Avoiding Short Term Overheat Failures of Recovery Boiler Superheater Tubes

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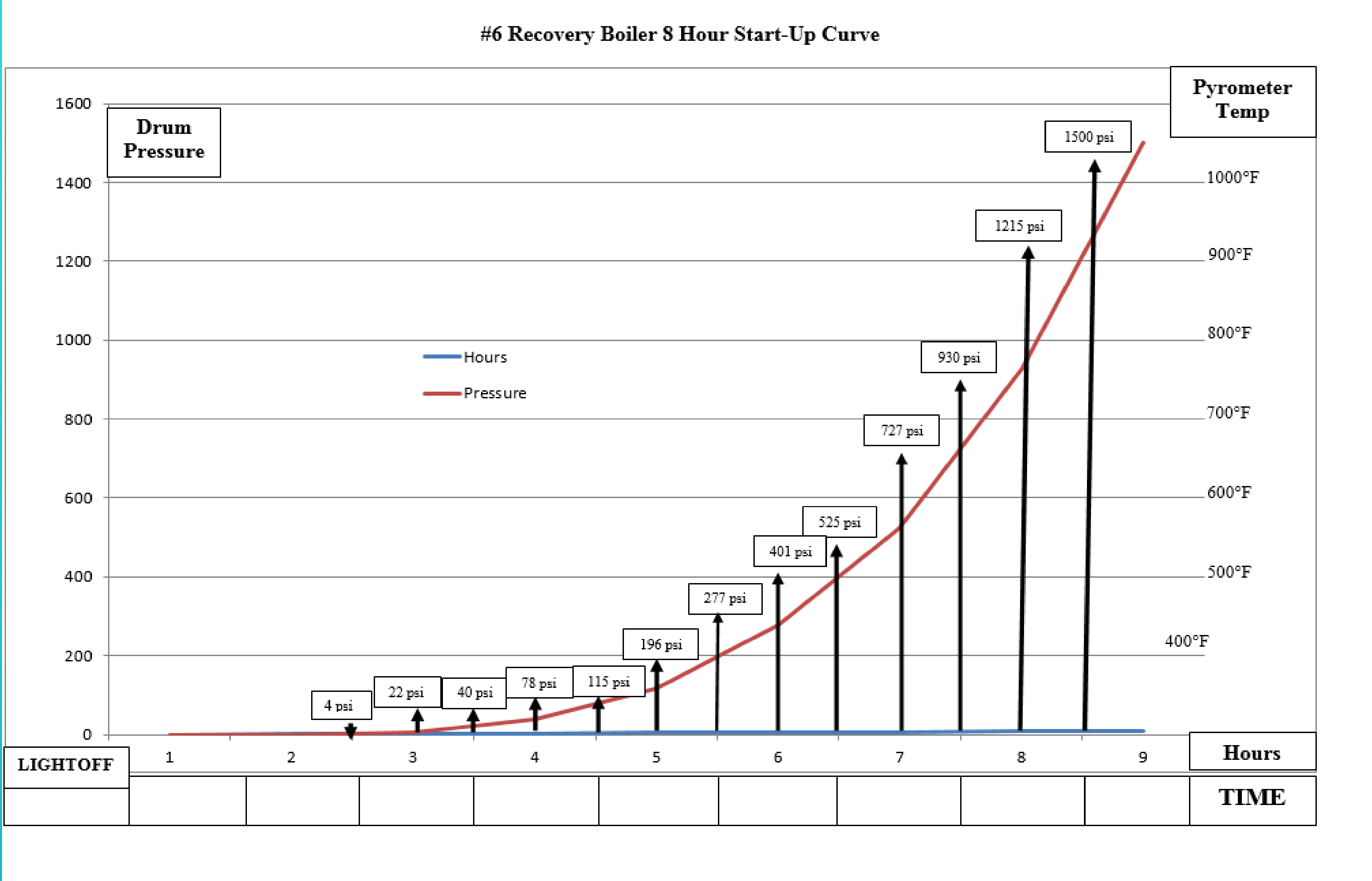
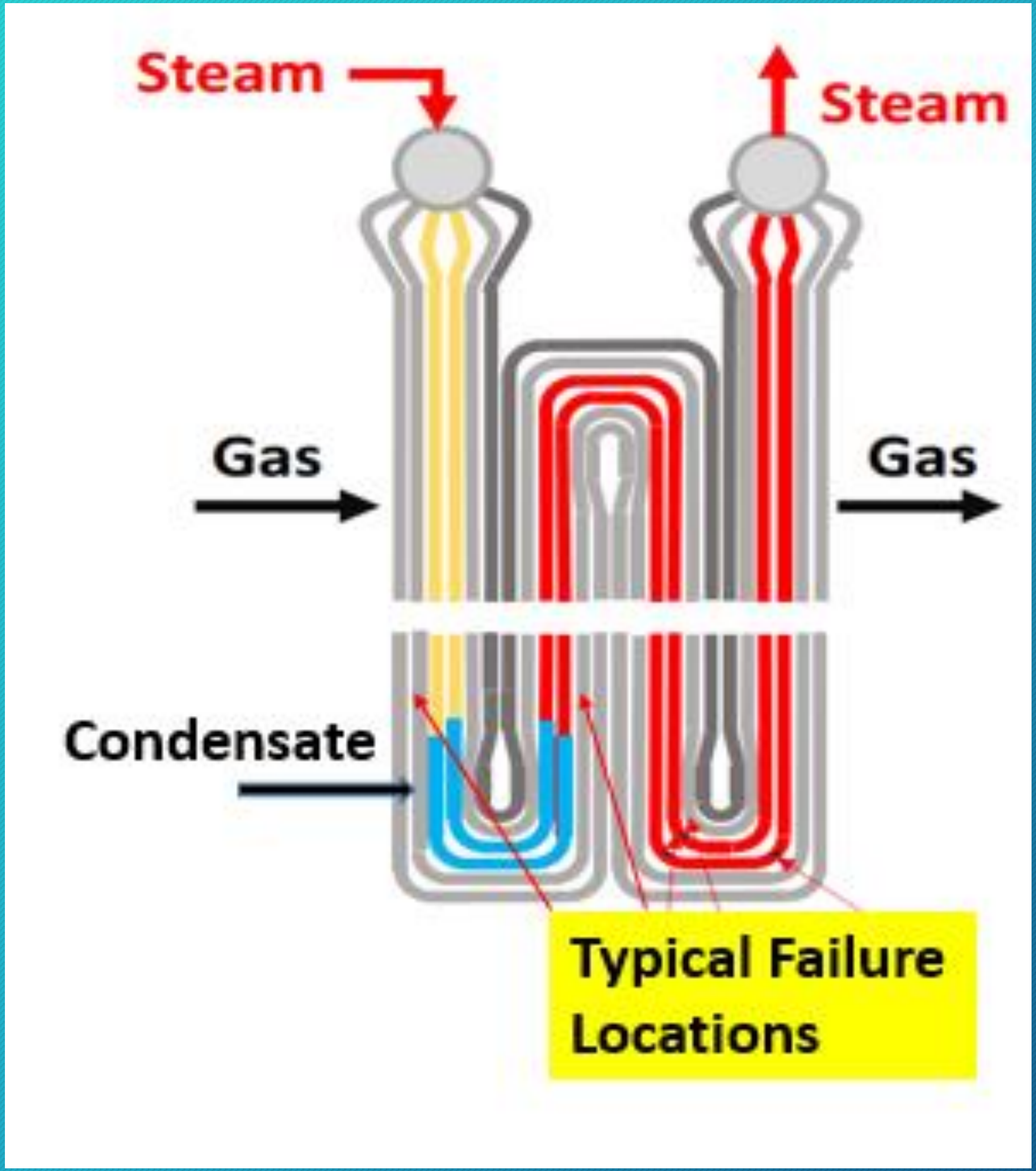
Background

