IGNORING THE FUNDAMENTALS OF COMBUSTION *CAN* AND *WILL* IMPACT THE LIFE OF YOUR SUPERHEATER AND REHEATER

A typical 500 MW boiler may be about 60 ft. wide by 50 ft. deep and, depending on the manufacturer, could have 24 to 48 burners located in the lower half of the boiler approximately 60 ft. below the nose arch or platen superheater assemblies. Most of these boilers are also equipped with tube metal thermocouples installed on the terminal superheater and reheater tubes and providing an indication on the final metal temperatures of the selected tubes. This is important because metals, just like most other materials when heated, have properties that begin to change and, therefore, knowing your metal's limitations is important.

In This Issue:

- How hot is too hot for your tubes?
- What kind of reduction in tube life can be expected if the tubes are operated above design temperatures?
- How can we prevent elevated tube metal temperatures?

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Boilers in this size range can have over 500 individual tube circuits for the superheater and reheater. Having at least 20% of these individual circuits equipped with a tube metal thermocouple is recommended. Since there is no significant heat transfer taking place in the penthouse; you will typically find the thermocouples installed in this location. When installed correctly, the measured tube metal temperature is normally very close to the steam temperature leaving that circuit. With that in mind, it is critical to ensure that, once the pad-welded tube metal thermocouples are installed, they also be insulated (as shown in Figure 1) to provide a truer temperature.

Figure 1: Tube Metal Thermocouples (Left); After Insulation (Right)

Without tube metal thermocouples in place, operators may only have a left and right-side steam temperature or spray flow indication to provide evidence of heat imbalances within the furnace; unless a complete High Velocity Thermocouple (HVT) test is conducted. Even with an HVT test, most HVT probes only have a 20' insertion depth. This means you are usually going to miss a relatively large portion of the furnace. The value that tube metal thermocouples provide is a more complete depiction of possible combustion imbalances taking place in the lower furnace. Storm has found temperatures within many furnaces deviating as much as 1,000°F which will greatly impacts heat absorption within the furnace. The following figure illustrates a furnace that had an average steam temperature that was steady at 1,005°F. However, the individual tube metal temperatures varied by over 150°F on a 360 MW coal fired utility boiler.

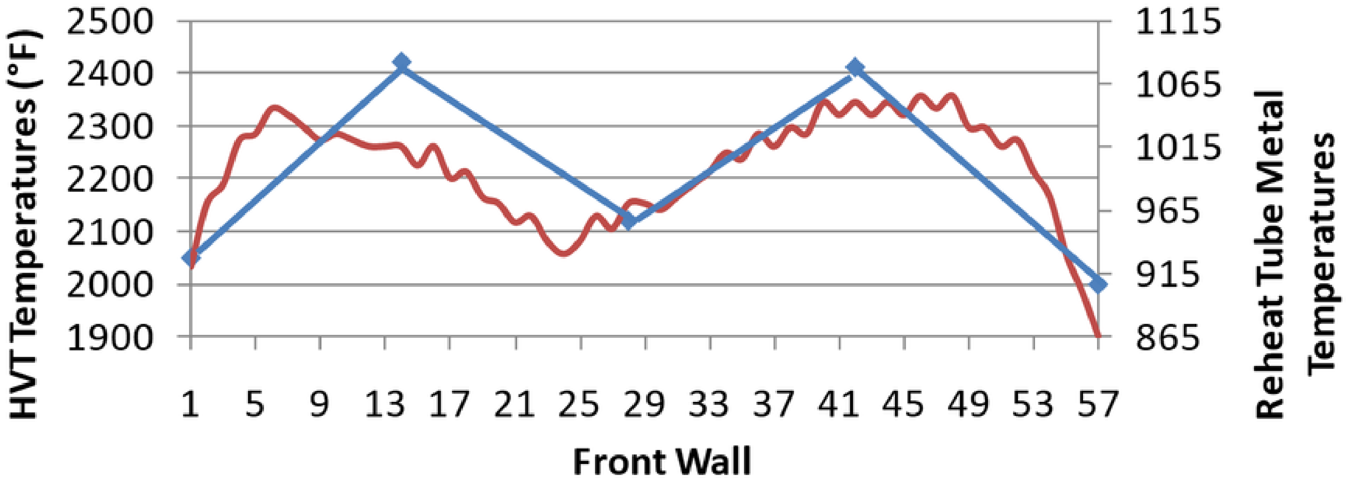

Figure 2: Tube Metal Temperatures vs. HVT Measured FEGT

How Hot is Too Hot for Your Tubes?

