Facility Dynamics Engineering

Introduction to the Controlled Systems

Boilers (Supplemental)

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What We Will Cover in This Module

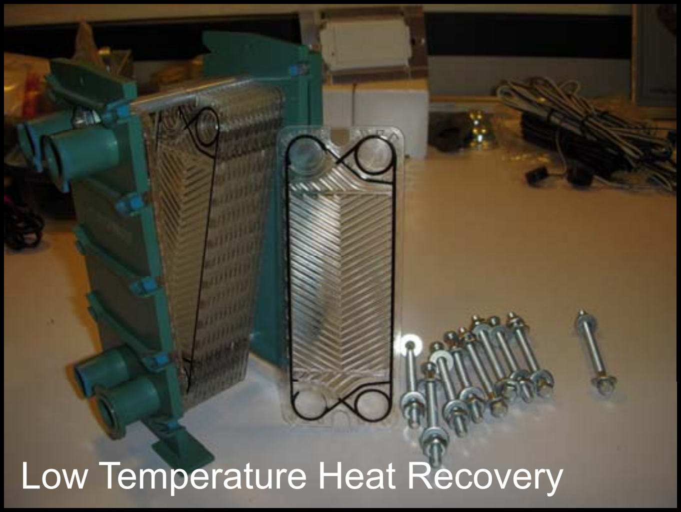
- Boilers
- How Boilers Interact with the Systems They Serve

Common Sources of Heat


Steam Boiler


Hot Water Boiler


Cogen Heat Recovery


Low Temperature Heat Recovery

A Really Big Boiler

The Steam Drum

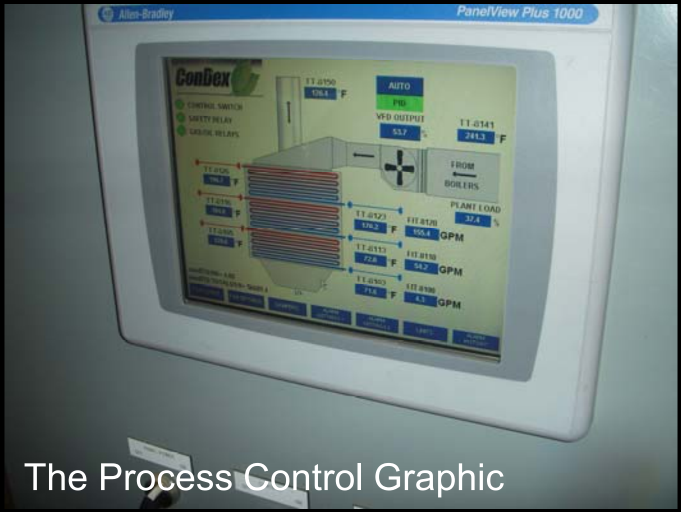

The Combustion Air Fan


Combustion Air and Fuel
Control Linkages


Adjustable Cam and Follower for the
Modulating Gas Control Valve

Flue Gas Energy Recovery System

Flue Gas Energy Recovery System



The Process Control Graphic

The Heat Exchangers


The Energy Recovery Pumps

The Flue Gas Condensate Pumps

Why Use Steam Instead of Hot Water?

Transferring 10,000,000 Btu/hr with Hot Water

Q = 500 x gpm x Δt

Q = 10,000,000 Btu/hr

Supply = 180°F

Return = 160°F

Δt = 20°F

gpm = 1,000

Line size = 8”

Number of lines = 2

Insulation = 1-1/2”

Transferring 10,000,000 Btu/hr with Steam

Q = Pounds per hour x $\Delta\eta$

Q = 10,000,000 Btu/hr

$\Delta\eta$ = 1,000 Btu/lb

Pounds per hour = 10,000

Supply line size = 6”

Temperature = 240°F

Insulation = 2-1/2”

gpm returned = 20

Return line size = 1-1/2”

Temperature = 200°F

Insulation = 2”

Steam and Condensate

They go hand in hand

- Condense a pound of steam, gain a pound of condensate
  - Condensate needs to return to the plant
    - Gravity and pipe pitch
    - Pumps

A Poor Man's Steam Meter

- Condensate receiver = known volume
- Pump cycles = easily logged
- Pump cycles x known volume = Condensate flow rate
- Condensate flow rate = Steam flow rate
  - Does not pick up steam leakage
  - *Does* pick up tube leaks
  - Does not pick up process steam use
  - Units need to be right
  - Pumps need to have a check valve

See *Assessing Steam Consumption with an Alarm Clock* at *www.Av8rDAS.Wordpress.com*

Aliasing

- Sampling time is critical in terms of having the logger or control system capture an accurate picture of the true operating pattern
  - In general, the logger needs to sample at least twice as fast as the shortest disturbance in the process you are observing

The Nyquist Theorem a.k.a the Sampling Theorem
The Theory Behind the Generalization

$$f_s \geq 2 \times f_c$$

Where:

