

BURNER FLAME TEMPERATURE DURING WARM UP AND HOT STANDBY

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Presented at the Brimstone Sulfur Symposium
Facilitated by Brimstone STS Limited
Vail Colorado

September 12 to 16, 2011

Summary

Typically, more damage occurs in an SRU during start-up and shutdown than any other time. Hot Standby is another Thermal Reactor and WHB killer. One of biggest concerns is operating the Thermal Reactor Burner at stoichiometric natural gas and air flame temperatures. The best available refractory cannot withstand the temperature of a stoichiometric flame. An understanding of the potential flame temperatures is critical since you cannot fully trust the temperature measurement devices. These flame temperature concerns can be successfully addressed by using a proper flow rate of tempering media (steam or nitrogen) whenever natural gas or other fuels are used during start-up, shutdown or hot standby.

Stoichiometric Flame Temperatures

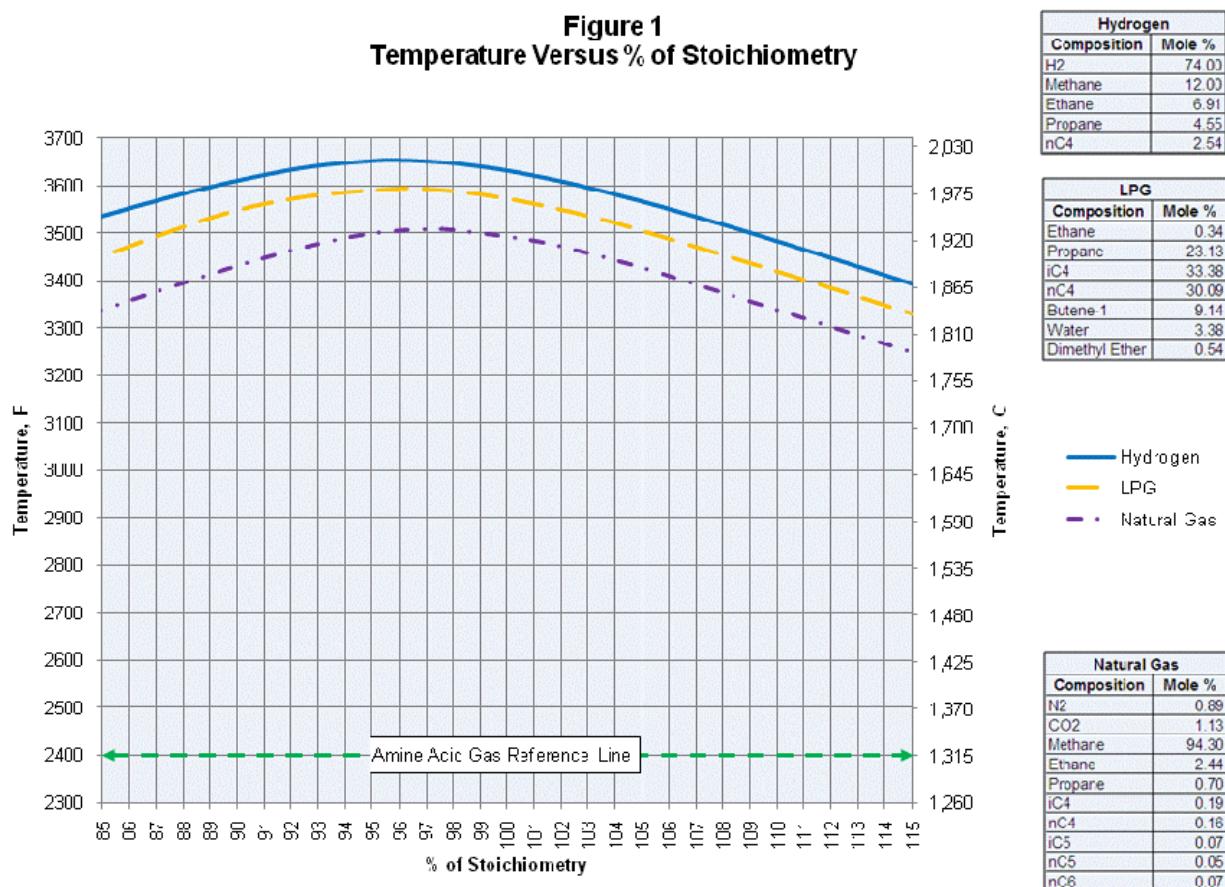
Start-up of an SRU Thermal Reactor involves operating the main burner with natural gas and air to heat the Thermal Reactor, WHB and downstream equipment. The ratio of air to natural gas is adjusted to stoichiometric conditions. If the unit was properly shutdown including operation to purge sulfur (heat soak) from the catalyst beds then the subsequent start-up of the Thermal Reactor burner can operate with some excess air until the catalyst beds approach 330F (165C). Typical start-up and shutdown steps were described by d'Haëne and Cicerone [1] at this conference in 2010. If the unit was shutdown without a sulfur purge then the main burner will need to be started and quickly adjusted to stoichiometric conditions. The headaches associated with a restart after a shutdown with no heat soak were discussed by Young [2]. Hot standby involves operating the Thermal Reactor Burner at stoichiometric conditions for a day or so while waiting to recharge acid gas feed.

