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The value of primary reformer temperature balancing and monitoring

Michael Dean – C.F. Industries
Kendra Briggs & Jamie Chisamore – Johnson Matthey

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Introduction

The steam reformer (reformer) is considered to be the most complex and expensive part of an ammonia, methanol, or hydrogen plant. A well operated reformer is key to ensuring that a plant remains efficient, produces the maximum potential product, and operates reliably and safely with minimal downtime. Monitoring the plant during both normal and transient conditions is extremely important.

Reformers can experience a range of potential issues all of which can lead to limitations on achievable production rates and reformer/plant efficiency. This in turn can lead to significant downtime to determine the root cause and effect repairs. High tube wall temperatures (TWT) of both the catalyst and riser tubes can arise from a number of sources:

- Sulfur slip on the primary reformer catalyst, and subsequent carbon formation
- Low steam to gas ratio which may lead to carbon formation on primary reformer catalyst
- Maldistribution of fuel gas and burner flame impingement issues on tubes and refractory causing high TWTs
- Reformer tube operation above design temperatures
- Reformer tube weld failures

Typical ammonia plant catalyst tubes have been designed to operate for 100,000 hours at TWTs approaching 1,700°F (927°C). Recent metallurgical advances in the design of catalyst tubes allows operation of the harps from between 12.5 to 25 years when TWTs are between 1,675°F (913°C) to 1,700°F (927°C)

TWT measurement techniques

Accurate measurement of TWTs in the primary reformer is vital. A TWT history may allow operators to estimate remaining tube life. High readings may lead to an artificial limitation of plant rate to stay inside design limits while low readings may mean that the tube life will be shorter than expected and failure could occur.

Beyond a standard visual inspection, three ways are examined to measure TWTs, each option with its own merit.

- Optical single point pyrometer
- Gold Cup pyrometer(also known as Gold Cup contact thermocouple)
- Reformer Imager

Tool	Tubewall temperature measurement	Background correction required	Time for survey	Video images
Optical pyrometer	Yes Point	Yes	Medium	No
Gold Cup conlact themocouple	Yes Point	No	Slow	No
Reformer Imager	Yes universal	Yes	Fast	Yes

Table 1 gives a summary of how these three different reformer measurement devices function.

Optical pyrometer

Optical pyrometers have been used and proven over decades and provide good results when compensated for background radiation.

Historically operations use an optical single point pyrometer on a regular basis to provide an indication of how well the TWTs are balanced.

However, thjs is a challenging and time consuming exercise: often the first few tubes in each row are not visible from the view port and it is also difficult to discern the individual tubes towards the center of the furnace. As a result, operators often record only the maximum temperatures measured during a survey, rather than all the tube temperatures giving a limited view of furnace uniformity.

In addition, the measurements themselves can vary significantly from operator to operator, and even from pyrometer to pyrometer, depending on wavelength and calibration.

Gold Cup pyrometer

The Gold Cup pyrometer has been proven to be reliable over many years and is an accurate measurement of TWTs when required. It is a direct contact pyrometer and therefore no correction is required for background radiation.

However, the Gold Cup pyrometer also has its limitations. This method is very labor intensive, requiring a heavy lance to be inserted into each furnace peep door. The lance itself is exposed to high temperatures requiring additional safety measures for both personnel and the equipment. Additionally, the Gold Cup pyrometer must physically touch each tube; therefore the measurement is limited to only a small number of tubes in each row for a multi-row furnace.

Reformer Imager

The portable reformer Imager is a relatively new addition to the range of reformer survey tools that has been developed by Johnson Matthey and partners. The reformer Imager operates at a suitable wavelength for the reformer radiant section. This new technique and equipment captures significantly more infonnation from the reformer than the other two techniques detailed previously. 324,000 data points are collected per still shot, with 15 still shots per second. This amasses 4.86 million points per second. Images are captured at a very high resolution. The imager provides a wide viewing angle - almost all of the tube row can be seen in one image. The videos are recorded directly to a laptop and can be taken away for further analysis. In addition, these images can be used as a future baseline reference to compare Reformer TWT perfonnance over a given time period.

Current reformer Imager technology allows operation at a wavelength of 1µm (micron) and operation of optical pyrometers is typically at a wavelength of of 3.9µm.

High temperature combustion gases are partially opaque over large portions of the infared spectrum. Figure I below displays the relationship between wavelength and opacity. Since minimum values are located at I J..Im and 3.9 flm, both wavelengths will maximize transparency through the flue gas.

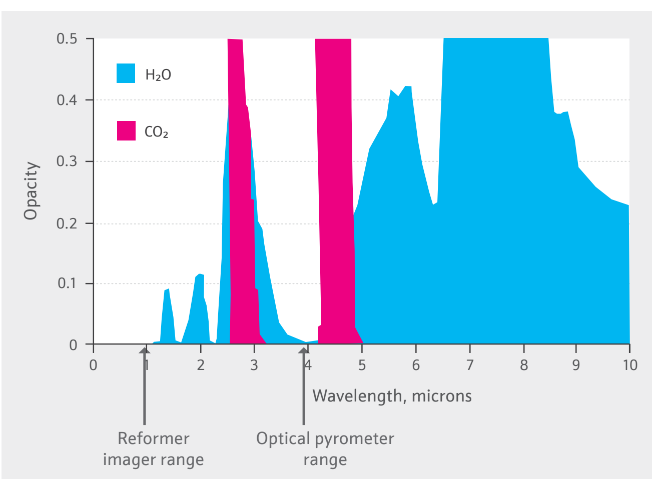

Figure I. Sight path absorption at various wavelengths

Another consideration of operation at various wavelengths is the effect of spectral radiance. By utilizing a lower wavelength, the Reformer imager is more sensitive to temperature changes in the 700K-1300K (800-1880 °F) range as this is where there is a high change in spectral radiance with temperature. Figure 2 details the spectral radiance curves, as given by Planck's law.