The reliability of your boiler requires maintaining metal temperatures below a certain threshold. Barring something like a flow restriction or scaling within the tube assemblies; the fire side flue gas temperatures are what drive the metal temperatures higher. This is a direct result of either secondary combustion or poor heat transfer rates in the lower furnace. Superheater and reheater materials vary between boilers and, in a lot of cases, can vary within the actual circuits and panels of a single boiler. For example, a recent facility Storm was involved with had a platen superheater assembly with multiple dissimilar metal welds for materials including (but not limited to) SA-213 TP-347H, SA-213 T22, SA-213 TP 304H and more. Let's look at some of the properties for these materials in Table 1: Common Alloys Used in Superheaters.

Table 1: Common Alloys Used in Superheaters

Common Alloys Used in Superheater Assemblies for Utility Boilers									
ASME Specification Number	Minimum Tensile Strength (psi)	Minimum Yield Strength (psi)	Carbon (Min. - Max)	Manganese (Min. - Max)	Silicon (Min. - Max)	Nickel (Min. - Max)	Chromium (Min. - Max	Molybdenum (Min. - Max)	Other
SA-213-T11	60,000	30,000	0.15	0.30 - 0.60	0.50 - 1.00	n/a	1.00 - 1.50	0.44 - 0.65	
SA-213-T22	60,000	30,000	0.15	0.30 - 0.60	0.5	n/a	1.90 - 2.60	0.87 - 1.13	
SA-213-T91	85,000	60,000	0.08 - 0.12	0.30 - 0.60	0.20 - 0.50	n/a	8.00 - 9.50	0.85 - 1.05	K - 0.02, S - 0.01
SA-213-TP304H	75,000	30,000	0.04 - 0.10	2.00	0.75	8.00 - 11.00	18.00 - 20.00	n/a	
SA-213-TP321H	75,000	30,000	0.04 - 0.10	2.00	0.75	9.00 - 13.00	17.00 - 20.00	n/a	Ti 0.60 Max
SA-213-TP347H	75,000	30,000	0.04 - 0.10	2.00	0.75	9.00 - 13.00	17.00 - 20.00	n/a	Ta 1.00 Max

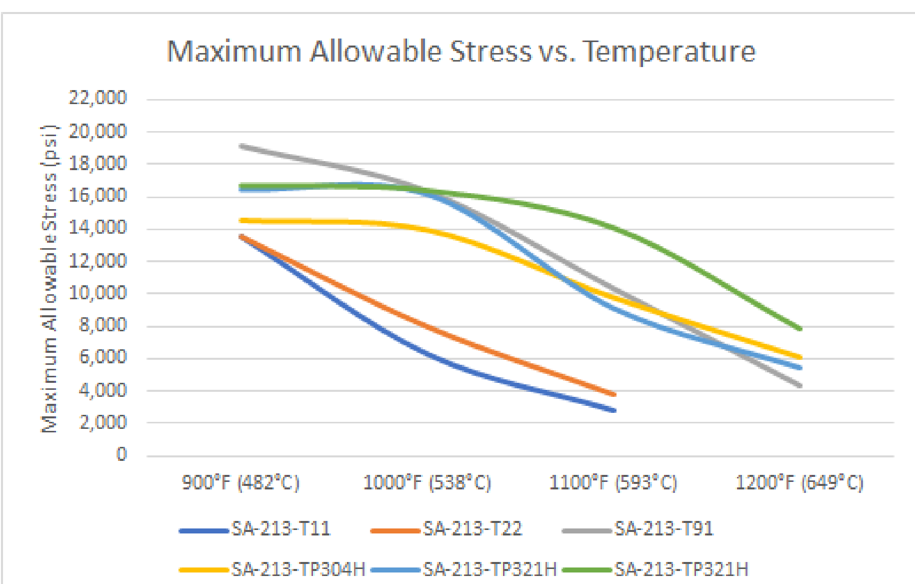

Figure 3: Max. Stress vs. Temperatures

Reviewing the maximum allowable stresses, published by the ASME, at the temperatures normally experienced in a superheater or reheater, plotted graphically in Figure 3, it becomes obvious how much the temperature can impact the reliability of your boiler.

