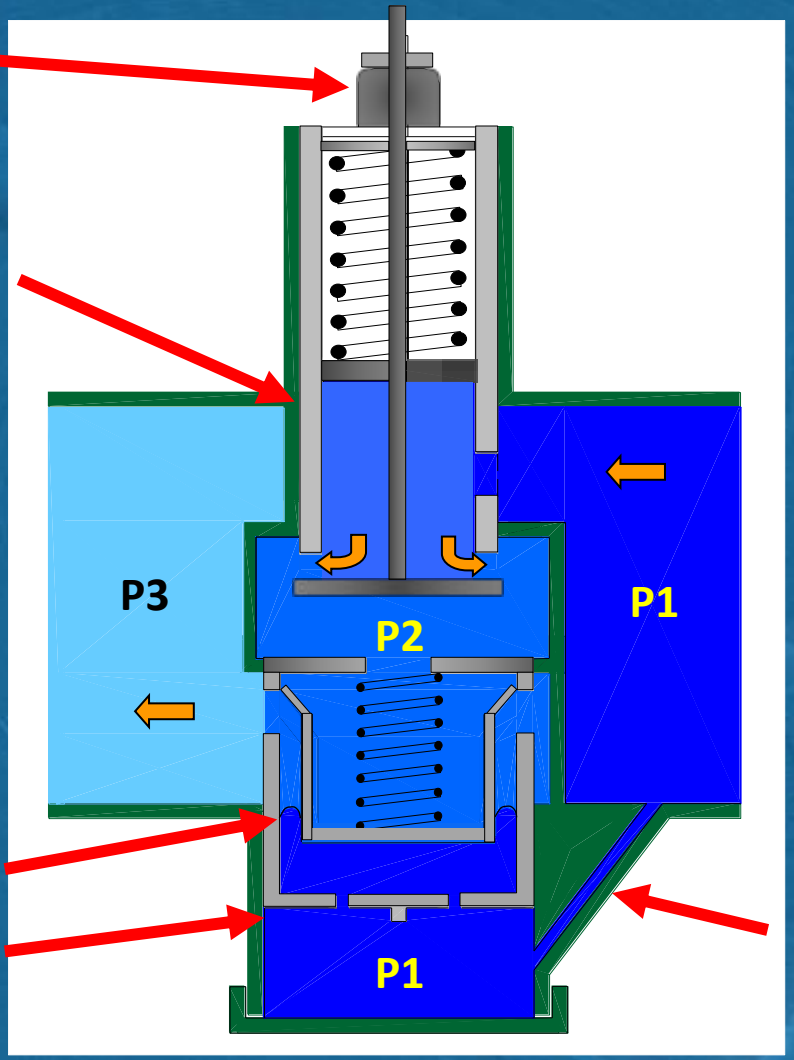


Control Valve



PI Flow Limiter

Pressure Independent Control Valves



Efficiency's Meaningless When Boiler Doesn't Work

Protect the Investment!

Thank You!

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