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DESIGN * ENGINEERING * SALES

TEMPERATURE SPECIALISTS

Syngas
Furnace Tubeskin Temperature Measurement

Temperature measurement through out the Syngas plants is critical to safe operations and start up. It can also be an important tool in troubleshooting, debottlenecking and optimizing the plant's operations. This paper only address's temperature measurement in the SMR furnace, for temperature measure solutions for other parts of the Syngas flow sheet please refer to Gayesco's other Syngas related papers.

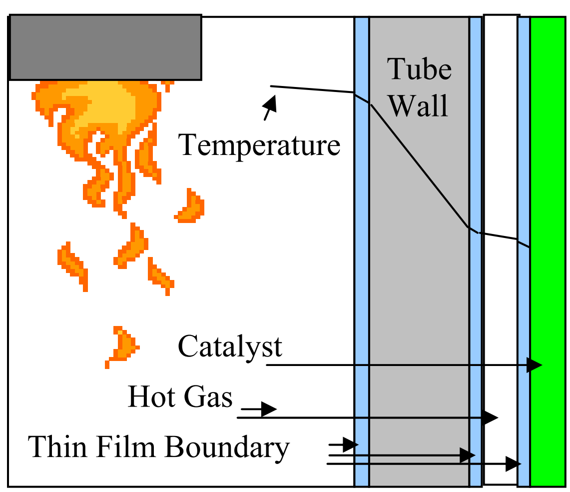
Temperature Measurement in Syngas furnaces

The furnace is the heart of the traditional design Syngas plant (Ammonia, Hydrogen, or Methanol Production). The reforming reaction requires a tremendous amount of heat and getting that heat into the gas and catalyst can be very hard on the equipment for both normal operation and in startup/shut down modes. The Steam Methane Reaction is listed below for reference.

$$CH_4 + H_2O \leftrightarrow CO + 3H_2 \quad \Delta H = +206 \text{ kJ Mol}^{-1}$$

Furnace Tube Life

Transferring enough heat to the reaction site is the key. If you look at the heat path from the burner to the catalyst reaction site, you encounter several regions where the heat transfer is impeded. These regions would be the thin film boundaries that surround the tube and the catalyst pellets, as well as the tube wall itself. In an effort to improve the heat transfer, modern tube manufacture tries to reduce the wall thickness of the tube. Certainly moving from HK 40 tubes to HP Modified or even to the advanced Micro Alloy tubes allows for thinner tube walls with a better heat transfer coefficients to be achieved.



Most Syngas furnace tubes are design to be for 10 year (100,000 Hrs) service at max design temperature. These design limitation are created from test data at the tube manufacturer which is used to create Larson –Miller curves for the particular material. These are usually done with accelerated short duration testing which is extrapolated out to run length. These curves can be used to generate a graph of mean tube life versus temperature. For a typical 4" HK 40 tube, an increase of operating temperature of

Syngas
Furnace Tubeskin Temperature Measurement

36° F can result in a dramatic change in tube life. [i]

Deg F	Deg C	Mean Tube Life
1580	860	10 Years
1616	880	5 Years
1652	900	2.5 Years
1697	925	11 Months
1742	950	4.5 months
1787	975	2 months
1832	1000	4 weeks
1922	1050	5.5 days
2012	1100	1 day

[ii]

Monitoring tube skin temperature is extremely important to any program concerned with maximizing furnace tube life and maintaining safe furnace operation. In addition, a common question from operators is how much life is left in my tubes? Basically, should I plan on changing out my tubes during this turn around or can I make it to some future turn around. It is possible to determine the approximate remaining tube life by first calculating the expired life fraction of the tube. This done with the formula

$$\textbf{Expired Life Fraction} = n_1/N_1 + n_2/N_2 + n_3/N_3 + \ldots.$$

Where n_i = the actual time at temperature i
N_i = the mean life at temperature i

Calculate n_i from actual thermal history
Calculate N_i from Larson – Miller Curve [iii]

It is not unusual for tubes to exceed the 10 year(100,000 hr) life if they were run at less than the design temperature. The expired life fraction calculation can help then to make a determination on how much life may be left. While this calculation can be done by regular temperature measurement with a pyrometer, it is most effective when tied into an online temperature measurement system. This allows for a complete temperature history of the tube at that location which leads to a better approximation of tube life. They also can be useful in determining the impact of a thermal excursion event by both giving the operator the time and duration of the event. The expired life fraction cause by the event can be calculated and a cost determined.

As we have shown, furnace tube life is directly affected by temperature. Tube temperatures may vary from tube to tube for a variety of reasons. Some common reasons would include

- Flame Impingement
- Uneven Flu gas Flow
- Uneven Process Flow
- Catalyst Deactivation / Poisoning

Variation in temperature may manifest as a difference in tube temperature or as a temperature difference localized to a particular spot on a tube. The calculations and limits are done with respect to the hot spot as that is the quickest aging portion of the tube and most likely to fail first.

On line temperature measurement was a concern to the industry for a long time for a couple of reasons, it involved welding a thermocouple to the tube, the accuracy of the thermocouples once they were in service, and the life of the thermocouple systems.
It good to address the first issue here as welding a thermocouple on the tubeskin is essentially a hot spot event.