As shown in Figure 1, the temperature of a stoichiometric natural gas and air flame is quite high at 3500F (1925C). The X axis is percentage (%) of stoichiometric air and the Y axis is flame temperatures.

The flame temperatures are simulated values from a Gibbs Minimization reactor in ProMax®. Typical refinery fuel gas produces a similar stoichiometric flame temperature. Some units are forced to use high hydrogen content fuels which have even higher stoichiometric flame temperatures 3655F (2010C). SRUs for Syngas units may have no choice other than to use LPG for start-up fuel that has a stoichiometric flame temperature of about 3600F (1980C). The reader may notice that the peak flame temperatures are occurring in the range of 96-97% of stoichiometry. The definition used for the stoichiometric air is that all carbon is combusted to carbon dioxide (CO₂). As excess air is reduced some of the carbon is combusted to carbon monoxide (CO). This effect shifts the peak temperature slightly to the left of 100% stoichiometric air.

In comparison to the stoichiometric fuel and air temperatures, operating with a typical refinery amine acid gas feed with air only combustion produces a temperature of about 2400F (1315C). Oxygen enriched combustion can produce very high temperatures and the oxygen concentration is typically limited so the flame temperatures due not exceed the capability of the refractory system.

Figure 1
Temperature Versus % of Stoichiometry



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Refractory Use Temperatures

Determining the hot face refractory maximum use temperature is not an exact science. Refractory datasheets may list a maximum use temperature but these values are based on an oxidizing environment and no applied load. In a Thermal Reactor the burner is operated in a reducing environment and the refractory is under varying compressive load. The refractory maximum use temperature needs to be lowered to account for these conditions. Arriving at a realistic maximum use temperature is a complex analysis requiring experience and an overall understanding of the entire refractory system and how the system will react (move and grow) as the system heats up, temperatures fluctuate during operation, and the system cools down. Also the composition of the refractory material will vary from the composition of the refractory sample used to generate the datasheet. Changes in the trace compounds in the refractory material can have a significant impact on the properties of the refractory. Bottom line is that not all 90% alumina bricks perform the same. Not even all 90% alumina bricks of the same type and brand name will perform the same due to slight differences in the trace compounds. If the design is going to push the limits of the refractory, testing of each lot is needed to confirm properties.

Table 1 shows some approximate maximum use temperatures for some common brick materials that have been used in Thermal Reactors.