f_s = The sampling frequency

f_c = The highest frequency contained in the signal

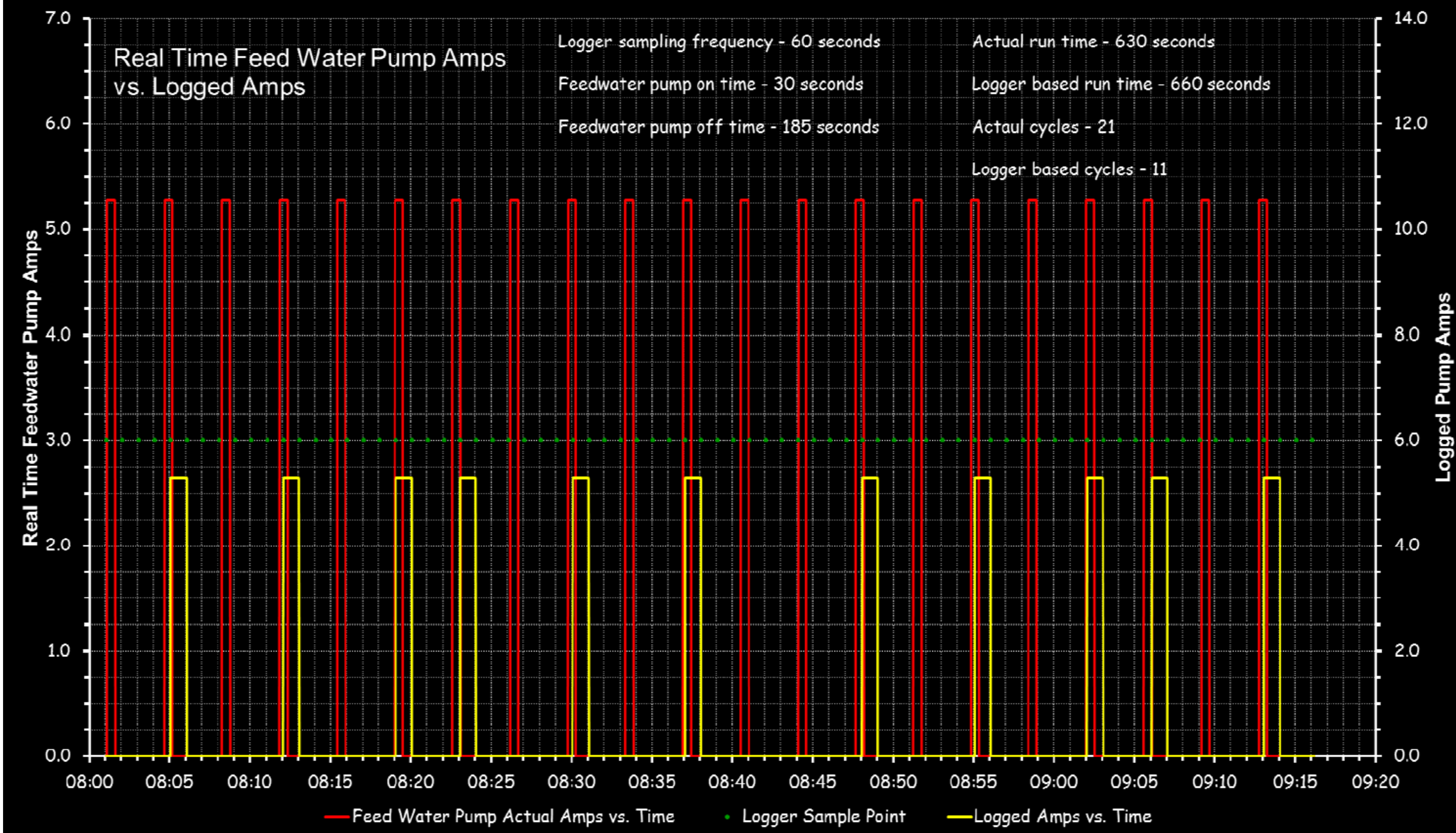
In words:

The sampling frequency should be at least twice the highest frequency contained in the signal.

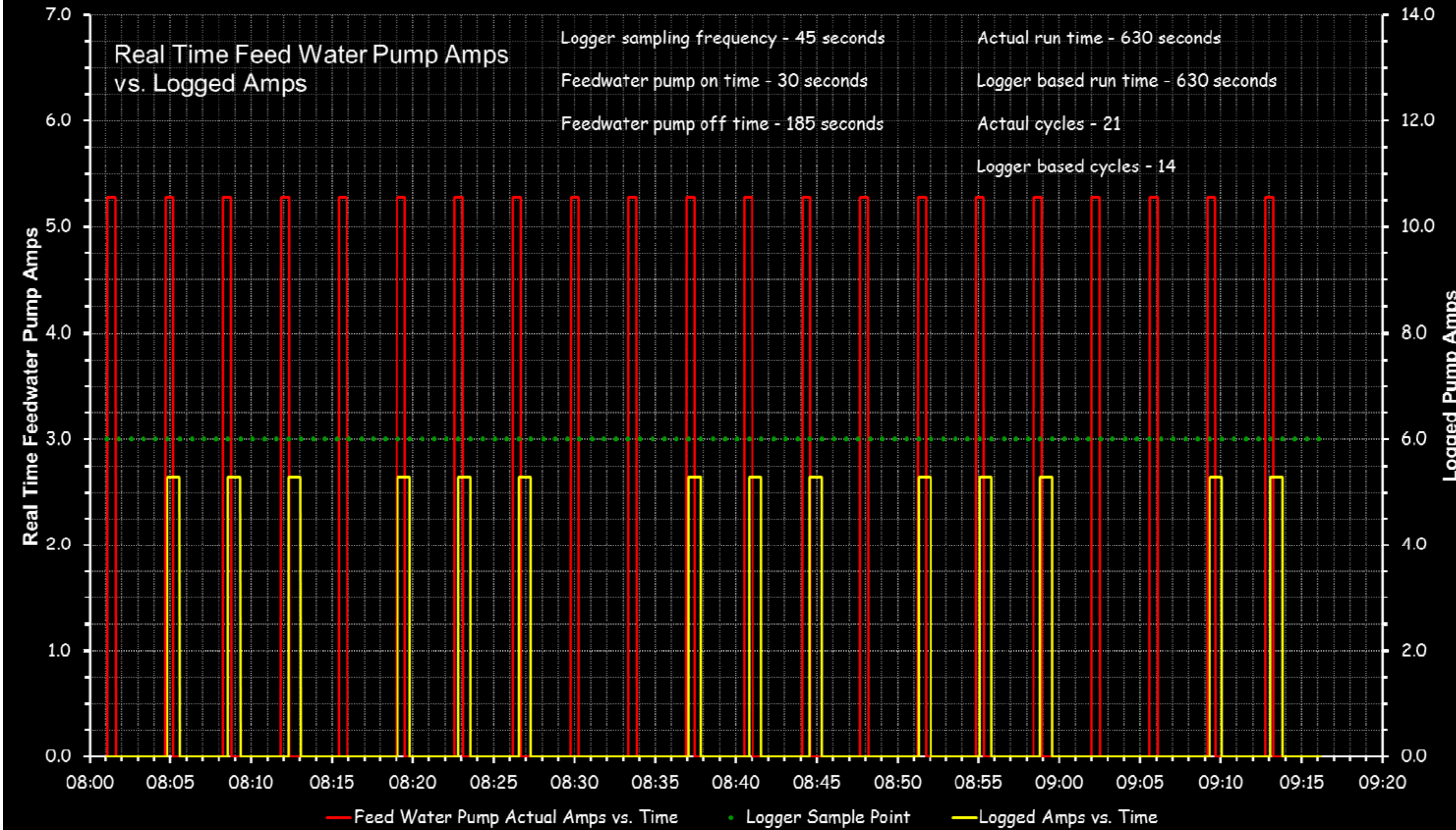
The Nyquist Theorem a.k.a the Sampling Theorem
The Theory Behind the Generalization