- During the normal startup of a recovery boiler a “start-up curve” is followed.
- Established by the OEM of the recovery boiler.
- Following this start-up curve DOES NOT ensure that superheater tubes will be cleared of condensate.
- Failure to clear condensate prior to exposing tubes to high furnace temperatures (>500C) risks short term overheat failure.



#6 Recovery Boiler 8 Hour Start-Up Curve
Drum Pressure
Pyrometer Temp
1600
1400
1200
1000
800
600
400
200
0
1500 psi
1215 psi
930 psi
727 psi
525 psi
401 psi
277 psi
196 psi
115 psi
78 psi
40 psi
22 psi
4 psi
1000°F
900°F
800°F
700°F
600°F
500°F
400°F
Hours
Pressure
LIGHTOFF
1
2
3
4
5
6
7
8
9
Hours
TIME


Steam
Steam
Gas
Gas
Condensate
Typical Failure Locations

Background

- Operators of recovery boilers use a variety of means to determine if the superheater tubes have cleared.
- Most commonly they use the terminal thermocouples on critical superheater loops to estimate the temperature of the tubes in the furnace cavity, a lower load is held until all tubes reach this threshold.
- Once a threshold temperature is reached then the load is increased to full normal operation.
- This process has two drawbacks:
  - Simply applying a threshold temperature does not ensure tube are cleared and free of condensate;
  - There are a large number of terminal thermocouple to monitor, on a large recovery boiler upwards of 250 thermocouples and mistakes can be made.

Background

- In order to remove the condensate from the tubes the boiler can be "burped" by manipulating the superheater relief valve.
- On some recovery boilers, especially older boilers with very low pressure drop over the superheater, this clearing of tubes can take many hours.
- Recovery boilers are often on the critical path for outages so typically there is significant pressure to minimize this time to remove the condensate and this can lead to risk taking.
- When a recovery boiler is fouled using a simple temperature target is complicated by the slag layer that reduces heat transfer, in addition condensate removal can be more difficult.

Background

- The consequence of not ensuring condensate removal is complete before proceeding to normal firing rates can be very significant including:
  - Attachment damage
  - Tube bowing
  - Tube swelling
  - Tube failure via short term overheat
- This can cause damage to the overheated tube but also to surrounding tubes as the failed tube can “whip” and damage other superheater, and water wall and screen tubes.

Example of short term overheat – the metal temperature rises so that the hoop stress from the internal steam pressure equals the tensile strength of the tube metal operating at an elevated temperatures – for example with SA192 tubes this would occur roughly at a skin temperature of 700^{o}C at typical boiler pressures

Description of Superheater Startup Management System

- This will cover:
  - Goals of System
  - Benefits of System
  - Overall Description of System
  - Details of the Software

Goals of System

- We identified four issues with current methodologies:
  - It is often not clear that a tube has cleared by applying simple criteria like a threshold temperature.
  - Tracking that each tube has cleared and keeping a record of this with a large number of thermocouples can be a complex and data intensive process prone to errors.
  - It can be unclear what the roles and responsibilities of the operators, shift managers, and area mangers are in this process.
  - Looking at historic data can be very difficult with many mill information systems, so looking back at a particular start-up to determine root causes of failures can be cumbersome.