Table 1 Brick Maximum Use Temperatures		
Hot Face Material	Korundal XD (90% alumina)	Greenal 90 (90% alumina)
Stated Maximum Use Temperature (oxidizing environment)	3250F	3100F
Reducing Environment	-200F 3050F	-200F 2900F
Mechanical Allowances and Temperature Measuring Differences	-200F 2850F*	-200F 2700F*
Note: All temperatures are approximate and must be verified for each specific application and specific system design.		
* Mean Temperature of Lining		

Table 2 shows some approximate maximum use temperatures for some common castable materials that have been used in Thermal Reactors.

Table 2 Castable Maximum Use Temperatures		
Hot Face Material	GreenCast 94 (94% alumina)	Mizzou Castable (60% alumina)
Stated Maximum Use Temperature (oxidizing environment)	3400F	3000F
Reducing Environment	-200F 3200F	-200F 2800F
Mechanical Allowances and Temperature Measuring Differences	-400F to -500F 2700F to 2800F	-500F 2300F
Note: All temperatures are approximate and must be verified for each specific application and specific system design.		

Castable materials require a larger deduct for mechanical allowances because of the following items.

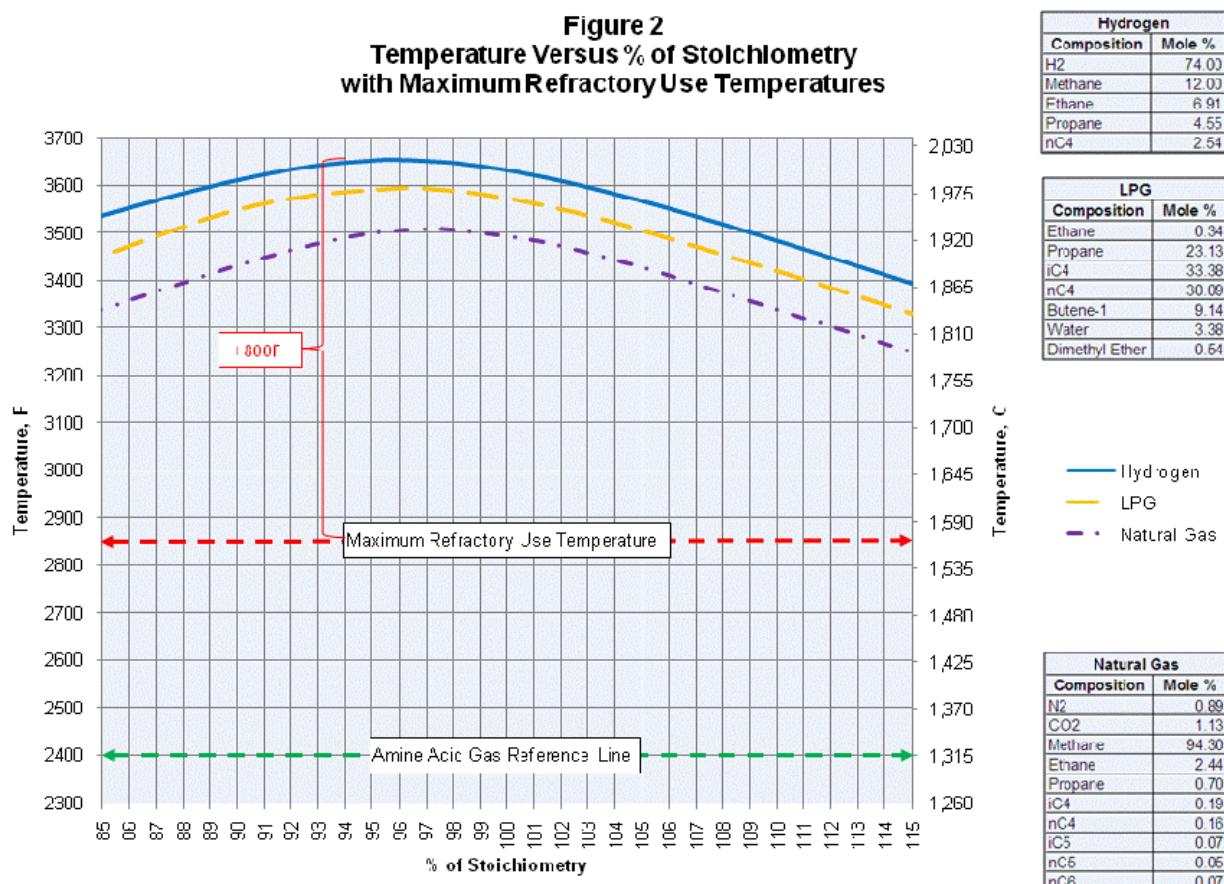
- The brick temperature numbers include some hot loading on the brick in operation while the castable numbers are from technical data sheets that do not have any hot loading.
- Castables will have calcium oxide (CaO) within them that comes from the calcium aluminate binder which acts as a flux at high temperatures and will excessively deform the castable when loaded during high temperature Thermal Reactor operation. *Flux materials are very active at high temperatures and combine with the surface molecules of a crystal and cause the crystal to dissolve.*
- Metallic anchor support systems to stabilize the castable construction can be easily overheated causing unpredictable cracking and slumping.
- Quality control over the water content during mixing, forming, and dryout is moved to the field versus the more easily controlled brick manufacturing. *This can be a major factor.*