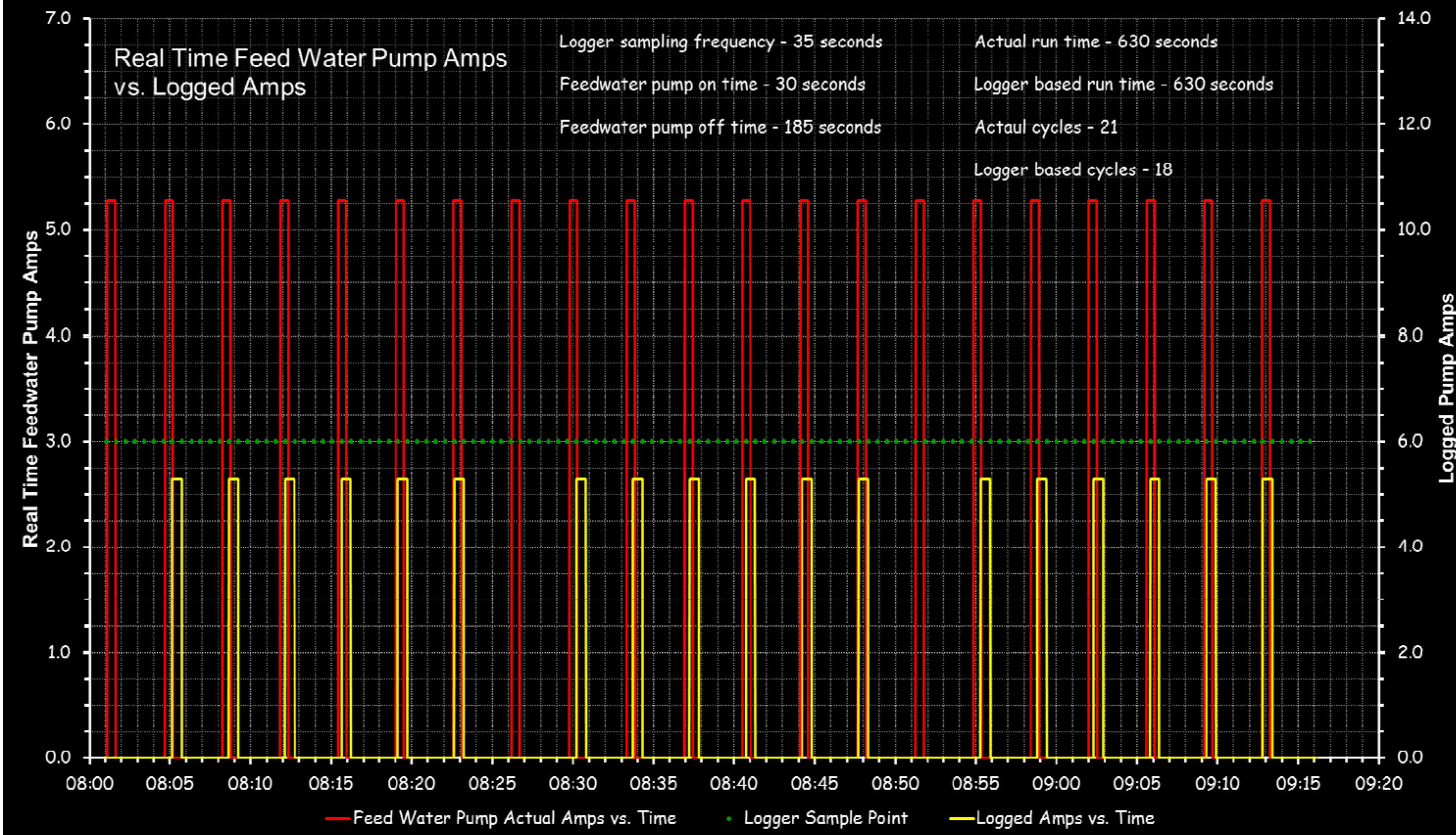
The slides that follow use a spreadsheet model to compare the number of pump cycles and total operating time predicted by data from a logger with the real time data stream

- The logger only knows what it sees at the time it takes its sample
- The logger is not averaging data between samples
- The logger sampling time starts out at twice the feed water pump run cycle time and is reduced to one third of the feed water pump run cycle time