Storm's experience throughout the years is that, generally, the oxidation limits for these commonly used alloys is slightly lower than what is commonly published. Table 2 illustrates our experience for the maximum temperature for each of these materials.

Table 2: Oxidation Limits

Maximum Use Temperatures		
ASME Specification Number	Storm Experience (Deg. F)	Commonly Published (Deg. F)
SA-213-T11	1,025	1,025
SA-213-T22	1,075	1,075
SA-213-T91	1,100	1,150
SA-213-TP304H	1,200	1,300
SA-213-TP321H	1,200	1,300
SA-213-TP347H	1,200	1,300

What kind of reduction in tube life can be expected if the tubes are operated above design temperatures?

Our team at Storm Technologies, Inc. has seen boilers operating with SA-213-T22 tube alloys that have not been replaced for 30 years. Those boilers operated below the peak outer skin tube temperature of 1,075°F. The Larsen-Miller Parameter (LMP) is one method for predicting the life of your tubes and reinforces our actual experience. What you will find when using the LMP is that, once your tube experiences temperatures above the maximum recommended temperature, you begin to lose years of life on that tube quickly. Keep in mind that once the tube's outer surface temperature exceeds the oxidation limit for the tube, even if that tube is cooled immediately, you have already inflicted damage to that tube that cannot be reversed.

The Larsen-Miller Parameter is defined by the following equation:

$$LMP=(T+460)\times(20+Log(t))$$

Where: T = Temperature (deg. F)
t = hours of operation

To better give you an idea of how the tube metal temperature affects the life of your superheater and reheater, I have provided a graphical example of the Larsen-Miller Parameter. For this example, I calculated the LMP of a material given a 30-year life at a tube metal temperature of 1,075°F. The LMP for this material is 39,002. As you can see the life of the material quickly lessens as the temperature is only marginally increased. At just 10 degrees over the design temperature of 1,075°F, the life is reduced by 31.5% to approximately 20 years. Whereas, if material operates 20 degrees over the design temperature, the tube's life is cut in half to approximately 14 years. If you remember, back in Figure 2, the tube metal temperatures varied more than 100°F between tubes. If they are above the design temperature, they are being irreparably damaged. This is another reason Storm tends to be more conservative on our maximum temperature recommendations.

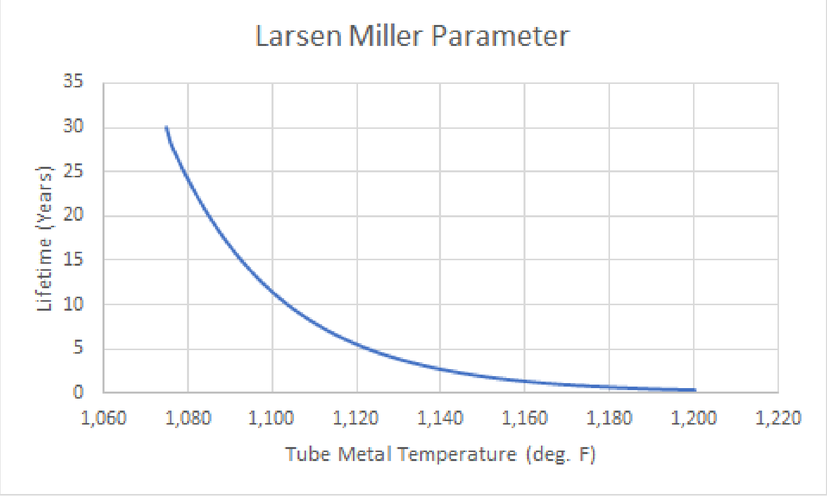

Figure 4: LMP Example

While tube metal thermocouples are a very resourceful tool for the operators and plant team, as stated earlier, these are located in the penthouse where there is no heat transfer to the steam so the surface temperatures are going to be less than those in the furnace, where active heat transfer is taking place. This brings me to the next discussion point; flue gas temperatures in the upper furnace. Most furnaces are designed to have a furnace exit gas temperature just slightly above 2,000°F. Storm typically recommends that the temperature be 2,150°F. These numbers are based off the total heat release rate for a boiler with commercially clean waterwalls and surfaces. At these temperatures, boilers can easily maintain their 1,000°F – 1,005°F steam temperature. Below are two examples of the typical temperature gradients through the tube wall in the upper furnace. The figure below on the left shows an ideal scenario where the flue gas temperatures are 2,150°F but the skin temperature is still slightly elevated for a SA213-T22 material in Storm's experience. The figure on the right, though, is what Storm commonly finds in over 50% of the boilers we test on a regular basis; the flue gas temperatures are somewhere north of 2,500°F. This is going to have a direct impact on the tube metal temperature in the furnace and will translate to higher indicated temperatures if thermocouples are installed on this tube. In the case of the tube on the right, if operating with metal temperatures above 1,200°F for many hours, the life of this tube will be reduced to less than five years very quickly.