Table 3 shows some approximate maximum use temperatures for some common ferrule materials that have been used in Thermal Reactor WHBs.

Table 3 Ferrules Maximum Use Temperatures		
Hot Face Material	Industrial Ceramics (90% alumina)	Industrial Ceramics (94% alumina)
Stated Maximum Use Temperature	No longer offered	3250F
Mechanical Allowances and Temperature Measuring Differences		-300F 2950F
Note: All temperatures are approximate and must be verified for each specific application and specific system design.		

The purpose of this paper is not to attempt to explain how to select the proper refractory for every application of a Thermal Reactor. There are others that are far more experienced than this author in selecting the correct materials and completing a good overall system design. Instead, the purpose of this paper is to point out that there is not a single refractory available that can withstand a stoichiometric fuel and air flame temperature.

As shown in Figure 2, the stoichiometric flame temperatures are much higher than the refractory maximum use temperatures.



Tempering

Some type of tempering of the flame is required to keep the temperature at a level that the refractory can handle. Nitrogen tempering is possible but in most applications it is expensive. Steam tempering is more commonly used because an SRU typically has an excess of steam available. Steam also has an added advantage in that the heat capacity is roughly double that of nitrogen and therefore takes half the mass flow to achieve the same tempering effect. Steam also will condense at the Quench Column and not add load to the downstream equipment (i.e., Incinerator).

Figure 3 shows the stoichiometric flame temperatures for natural gas at air with different amounts of tempering steam injection. The data shows that it would take at least 5 lbs of steam for every lb of natural gas burned at stoichiometric conditions to keep the flame temperature below 2600F (1425C) to provide a safety margin under the refractory maximum use temperature.