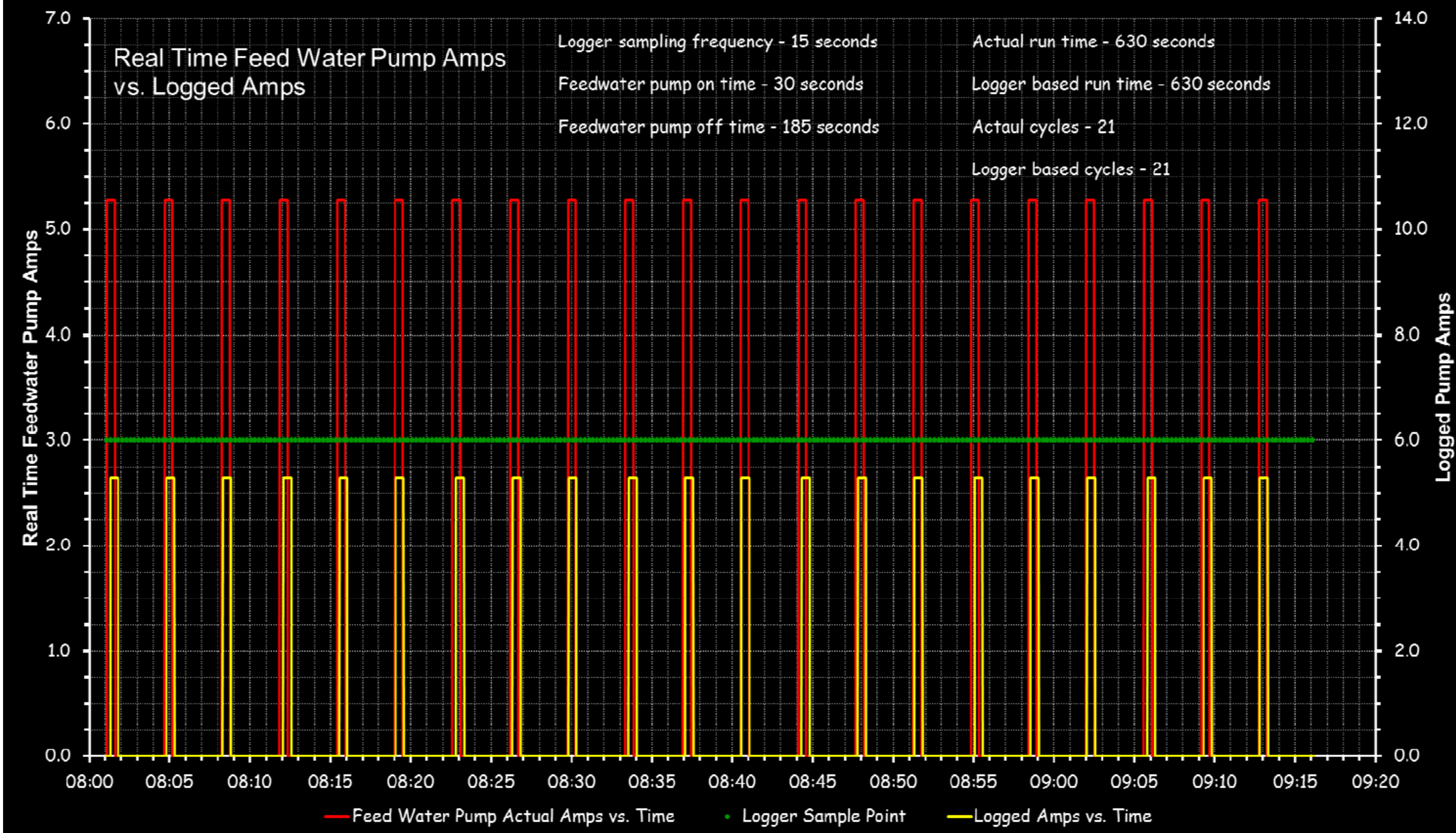


FEED WATER PUMP ALIASING EXAMPLE

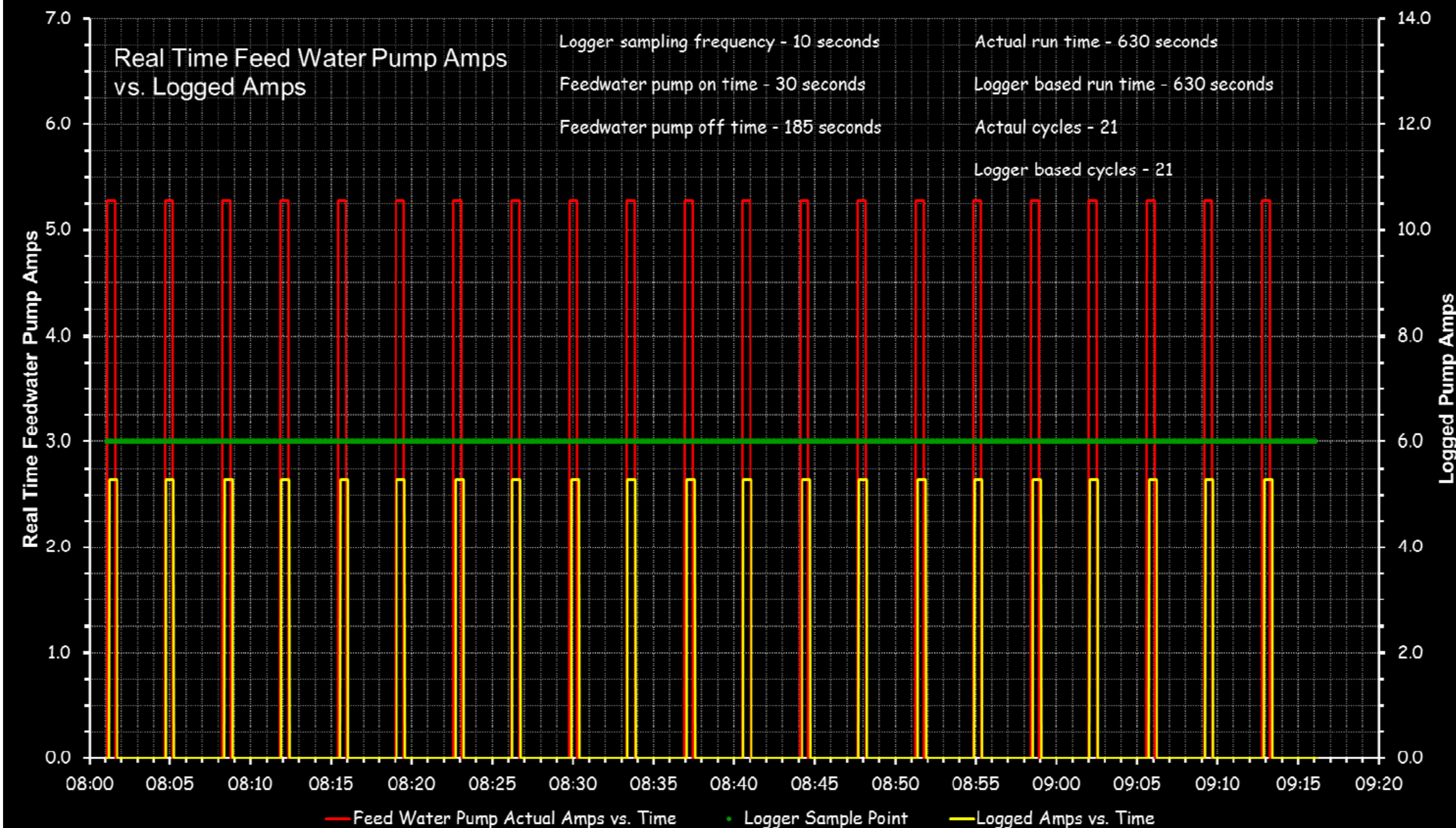

Real Time Feed Water Pump Amps
vs. Logged Amps
Logger sampling frequency - 45 seconds
Feedwater pump on time - 30 seconds
Feedwater pump off time - 185 seconds
Actual run time - 630 seconds
Logger based run time - 630 seconds
Actaul cycles - 21
Logger based cycles - 14
Real Time Feedwater Pump Amps
Logged Pump Amps
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
08:00
08:05
08:10
08:15
08:20
08:25
08:30
08:35
08:40
08:45
08:50
08:55
09:00
09:05
09:10
09:15
09:20
Feed Water Pump Actual Amps vs. Time
Logger Sample Point
Logged Amps vs. Time