Benefits of System

- If we were able to design and implement a system that addressed the known issues, then we identified the following benefits:
  - 1. Avoidance of risky start-up practices where tubes are subjected to high heat flux without proper cooling resulting in short term overheat damage.
  - 2. A training tool for operators to better understand how to monitor the recovery boiler during start-ups.
  - 3. An easily accessible historic record of how a start-up was done and how the various steps in the process were checked off. This is comparable to a BMS system for starting an auxiliary fuel burner.

Overall Description of the System

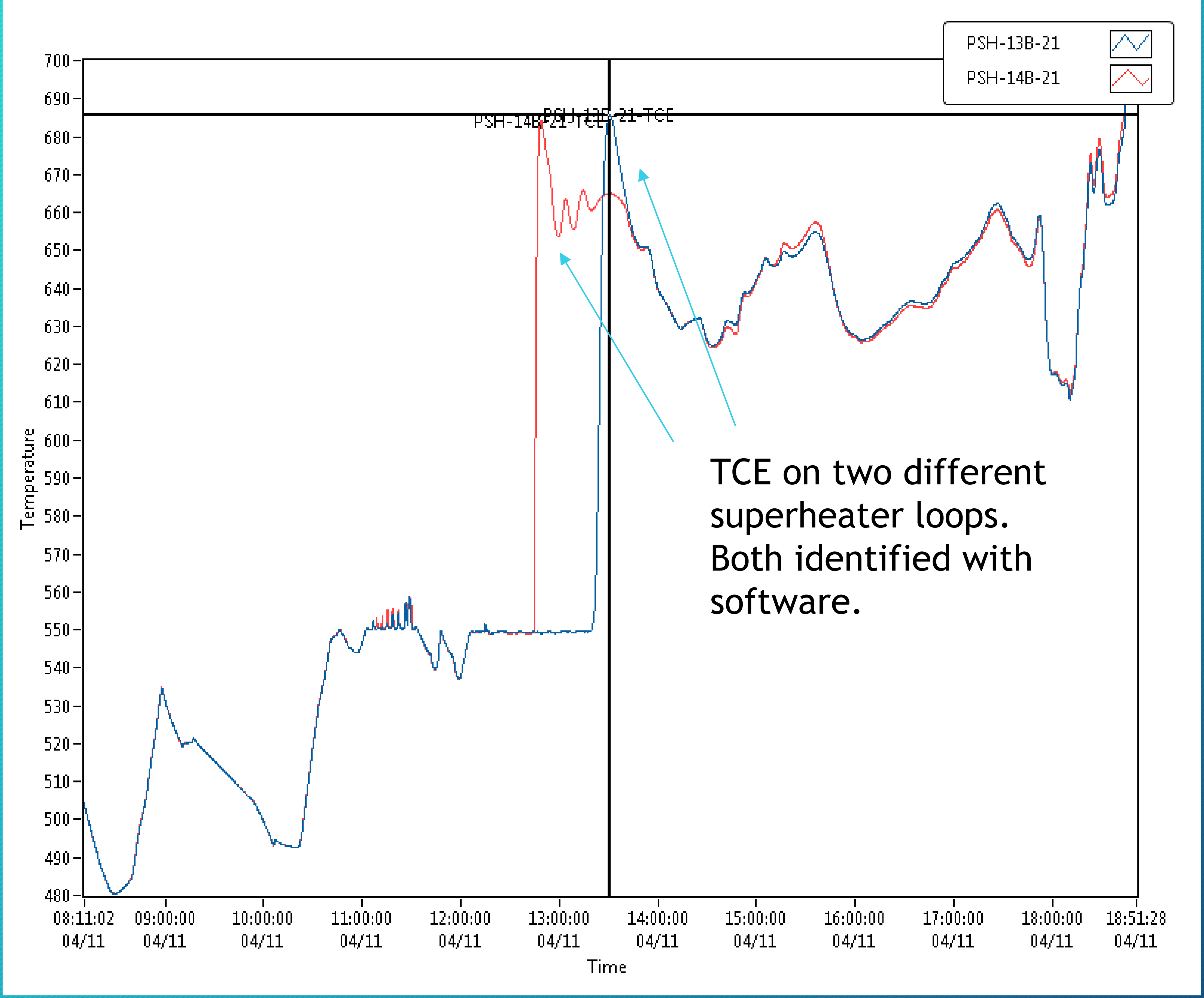
- We call the system SHOP for SuperHeater Overheat Protection
- The underlying methodology that is used and discussed in a few minutes is covered by U.S. Patent US9541282 B2
- The system consists of three components:
  - The superheater terminal thermocouples – in the preferred practice this also includes a PLC dedicated to collecting the data from the thermocouples, most OEMS have recommendations on the tubes that should be instrumented, most critical are the outside loops and the superheaters closest to the furnace cavity.
  - Furnace outlet temperature monitoring – the preferred approach is to use an optical pyrometer designed specifically for this duty.
  - The software which will be discussed in more details.