Figure 3
Temperature Versus % of Stoichiometry
Natural Gas with Steam Tempering

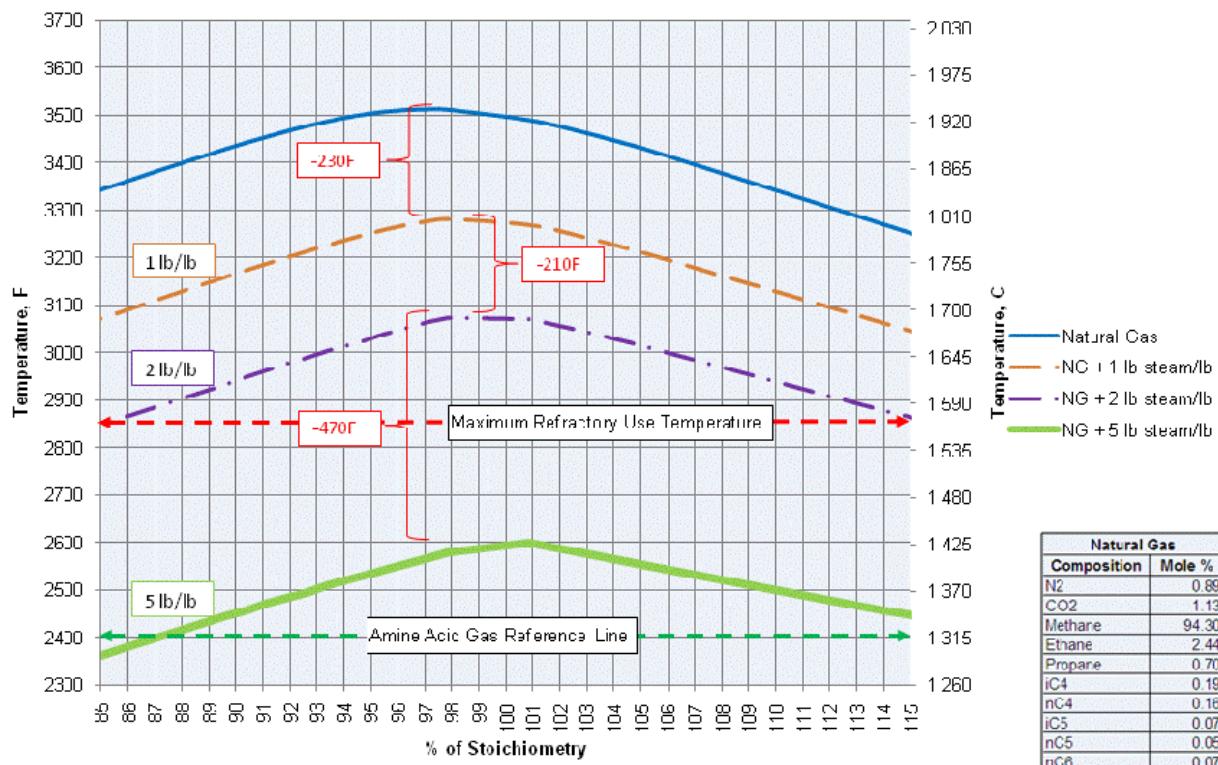


Figure 4 shows that 7 lbs of steam is required for every lb of hydrogen burned at stoichiometric conditions to keep the flame temperature below 2600F (1425C).