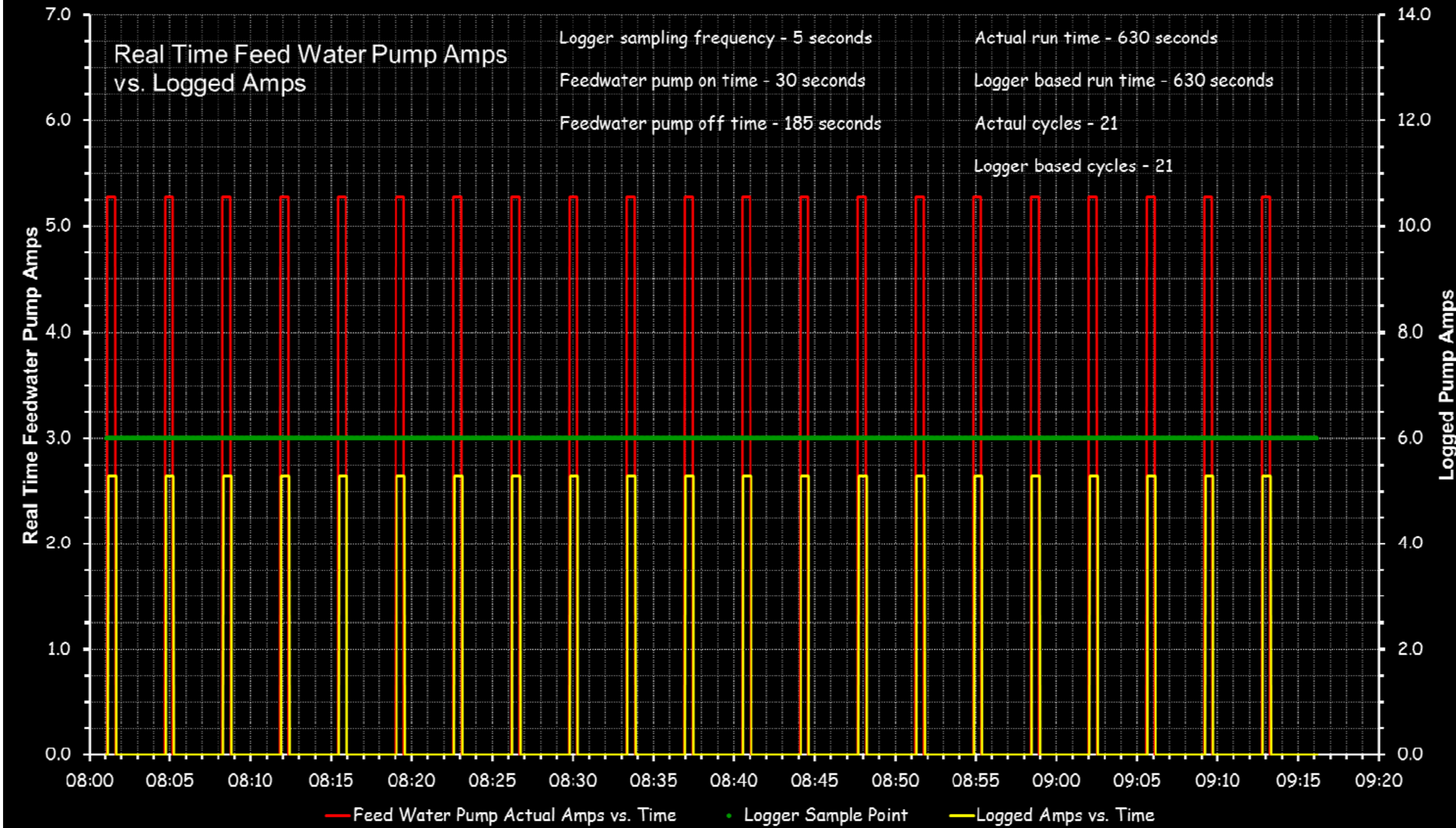


Real Time Feed Water Pump Amps
vs. Logged Amps
Logger sampling frequency - 35 seconds
Feedwater pump on time - 30 seconds
Feedwater pump off time - 185 seconds
Actual run time - 630 seconds
Logger based run time - 630 seconds
Actaul cycles - 21
Logger based cycles - 18
Real Time Feedwater Pump Amps
Logged Pump Amps
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
08:00
08:05
08:10
08:15
08:20
08:25
08:30
08:35
08:40
08:45
08:50
08:55
09:00
09:05
09:10
09:15
09:20
Feed Water Pump Actual Amps vs. Time
Logger Sample Point
Logged Amps vs. Time



FEED WATER PUMP ALIASING EXAMPLE


Real Time Feed Water Pump Amps
vs. Logged Amps
Logger sampling frequency - 10 seconds
Feedwater pump on time - 30 seconds
Feedwater pump off time - 185 seconds
Actual run time - 630 seconds
Logger based run time - 630 seconds
Actaul cycles - 21
Logger based cycles - 21
Real Time Feedwater Pump Amps
Logged Pump Amps
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
08:00
08:05
08:10
08:15
08:20
08:25
08:30
08:35
08:40
08:45
08:50
08:55
09:00
09:05
09:10
09:15
09:20
Feed Water Pump Actual Amps vs. Time
Logger Sample Point
Logged Amps vs. Time


Real Time Feed Water Pump Amps vs. Logged Amps
Logger sampling frequency - 5 seconds
Feedwater pump on time - 30 seconds
Feedwater pump off time - 185 seconds
Actual run time - 630 seconds
Logger based run time - 630 seconds
Actaul cycles - 21
Logger based cycles - 21
Real Time Feedwater Pump Amps
Logged Pump Amps
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
08:00 08:05 08:10 08:15 08:20 08:25 08:30 08:35 08:40 08:45 08:50 08:55 09:00 09:05 09:10 09:15 09:20
Feed Water Pump Actual Amps vs. Time
Logger Sample Point
Logged Amps vs. Time

Bottom Lines

1. If the sampling rate is to slow:

   The operating pattern predicted by the logger data does not match the actual operating pattern. That means the shape of the load profile you predicted with the logger data would not match the actual load profile shape.