Details of Software

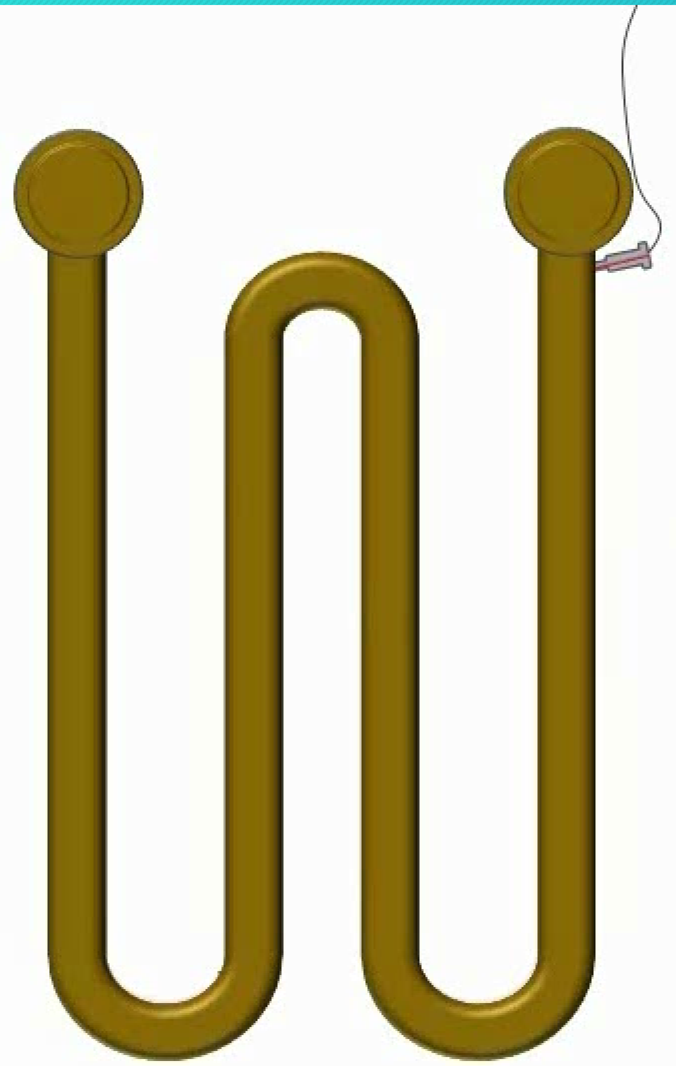
- The application can be implemented on a Windows based PC or Server with minimum requirements of (Core i7 (or equivalent) or later (64-bit); RAM: 8 GB; Screen Resolution: 1024 x 768 pixels; Drive: 500GB).
- The PC must be linked to the device collecting the thermocouple data and the optical pyrometer, additional data such as steam flow rate, pressure and temperature, and liquor firing rates also need to be provided using the OPC standard.

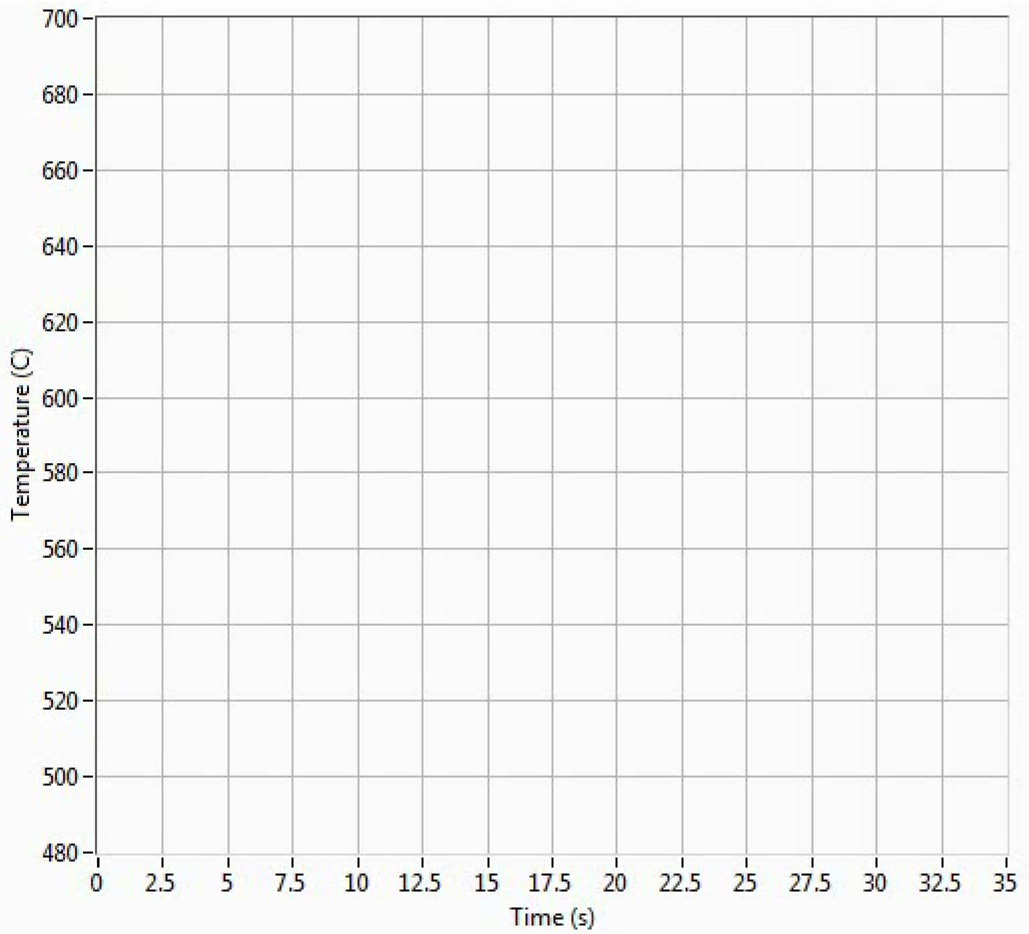
Detecting Tube-Clearing Events (TCE)

- A fundamental feature is the logic necessary to detect a TCE. This is a more definitive way to verify that the condensate has been removed from a tube then by using a simple threshold temperature.
- A TCE has a very specific fingerprint.
  - The temperature rapidly increases, typically 25-75^{o}C over a few minutes
  - Followed by drop in temperature of 10-20^{o}C
  - This will now be shown graphically and via a short video
- The temperature rise is much more rapid than seen during a load increase, the maximum temperature during the TCE is also higher than the current drum temperature.