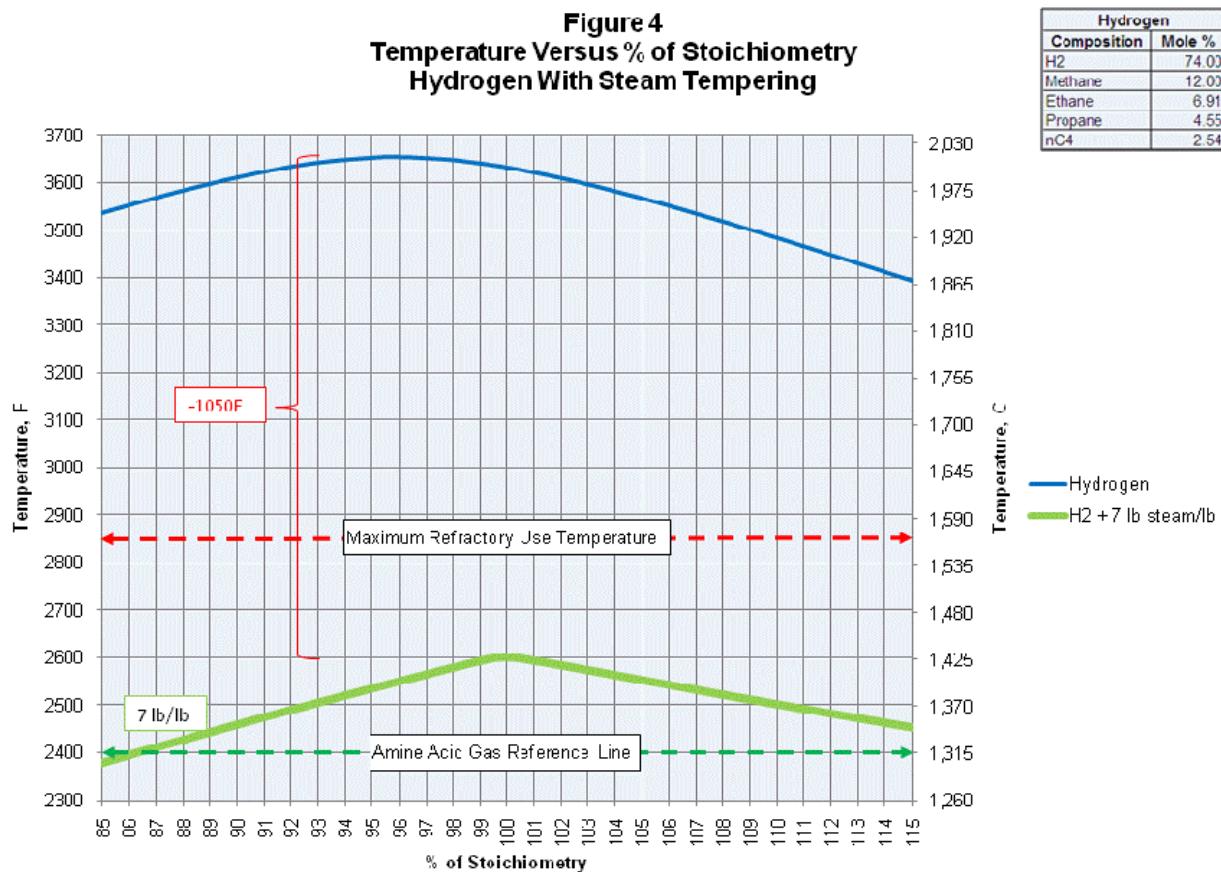
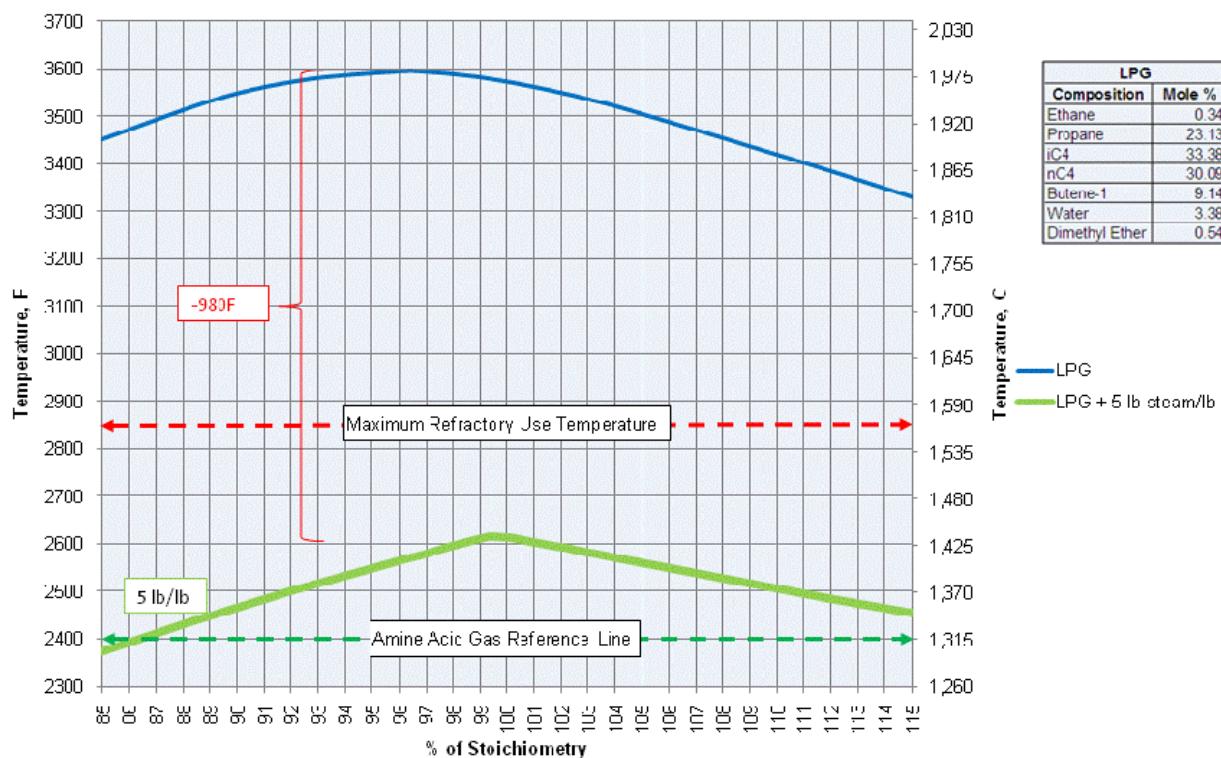