Bottom Lines

1. If the sampling rate is to slow:

   The number of cycles predicted by the logger data does not match the number of cycles that actually happened. So, if you were assuming "X" gpm went into the boiler for each cycle based on a field test of the actual pump, then you would under-estimate the actual steam consumption.

Bottom Lines

1. If the sampling rate is to slow:

   The total run time for the pump predicted by the logger data tends to be more than the actual run time. So, if you were assuming a pump flow rate based on a pump test and then multiplying that flow rate by the run time to get the total gallons of water that were converted to steam over a given time period, the logger data would cause you to over-estimate the actual steam consumption.

Bottom Lines

2. With the sampling rate set to the value suggested by the Nyquist Theorem:

   The number of cycles and the total run time predicted by the logger now are in agreement with reality. That means that you would accurately predict the steam consumption using either of those pieces of information along with data from a field test of the pump

   Gallons per Minute x Minutes = Gallons

   Assumes the flow rate is constant any times the pump runs, which is reasonable if the boiler pressure is steady and the head above the pump in the feed water tank does not vary much

Bottom Lines

2. With the sampling rate set to the value suggested by the Nyquist Theorem:

   The number of cycles and the total run time predicted by the logger now are in agreement with reality. That means that you would accurately predict the steam consumption using either of those pieces of information along with data from a field test of the pump

   Gallons per Cycle x Cycles = Gallons

   Assumes the on cycle for a typical feed water pump cycle is the same all of the time, which is reasonable if the pump is controlled by a consistent level change and pumps at a relatively steady rate

Bottom Lines

2. With the sampling rate set to the value suggested by the Nyquist Theorem:

   The operating pattern predicted by the logger data still does not match the actual operating pattern although it is closer. That means the shape of the load profile you predicted with the logger data would not exactly match the actual load profile shape.

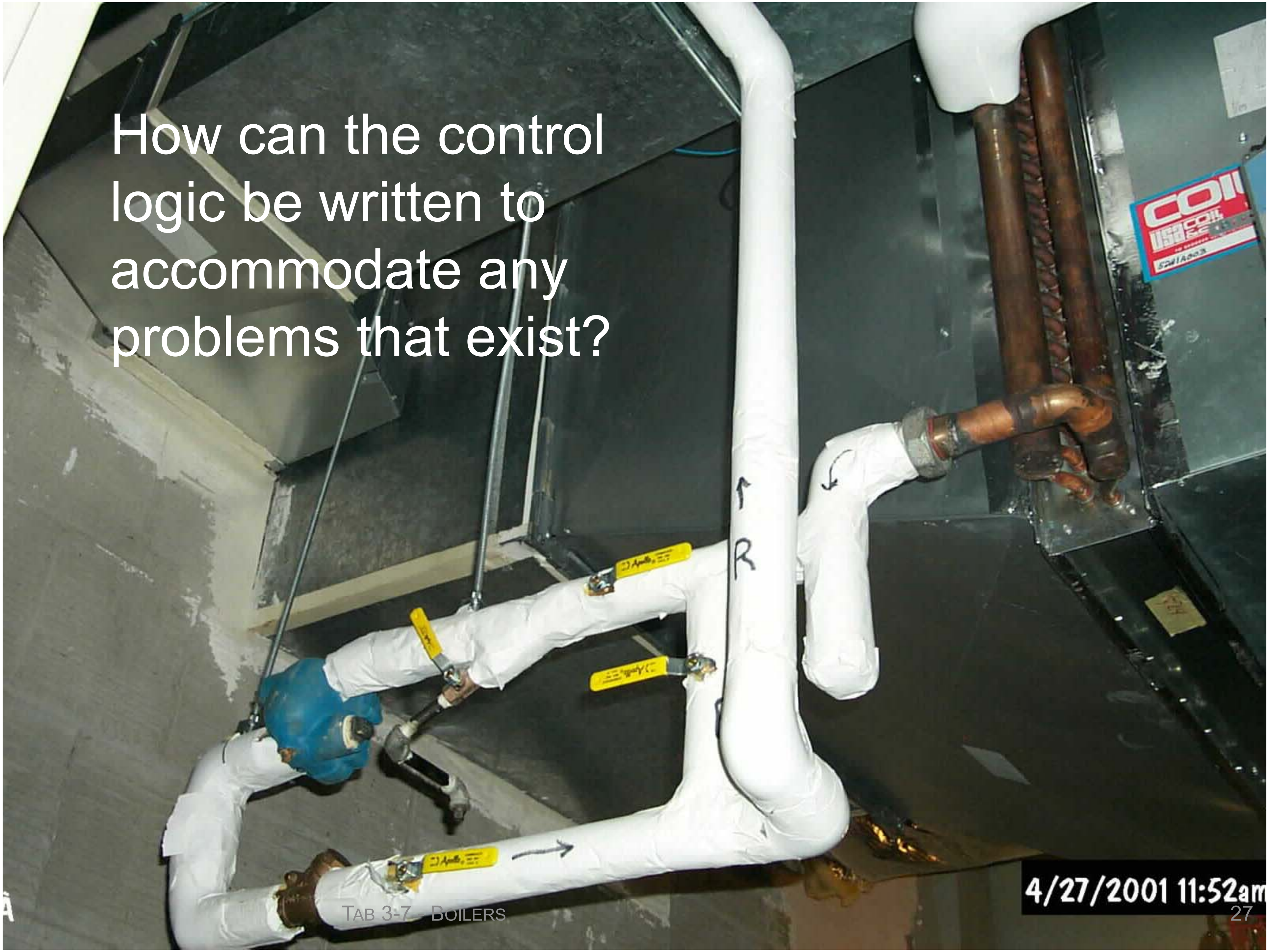
   > *How close the patterns match with the sampling rate set to the Nyquist suggested value is generally related to when the logger samples relative to the start of a pump operating cycle.*

Bottom Lines

3. With the sampling rate set to a value that is significantly faster than what is suggested by the Nyquist Theorem:

   The pattern predicted by the logger is a much closer match to the actual operating pattern. That means that if you want to not only reflect the steam consumption, but also the shape of the load profile, then you probably want to sample faster than the Nyquist Theorem suggested sampling rate unless you can launch the logger so that it starts logging data exactly when a pump starts

Do You See Any Problems with How This Steam Reheat Coil is Piped?