TCE on two different superheater loops. Both identified with software.





Note: Speed of Tube Clearing process is increased for demonstration purposes

Operating States

- It is important to track the current operating state of the recovery boiler in order to determine when to activate the monitoring system.
- Any time there is a stoppage in the total fuel firing on the boiler ("Boiler Trip") the system must be activated as there is a risk of condensate being present in the lower tube bends.
- The system is only active in the "startup" state.

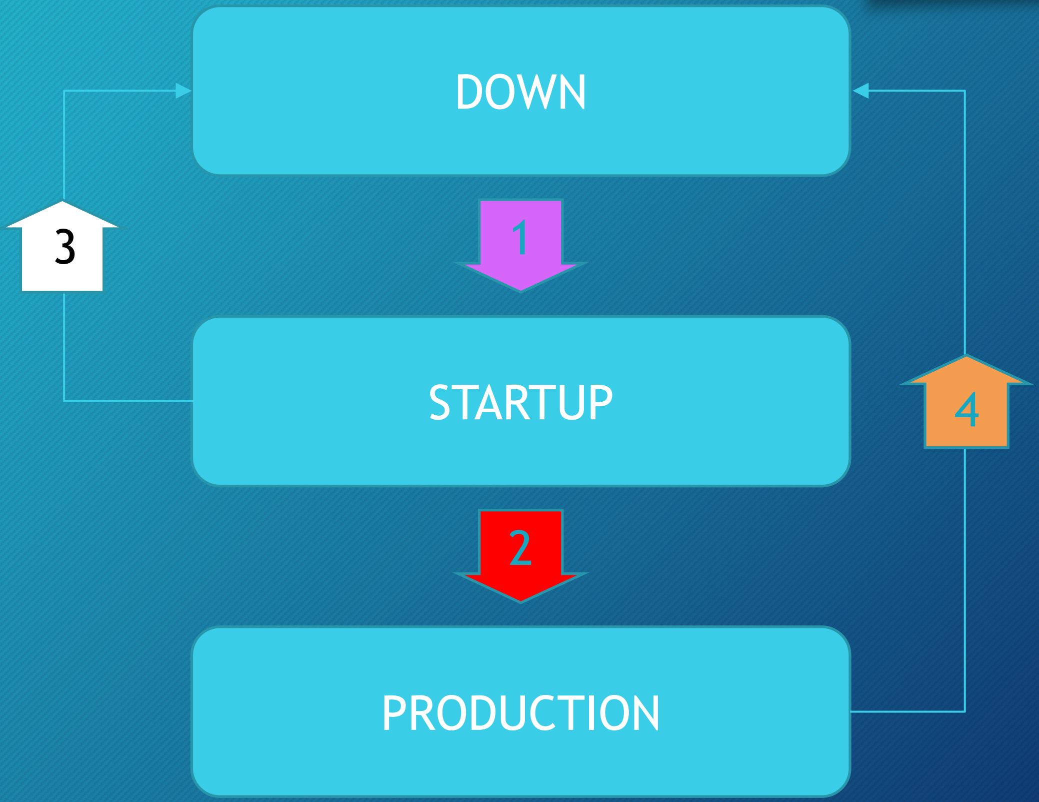
SHOP Operating "STATES"

State Change 1 would capture when the boiler is restarted after any downtime where condensate could accumulate in superheated tubes.

State Change 2 is determined once all instrumented loops have shown a TCE or this indication has been overridden by authorized personnel (e.g. bad thermocouple). Firing rates would then increase allowing the IR probe at the furnace outlet to rise above a predetermined limit (e.g. 500ºC).

State Change 3 STARTUP to DOWN would cover the cases where normal startup is aborted prior to reaching all permissives to move to the production state, an example here would be a main fuel trip during startup.

State Change 4 would be a boiler trip when operating normally. It is possible that some very short trips and restarts would not require that the boiler go to the DOWN state



Verification Features

- The TCE feature of the software is key to identifying when condensate is removed from the tubes.
- The most complete verification method would then have operator use software to verify that all instrumented tubes have seen a TCE. A Supervisor would then double-check and if satisfied release to “PRODUCTION” state.
- In practice not all loops may see a TCE due to lack of condensate in loop or a bad thermocouple. A loop can then be overridden.
- An alternative approach is to just examine the loops where a TCE has not been seen by the system and rely on the system to “auto-acknowledge”, this would require gaining confidence in the system.
- Supervisor verification can also be skipped if confidence is gained.
- All of these options are configurable.
- Progress can be tracked on a dashboard

List of Tube Clearing Events Identified in the Startup Report

IPG2 20140323 Startup.xlsx - Microsoft Excel

SuperHeater Overheat Protection (SHOP)

Server Name:	SHOP_IPG	User Name:	tcarlier
Server Version:	Version (1.1)	Startup Date/Time:	3/23/2014 16:41
Boiler Name:	RB2		
Boiler Description:	IP Georgetown Recovery Boiler #2		