Figure 5 shows that 5 lbs of steam is required for every lb of LPG burned at stoichiometric conditions to keep the flame temperature below 2600F (1425C).

Figure 5
Temperature Versus % of Stoichiometry
LPG With Steam Tempering



Addition of tempering steam also has the added benefit of improving mixing especially at turndown conditions that are experienced during start-up, shutdown or hot standby. The improved mixing helps to eliminate areas deficient in air and thereby reduces the chance of soot formation. Addition of steam and the high temperatures also promotes the methane shift reaction (reforming) where the carbon is shifted to carbon monoxide (CO). This reaction also reduces the chance of soot formation.

Adequate flow measurement of the fuel, air and tempering media (steam or nitrogen) is the best practice to avoid high flame temperatures.

Temperature Measurement

Accurate temperature measurement may be a problem at start-up and hot standby. On a cold start-up, the optical pyrometers cannot read until the temperature gets to about 600F (315C). Start-up thermocouples should be purchased from the optical pyrometer supplier and used during each cold start-up. The start-up thermocouples can use the same electrical connection as the optical pyrometers. Installation has to be correct, if you want any chance of accurate measurement. One of the keys to installation is making sure the optical pyrometer is aimed correctly or it could just report the temperature of the inside of the nozzle.

Also, operations need to be aware of the type of optical pyrometer that has been specified. Is it measuring maximum gas temperature, average integrated gas temperature or refractory surface temperature? Basic information on temperature measurement was presented by Hampsten [3] at the Brimstone Sulfur Symposium in 2009. The emissivity of the gas affects the temperature readings. The optical pyrometer is typically calibrated for the normal acid gas flames. How accurate is the reading while in start-up or hot standby with a natural gas flame, how accurate is it for operating with a high hydrogen content flame? More information on optical pyrometers was presented by Croom [4] at the Brimstone Sulfur Symposium in 2010.

Purged ceramic thermocouples are the other accepted measurement device for temperature measurement within the Thermal Reactor. Again, installation has to be correct if you want any chance of accurate measurement. Installation criteria were presented by Croom [4] in a past paper. One of the keys is location of the tip of the thermocouple. The outer ceramic wells should stick beyond the face of the refractory by about 1 ½" so the inner well and thermocouple tip will reside very near the hot face. One common mistake is that the overall length is not specified and the thermocouple tip is back from the hot face and therefore not an accurate indication of the temperature of the face.