How can the control logic be written to accommodate any problems that exist?

Steam and Condensate

They go hand in hand

- Condense a pound of steam, gain a bunch of energy

$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O + \text{Heat}$$

Since air is more than just Oxygen, what happens to the other stuff?

Steam and Condensate

They go hand in hand

- Condense a pound of steam, gain a bunch of energy

$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O + \text{Heat}$$

What would happen to boiler efficiency if we condensed this water vapor?

Steam and Condensate

They go hand in hand

- Condense a pound of steam, gain a bunch of energy

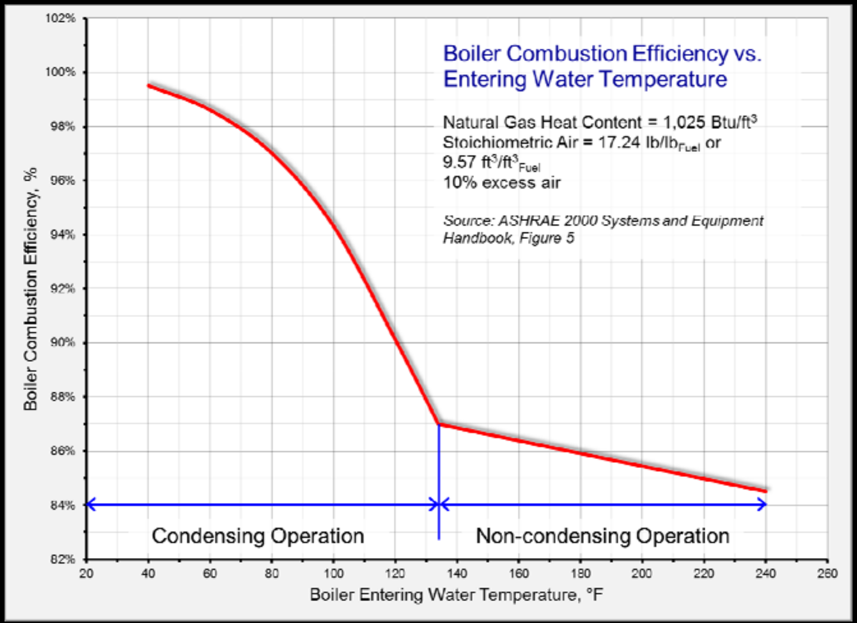
$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O + Heat$$

How do we get the water vapor to condense?

Condensing Boilers Need to Condense

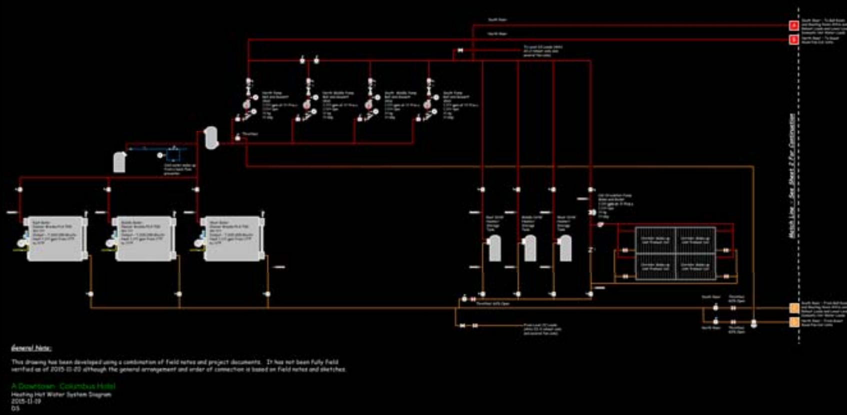
To achieve advertised efficiency, the return water temperatures need to drive the boiler into condensation mode

- 130-140°F flue gas dew point for gas combustion processes
- 160-170°F flue gas dew point for oil combustion processes