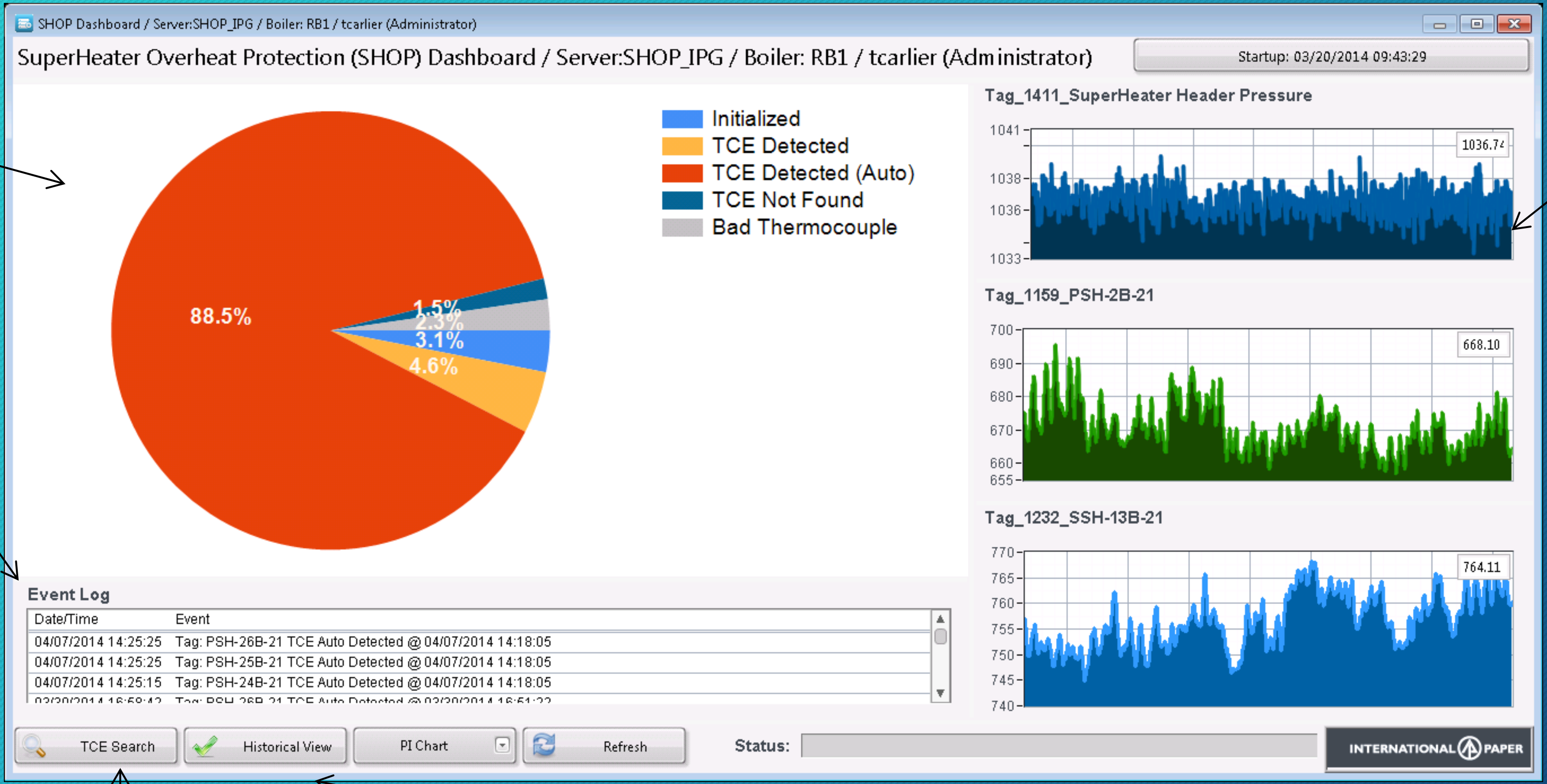
Tag	Location	TCE Status	TCE Date/Time	Auto Detection	Auto Detection Date/Time	User Name
PSH-1B-22	Primary Superheater	Detected	3/25/2014 0:41	Yes	3/25/2014 0:41	tcarlier
PSH-2B-22	Primary Superheater	Detected	3/25/2014 0:40	Yes	3/25/2014 3:20	tcarlier
PSH-3B-22	Primary Superheater	Detected	3/25/2014 0:41	Yes	3/25/2014 2:56	tcarlier
PSH-4B-22	Primary Superheater	Detected	3/25/2014 0:39	Yes	3/25/2014 2:55	tcarlier
PSH-5B-22	Primary Superheater	Detected	3/25/2014 0:40	Yes	3/25/2014 2:55	tcarlier
PSH-6B-22	Primary Superheater	BAD TC	3/21/2014 13:36	No	na	tcarlier
PSH-7B-22	Primary Superheater	Detected	3/25/2014 0:42	Yes	3/25/2014 2:55	tcarlier
PSH-8B-22	Primary Superheater	Detected	3/25/2014 0:44	Yes	3/25/2014 2:55	tcarlier
PSH-9B-22	Primary Superheater	Detected	3/25/2014 0:41	Yes	3/25/2014 2:55	tcarlier
PSH-10B-22	Primary Superheater	Detected	3/25/2014 1:07	Yes	3/25/2014 3:20	tcarlier
PSH-11B-22	Primary Superheater	BAD TC	3/21/2014 13:32	Yes	3/25/2014 0:50	tcarlier
PSH-12B-22	Primary Superheater	Detected	3/25/2014 0:40	Yes	3/25/2014 2:55	tcarlier
PSH-13B-22	Primary Superheater	Detected	3/25/2014 0:54	Yes	3/25/2014 2:55	tcarlier
PSH-14B-22	Primary Superheater	BAD TC	3/21/2014 13:37	No	na	tcarlier