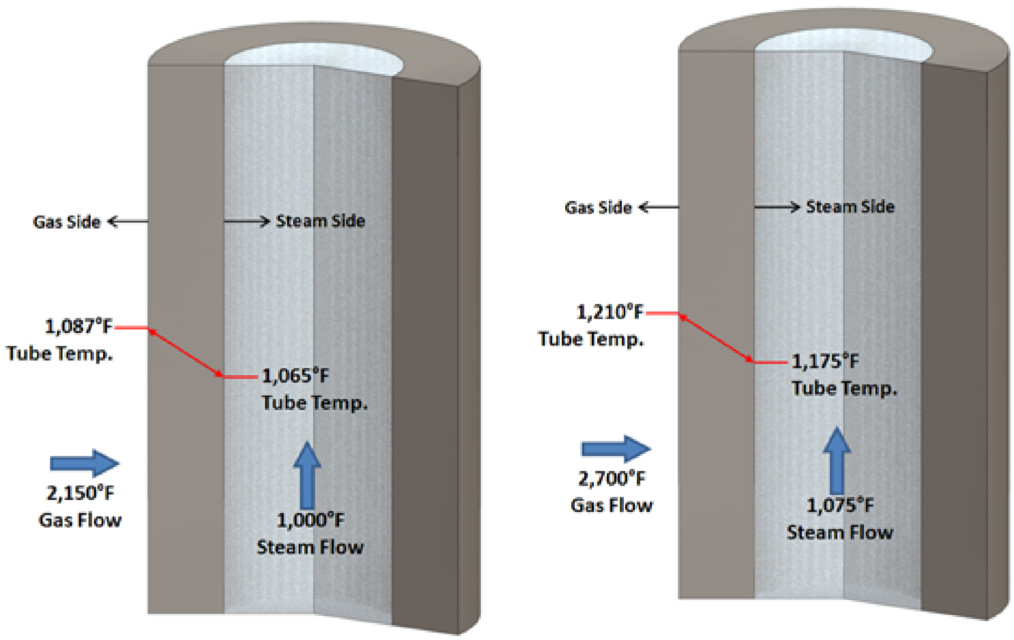

Figure 5: Tube Wall Temperature Gradient Examples

How Can We Prevent Elevated Tube Metal Temperatures?

What is done to improve the combustion in the burner belt and improve lower furnace heat absorption is going to be critical for reducing the flue gas temperatures in the upper furnace and effectively reducing tube metal temperatures. Back in Figure 5, I included an example where you have two tubes; one that is in a zone of the furnace that has a flue gas temperature of 2,150°F and another at 2,700°F. Most performance engineers and plant folks may find it hard to believe that their furnace can have areas within the same boiler that are operating at these two different temperatures at the same time. Well, it's not uncommon but it is often overlooked when using infrared temperature devices. These may be permanently installed or just a handheld device that is shot through the observation doors. Infrared devices can do a pretty good job at providing you with a bulk gas temperature, but they do not do a very good job at determining peak temperatures or providing you with a temperature profile. The best first step for understanding what is going on in the furnace is to conduct a comprehensive boiler performance test including an HVT traverse of the upper furnace. An HVT test utilizes a water-cooled probe to measure a true flue gas temperature every 2' within the furnace. This method provides the test team and plant with a point by point map of the temperature profile within the furnace. Storm measures temperature variations over 500°F on a routine basis, no matter the boiler design, as shown in Figure 6. On average, the bulk gas temperature in this boiler was 2,154°F, dead on with what Storm recommends and probably very close to the boiler's design furnace exit gas temperature. It is not until you examine the temperatures on a point by point basis do you find that there are gas touched tubes within the furnace in an atmosphere that exceeds 2,500°F, which is going to negatively impact the life of the tubes.