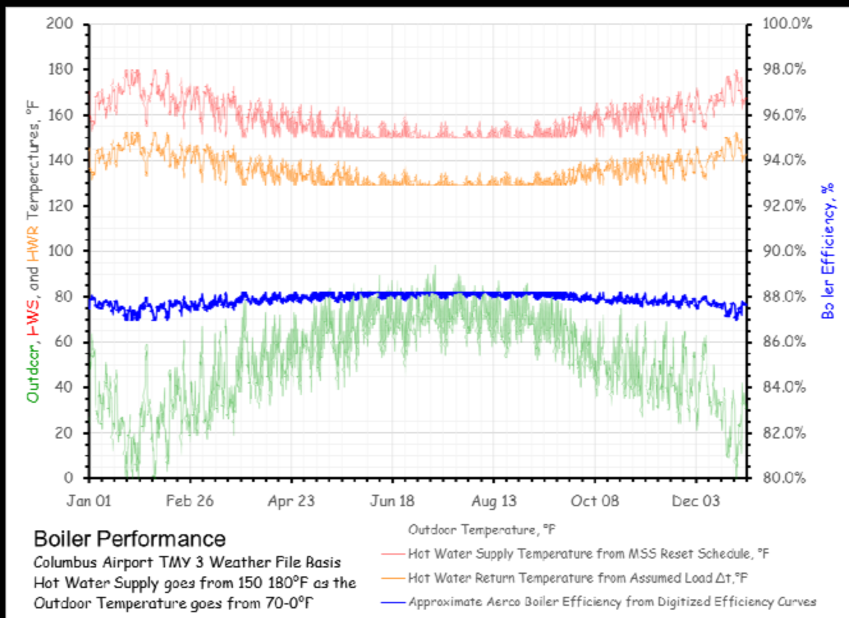
Condensing Boilers Need to Condense

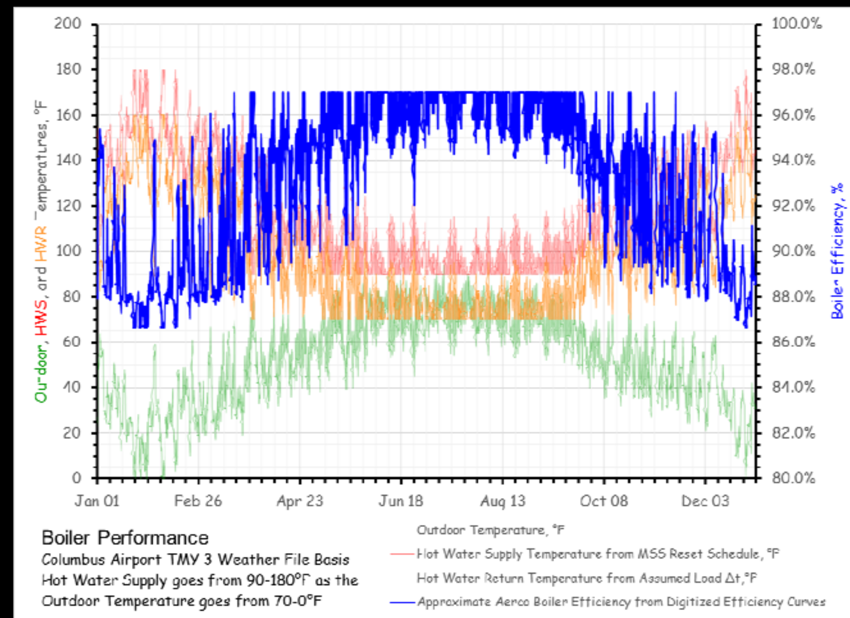
1. If the existing boilers in the system to the right are replaced with condensing boilers, can the targeted efficiency improvement and savings be achieved?
2. Can the control system and related logic solve any problems that might exist?
3. If the boilers fail to deliver savings, what is the likelihood that the control system will be blamed?



You have a full size version of this diagram in the supporting information folder

Condensing Boilers Need to Condense





As Designed

- Average efficiency – 86% with times at 87%
- 1-2% more efficient that a good quality non-condensing boiler

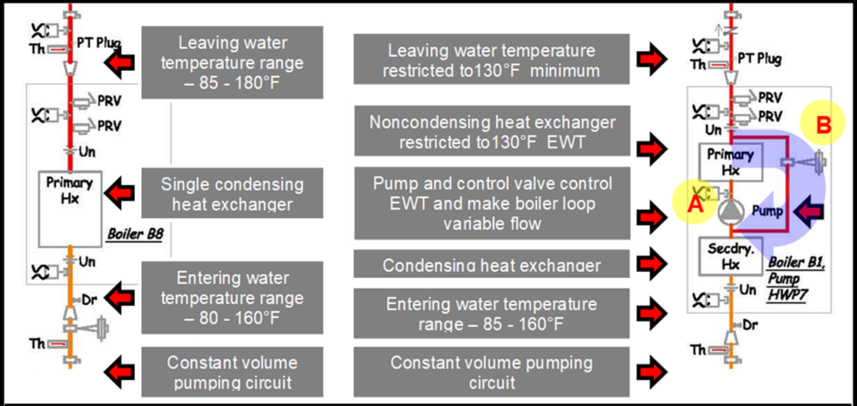
Potential with Some Creativity

- Average efficiency – 93% with times at 96-97%
- $9,000 – $11,000 additional annual savings
- 20-23% additional savings possible

Condensing Boilers Need to Condense

Not all condensing boilers are created equal

If they are not created equal do you think they can be controlled the same way?



The primary difference between the Aerco Benchmark BMK2.0 boilers (left illustration) that were the basis of design and the Lochinvar Intellifin IBM2000 boilers (right illustration) that were actually furnished is that the Aerco units employ a single heat exchanger, rated and designed for condensing operation. In contrast, the Lochinvar units employ two heat exchangers, one of which (termed the secondary heat exchanger) is rated and designed for condensing operation and one of which (termed the primary heat exchanger) is not. To protect the primary heat exchanger from damage do to the corrosive by-products associated with condensing operation, the Lochinvar boilers incorporate a circulating pump (A) and a control valve (B), arranged to ensure that the entering water temperature to the primary heat exchanger never drops below 130°F. This is accomplished by recirculating water from the boiler's discharge to the inlet side of the primary heat exchanger as indicated by the blue shaded arrow in the right illustration. For this approach to work, the boiler must be controlled so that the leaving water temperature from the primary heat exchanger is never below 130°F. As a result, a system that employs the Lochinvar units and must directly control for supply water temperatures below 130°F need to incorporate some other mechanism for achieving the supply temperature requirement while protecting the boilers. One common approach for accomplishing this is to provide the system with a three-way valve that allows water from the boiler loop to be mixed with return water from the system to achieve the required supply temperature. Since the Aerco boilers are rated to control directly for any set point from 50-190°F, the basis of design system did not in incorporate such a feature. As a result, when the Lochinvar boilers are applied in the basis of design system configuration, there is no direct method for controlling supply temperature to a set point of 130°F. Rather, the master controller charged with cycling the boilers to maintain a desired system supply temperature must try to find a combination of boiler settings that indirectly produces the desired result by forcing the distribution system into an over-flow condition (distribution flow exceeds boiler loop flow) while the individual boiler controllers work to prevent the entering water temperature to their primary heat exchangers from dropping below 130°F. This is a complex hydraulics problem at best and may be impossible to achieve under some operating conditions with out considerable operator intervention.

Condensing Boilers Need to Condense

Not all condensing boilers are created equal

If they are not created equal do you think they can be controlled the same way?

Answer: No

Non-Condensing Boilers *Should Not* Condense

They *will* condense if you operate them with water temperatures below the dew point of the flue gas

- Boiler O&M typically clearly state this
- Boiler O&Ms also clearly state that you will void the warranty if you do that

Video courtesy Christian Weber of E Design C

Non-Condensing Boilers *Should Not* Condense

They *will* condense if you operate them with water temperatures below the dew point of the flue gas

- Boiler O&M typically clearly state this
- Boiler O&Ms also clearly state that you will void the warranty if you do that
- Control systems can do that

Non-Condensing Boilers *Should Not* Condense

They *will* condense if you operate them with water temperatures below the dew point of the flue gas

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- Boiler O&Ms also clearly state that you will void the warranty if you do that
- Control systems can do that

All boilers will condense at start-up

- Manufacturer’s may limit the number of starts per day
- Manufacture’s may require maintaining a minimum temperature

Bottom Lines

1. The word "boiler" is somewhat general in terms of describing the specifics of a given piece of equipment that you might be controlling
2. The specifics are important in terms of how your control logic will perform
3. If you don't recognize the specific requirements and limitations of the equipment and address them, you could run into a few significant problems with the installation