Sheet1 Sheet2 Sheet3

SHOP Client: Dashboard

Summary

Event timeline



Real-time trend: User selectable

View past startups

View Active Startup TCE's

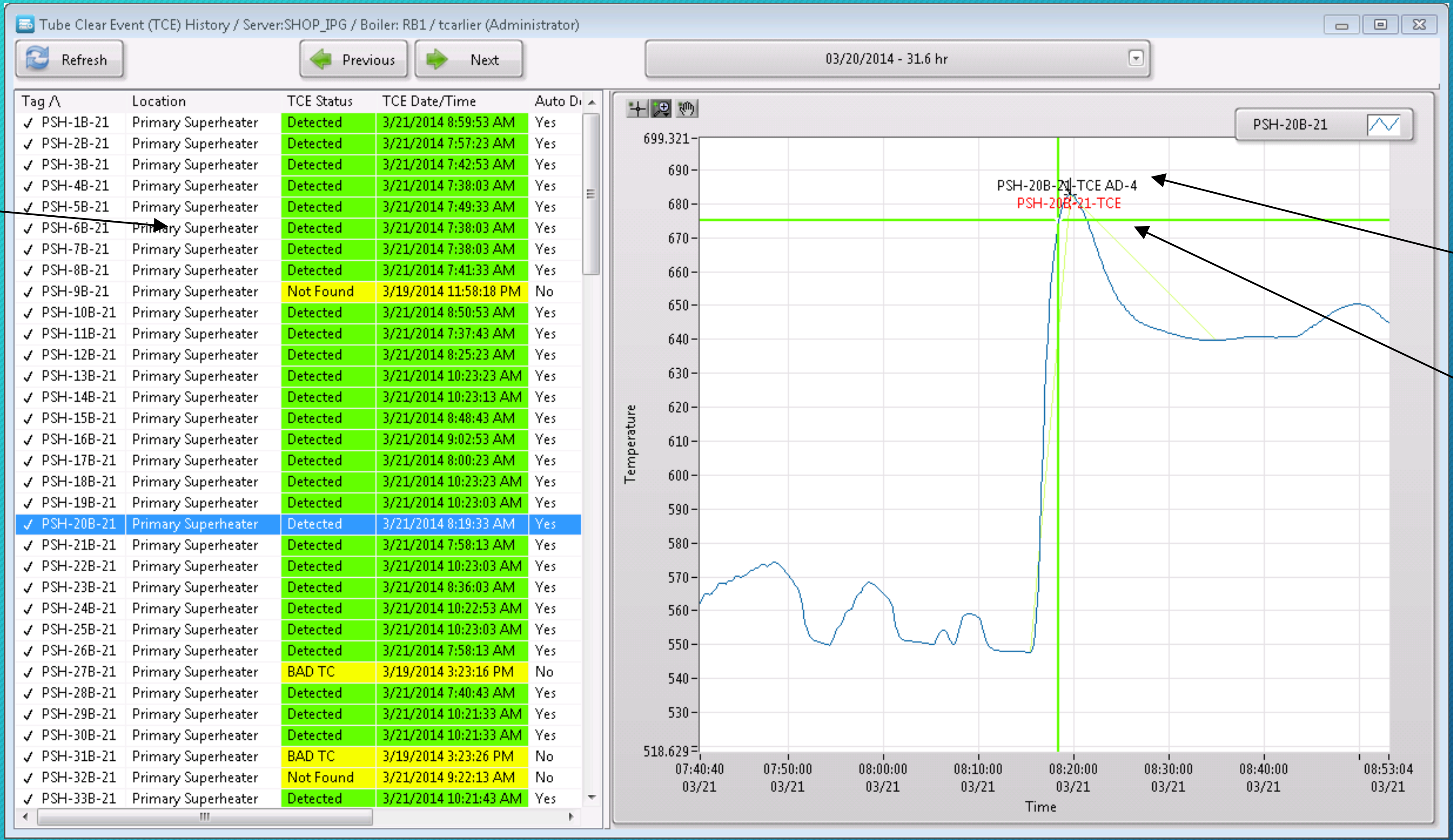
Historian Features

- Previous startups can be viewed with the historian.
- Operators can then learn what actions may assist in clearing tubes (burner operation, exercising the superheater relief vent, pressure control, etc.) as the system is used with multiple startups.
- Problematic loops could be identified that clear later, closer inspection of these tubes could be done as they would be potential exposed to higher temperatures.
- In the case where a tube has failed a record of the event would be preserved.
- Other boiler operating data can be added to the historian as long as a linkage to the mill information system is made.