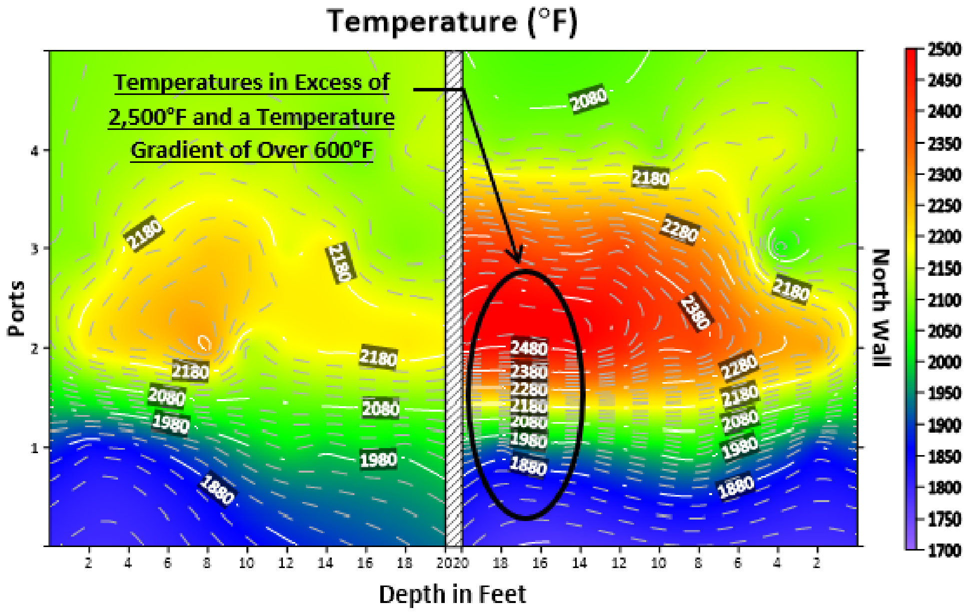

Figure 6: 2020 HVT Test Data Showing 600°F+ Temperature Stratifications

Poor heat transfer in the lower furnace at the burner belt will cause an overall elevated furnace exit gas temperature, but what about localized hot spots? A case like what was shown in Figure 4 is likely due to poor combustion, since there is a localized hot spot within the furnace. This is going to come down to the inputs of the furnace: fuel and air. Proper distribution of the air and fuel, correct fuel sizing, and optimized mechanical tolerances of the burners can all impact the combustion efficiency.

Much of this article focused solely on the life of the tubes as a result of elevated tube metal temperatures. There are many other factors that can impact the reliability and performance of your boiler that are also directly affected by elevated furnace exit gas temperatures and poor combustion. Here are a few other items that should also concern you regarding your plant's reliability:

- Boiler slagging
- Excessive soot-blower operation due to boiler slagging
  - This can increase tube erosion and can lead to an increase in popcorn ash that can become a burden to SCR and APH performance.
- Increased fan power requirements due to slagging and higher draft losses
- Tube alignment issues due to damage of alignment attachments.
  - This can locally increase flue gas velocities and catch more ash and slag due to more narrow gas lanes.
- Major heat rate penalties associated with increased SH and RH spray flows

To be fair, we understand that tube metal temperatures can also be commonly affected by poor circulation and scale buildup within the tubes. However, when the gas temperatures line up with the tube metal thermocouples as shown earlier in Figure 1, the metal temperatures can mainly be attributed to flue gas temperature imbalances. To that point, Storm's experience has been that a single burner with a large fuel imbalance can cause localized zones of high temperatures in the upper furnace. By focusing on the fundamentals, Storm's 13 Essentials for Optimum Combustion, you can be sure that elevated tube metal temperatures due to poor combustion are not going to be a problem. Bringing in an outside firm with the experience and expertise to address and mitigate high tube metal temperatures may seem expensive at first glance, but it is merely a drop in the bucket when compared to the costs to replace a superheater due to overheating or even a short forced outage caused by a tube leak. If this is something you are experiencing, or maybe your boiler doesn't have the thermocouples in place to measure this, and you would like to have more information on an effective combustion improvement program or high-quality tube metal thermocouples; please feel free to give us a call. We would love to work with you to evaluate or improve your tube metal temperatures and the reliability of your boiler.

Respectfully,

Shawn Cochran, P.E. and The Storm Technologies Team