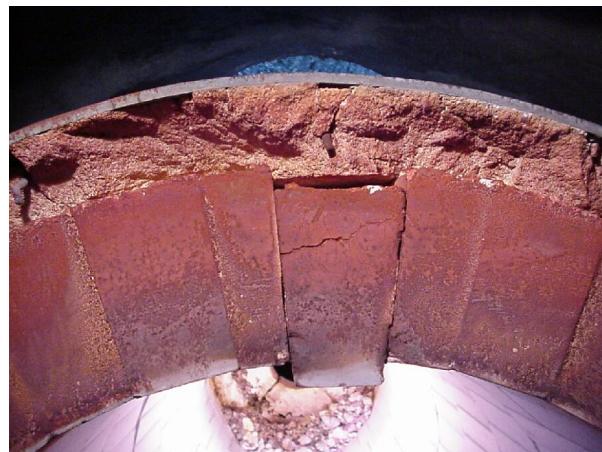
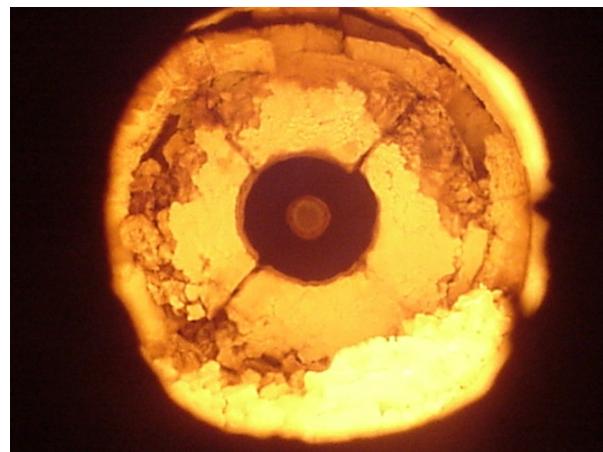
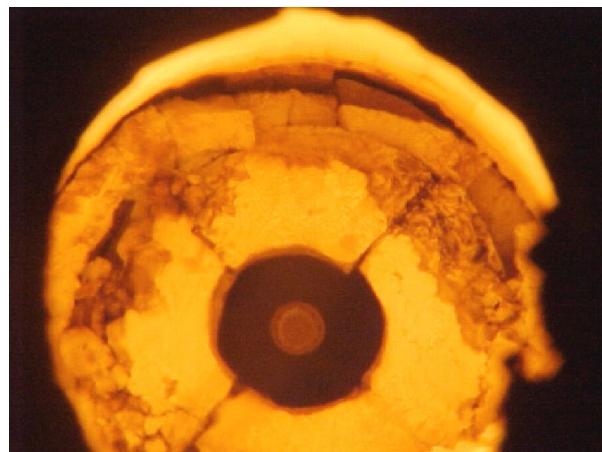
The best installation is to use both technologies.

Several papers have been presented at this conference in the past showing CFD models of poor burner designs and good burner designs. The CFDs all show that there is a temperature profile throughout the Thermal Reactor Burner and Thermal Reactor. The temperature patterns are not necessarily what you might think they should be and they can change with changing load. The temperature measurement devices measure a temperature at a point. What are the odds that the temperature measurement is at the point of maximum temperature? Recognition of this issue is critical during start-up and hot stand-by.

An understanding of the simulated flame temperatures, based on the actual fuel compositions, is an important factor in deciding whether the measured temperatures are realistic.

Failures

There have been some fairly spectacular failures when trying to operate with a natural gas and air stoichiometric flame without steam tempering. See photos below of one such case.



References [1]

1. Sulphur Plant Startup and Shutdown by Paul E. d'Haêne (DANA Technical Services) and Doug Cicerone (Cicerone & Associates, LLC) presented at the 2010 Brimstone Sulfur Symposium
2. SRU Modified Cold Start-up From Emergency Shutdown by Mark Young (Suncor Energy) presented at the 2010 Brimstone Sulfur Symposium
3. Critical Instrumentation in Sulfur Recovery Units by Jim Hampsten (Principal Technology Engineering, Inc.) presented at the 2009 Brimstone Sulfur Symposium
4. Claus Reaction Furnace Temperature Measurement – An Overview by Steve Croom and Ted Keys (Delta Controls) presented at the 2010 Brimstone Sulfur Symposium.