Historian showing tabular and graphical data

Listbox of All TC Tags

Selected Tag (s)


Tube Clear Event (TCE) History / Server:SHOP_IPG / Boiler: RB1 / tcarlier (Administrator)

Refresh | Previous | Next | 03/20/2014 - 31.6 hr

Tag /\	Location	TCE Status	TCE Date/Time	Auto D
✓ PSH-1B-21	Primary Superheater	Detected	3/21/2014 8:59:53 AM	Yes
✓ PSH-2B-21	Primary Superheater	Detected	3/21/2014 7:57:23 AM	Yes
✓ PSH-3B-21	Primary Superheater	Detected	3/21/2014 7:42:53 AM	Yes
✓ PSH-4B-21	Primary Superheater	Detected	3/21/2014 7:38:03 AM	Yes
✓ PSH-5B-21	Primary Superheater	Detected	3/21/2014 7:49:33 AM	Yes
✓ PSH-6B-21	Primary Superheater	Detected	3/21/2014 7:38:03 AM	Yes
✓ PSH-7B-21	Primary Superheater	Detected	3/21/2014 7:38:03 AM	Yes
✓ PSH-8B-21	Primary Superheater	Detected	3/21/2014 7:41:33 AM	Yes
✓ PSH-9B-21	Primary Superheater	Not Found	3/19/2014 11:58:18 PM	No
✓ PSH-10B-21	Primary Superheater	Detected	3/21/2014 8:50:53 AM	Yes
✓ PSH-11B-21	Primary Superheater	Detected	3/21/2014 7:37:43 AM	Yes
✓ PSH-12B-21	Primary Superheater	Detected	3/21/2014 8:25:23 AM	Yes
✓ PSH-13B-21	Primary Superheater	Detected	3/21/2014 10:23:23 AM	Yes
✓ PSH-14B-21	Primary Superheater	Detected	3/21/2014 10:23:13 AM	Yes
✓ PSH-15B-21	Primary Superheater	Detected	3/21/2014 8:48:43 AM	Yes
✓ PSH-16B-21	Primary Superheater	Detected	3/21/2014 9:02:53 AM	Yes
✓ PSH-17B-21	Primary Superheater	Detected	3/21/2014 8:00:23 AM	Yes
✓ PSH-18B-21	Primary Superheater	Detected	3/21/2014 10:23:23 AM	Yes
✓ PSH-19B-21	Primary Superheater	Detected	3/21/2014 10:23:03 AM	Yes
✓ PSH-20B-21	Primary Superheater	Detected	3/21/2014 8:19:33 AM	Yes
✓ PSH-21B-21	Primary Superheater	Detected	3/21/2014 7:58:13 AM	Yes
✓ PSH-22B-21	Primary Superheater	Detected	3/21/2014 10:23:03 AM	Yes
✓ PSH-23B-21	Primary Superheater	Detected	3/21/2014 8:36:03 AM	Yes
✓ PSH-24B-21	Primary Superheater	Detected	3/21/2014 10:22:53 AM	Yes
✓ PSH-25B-21	Primary Superheater	Detected	3/21/2014 10:23:03 AM	Yes
✓ PSH-26B-21	Primary Superheater	Detected	3/21/2014 7:58:13 AM	Yes
✓ PSH-27B-21	Primary Superheater	BAD TC	3/19/2014 3:23:16 PM	No
✓ PSH-28B-21	Primary Superheater	Detected	3/21/2014 7:40:43 AM	Yes
✓ PSH-29B-21	Primary Superheater	Detected	3/21/2014 10:21:33 AM	Yes
✓ PSH-30B-21	Primary Superheater	Detected	3/21/2014 10:21:33 AM	Yes
✓ PSH-31B-21	Primary Superheater	BAD TC	3/19/2014 3:23:26 PM	No
✓ PSH-32B-21	Primary Superheater	Not Found	3/21/2014 9:22:13 AM	No
✓ PSH-33B-21	Primary Superheater	Detected	3/21/2014 10:21:43 AM	Yes

Auto detected TCE
(black – AD-4)

User Verified TCE
(Red - TCE)

Results of First Installation

- During the initial installation of this system we were able to observe a number of issues, namely
- When to activate the system – We observed that it is not necessary to start the system immediately after fuel is added to the boiler, it may be best to wait until some threshold boiler drum pressure is reached prior to activating so that false TCEs are avoided due to large fluctuations in fuel input early in the startup. This was addressed in the "automatic" detection system that was subsequently installed at the first host site by requiring that the TCE be in a defined temperature range.
- How do you balance between missing clearing events and miss identifying a clearing events? – We were able to refine the algorithm that identified the TCE, most likely some customization on each boiler will be necessary but this can easily be done using the existing software. This would capture correctly the vast majority of these events, but some boilers may still require an operator to review the suspected events to verify.

Results of First Installation

- We observed that trips on a recovery boiler with a dirty superheater are the most difficult cases, especially difficult are trips during the restart of a dirty boiler, for example losing burners when trying to restart.
  - We observed cases where the system should have gone into Offline mode in order to properly clear tubes, but did not.
  - Clearly there is a need to carefully select boiler operating parameters and thresholds for these parameters so that this is handled correctly. A boiler “trip” tag is one means to handle this.

Conclusions

- Short term overheat of superheaters on recovery boilers is an ongoing issue – many cases have been seen even on very recently constructed boilers where inadequate clearing of tubes has led to failures. These failures risk equipment damage, personnel exposure and downtime on the recovery boiler.
- The tool presented has three components: properly instrumented superheater loops, an optical pyrometer located immediately upstream of the superheater section, and a software tool.
- The software tool includes features for identifying TCEs, managing the process of ensuring all tubes have cleared or have been over-ridden prior to increasing firing rates on the boiler, and an historian to view past startups in an easy to navigate manner.

Conclusions

- We were able to conclude that as designed and implemented this tool will significantly reduce the risk of overheat failures, as it will prevent premature ramp up of firing rates on recovery boilers, a significant root cause of short-term overheat failure of superheater tubes.
- Preliminary installation of this system has shown that restarts with dirty tubes can be more difficult. Care must be used when deciding under which operating conditions the “startup” mode of the system is activated in order to capture all times that there is risk of condensate being in the superheater loops.