One of the best ways to insure contact of a thermocouple to the tubeskin is to weld it to the surface. Some types of tubeskin thermocouples (Fan Type, Knife edge, etc..) utilize a very large weld in an attempt to increase the heat sink effect of the tube and get a more accurate tubeskin temperature. Unfortunately, the large welds required for this type of tubeskin thermocouple cause a lot of stress to the tube itself during installation which can reduce the life of the tube. Also, if in the severe heat flux duty of the Syngas furnace, the thermocouple should fail, the entire assembly has to be ground off and a new one welded back on, further reducing the remain life of the tube.

Gayesco's introduced the Xtracto - Pad™ tubeskin thermocouple to address this problem in several ways. First, a guide tube and shield are welded to the tube with very small, 1/8th " filet welds on three sides. This reduces the stress on the tube by reducing the amount of welding involved. The thermocouple itself is inserted into the tube under the heat shield. Since the thermocouple is separate from the welded pieces, the guide tube and shield are only installed once and need not be replaced if the thermocouple should ever fail. For new tubes, the guide tube and shields are often sent to the tube manufacturer for installation. This allows the tube manufacturer to heat treat the tube and all the welds at one time, maintaining tube life. The thermocouple is then installed after the tube is hung in the furnace. This protects the thermocouple from being damaged during the transportation of the tube or in the heat treating process. Thermocouple replacements are handled in the same way with no additional welding, inspection, or loss of tube life.

Effects of Temperature on Reformer operation

Temperature and Rate throttling Decisions

Tube wall temperature limits (TWTL) are important in maximizing furnace tube life. As we have already shown, elevated temperatures can dramatically decrease the expected tube life. It may be necessary for the operator to either throttle back rate to the unit, decreasing production, or live with a less desirable methane slip because of reduced firing to maintain a TWTL. Both are real costs to the operator.

It is common to monitor an individual hot spot with an infrared pyrometer. While many of these have a control for dealing with emissivity, the hand calculation can be quite tedious. A common synergy for plants with online temperature measurement like the Xtracto Pad, is to compare a pyrometer reading with an online temperature measurement. This allows for a quick comparison of the temperature readings and an adjustment of the emmissivity setting on the pyrometer to better simulate the actual conditions in the furnace. If the furnace is rate limited because of a hot spot TWTL you want that temperature measurement to be as accurate as possible. It is not uncommon for older pyrometer models to read 40° F high if not properly set for the real furnace emmissivity which could translate into millions of scfd in lost production.

This is an appropriate time to discuss tubeskin thermocouple accuracy. We introduced earlier that the other designs (Fan type, Knife edge, etc...) utilize large welds to increase the heat sink property of the tube and get a more accurate tube temperature indication. Any protrusion from the tube collects more radiant heat to the tube. This principle has been used extensively with fin and spike type tubes for years. This now causes an exposed thermocouple to get heat input from both the tube and from radiant heat source. Why doesn’t this read like the tube surface? We theorize that the increase of surface area with the same amount of heat transfer area to the process flow gives and area of higher temperature. Test data shows that these thermocouples read high.

The Xtracto Pad was developed with a heat shield over the measuring tip. By using an extremely opaque insulation, we get the thermocouple to get its heat input from the tubeskin, rather than act as a fin for receiving the radiant heat. This provides a more accurate and repeatable temperature measurement. Since the measuring junction is also more protected, the life of the thermocouple is extended.

Temperature and ATE Calculations
Temperature measurement is part of an important window into unit and catalyst performance. The temperature profile of the steam methane reformer tubes combined with the inlet and outlet gas analysis allows the user and the catalyst vendor to make analysis of catalyst activity. Typically this is Approach to Equilibrium(ATE) "The approach to equilibrium at the exit of a catalyst bed is the difference between the gas temperature at the exit of the catalyst bed and the equilibrium temperature corresponding to the gas composition" [iv] Accuracy of the temperature measurement is important as to not give a false indication of catalyst performance at a given temperature.

Safety
Start up of a Steam Methane Reformer can be one of the most dangerous operating times the plant will see. Typically during start up, hot nitrogen is circulated until temperatures above the dew point are reached. At this point, dry steam can be used to get to minimum operating temperatures or in the case of fresh catalyst, reduction temperatures. The amount of heat required to get steam to operating temperature is about 1/6th that required for reforming methane. This makes burner management and the burner lighting pattern extremely critical during start up. There are several cases of operators who lit too many burners and quickly over temped the reformer. Problems can happen very quickly during start up as well. There are several cases of reformer tubes being melted in less than 30 minutes during a start up excursion.

The start up of any unit requires lots of simultaneous activities. Plant personnel are busy and manual temperature measurement systems can be too slow in getting critical information to decision makers. Online temperature measurement systems like the Xtracto Pad can feed need temperature measurement information directly to the control board. Multiple Xtracto Pads located in different part of the reformer furnace can give early indications of unacceptable temperature variations. Plant personnel can the quickly determine if this is a burner management issue and correct it or if it is a potentially larger flow unbalance problem. This is not true of traditional inlet and outlet header temperatures. The combined flow may mask a problem early until it is already developed into a serious situation.

Syngas
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[i] Barry Fisher, Reformer Tube Metallurgy – Design Considerations, Failure Mechanisms, and Inspection Methods, (Presented at the 2003 International Hydrogen Seminar, Houston. Texas), Sides 6 – 9

[ii] Fisher, slide 10

[iii] Fisher, slide 11

[iv] Martyn V. Twigg, Catalyst Handbook, Second Edition, (London: Manson Publishing Ltd, 1996) Page 128