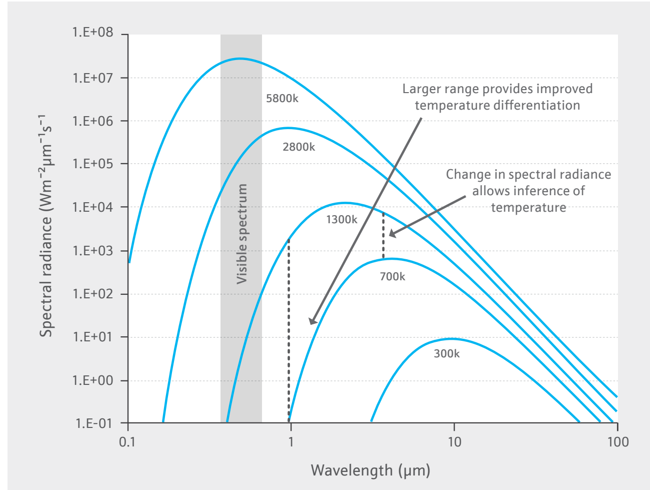

Figure 2. Blackbody spectral radiance curves, as given by Planck 's law

Although the optical pyrometer and Reformer Imager utilize different wavelengths, the resultant temperature measurements are very similar.

A comparison can be done to validate accuracy. Figure 3 shows a comparison of 36 TWT measurements obtained by use of multiple calibrated 3.9µm optical pyrometers and the 1.0µm Reformer Imager. The results of this assessment show a 0.3% differential between the two methods of temperature measurement, with an average difference of only 5°F (2.8°C).

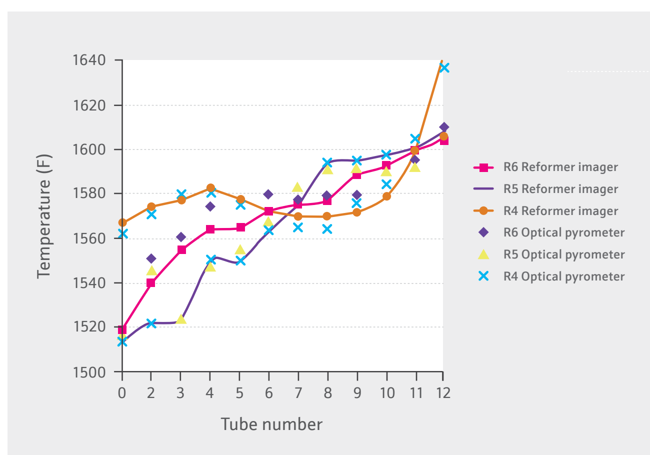

Figure 3. Comparison of TWT measurement by thermal Imager and optical pyrometer

The requirement for background radiation correction is not an issue, as the correction method is the same for optical pyrometers and the reformer Imager.

Reformer surveys

Reformer surveys go beyond straightforward TWT measurement, incorporating temperature correction, process engineering simulation allowing characterization of reformer performance and benchmarking against similar reformers. This type of survey allows the operations team to make changes to the reformer balancing to ensure optimal reformer performance, often delivering improved plant production, efficiency, and safety.

Reformer surveys typically involve participation from Engineering and Operations and may include an on-site visit from an experienced reformer Survey Engineer, allowing them to accurately assess the reformer performance. The reformer survey initially consists of a visual inspection of the reformer by a Survey Engineer. The Survey Engineer then conducts the measurement of TWT's using an optical pyrometer, gold cup contact thermocouple, or Reformer Imager. The measured TWTs must be corrected Temperature Comparison Rerormer Imager Vs. Optlul pyrometer to account for the effect of background radiation from refractory and flue gas (a technique that need only be applied to the measurements obtained through optical pyrometers and reformer imaging camera).

As part of the reformer survey, plant data is collected including flow rates, temperatures, compositions and pressures, and this data is then reconciled to eliminate any measurement inaccuracies. The reconciled data is then typically used in a process simulation program to provide a detailed assessment of the overall process performance of the reformer. The TWTs from the process simulation are matched against the corrected TWTs to characterize the reforming catalyst performance. Models also calculate pressure drop, carbon formation potential, approach to design temperature, fuel requirements, and fluegas conditions.

The measured and corrected TWTs are statistically and graphically analyzed to highlight any hot and cold zones or rows within the reformer. The results of this analysis are compared to the visual inspection of the reformer.

The performance of the reformer is also compared against other similar reformers to benchmark the reformer operation. Finally, the Survey Engineer assesses the overall reformer performance and catalyst performance.

The benefits of using reformer Imaging when performing primary reformer surveys:

The following examples demonstrate the use of the Reformer Imager tool during reformer surveys in industry.

Case Study 1: Reformer Imager identifies unseen hot bands on catalyst tubes

C.F. Industries' Ammonia 2 plant at Courtright, ON is originally a 1,287 STPD (1,168 MTPD) ICI design plant that is currently operating at 2015 1,430 STPD (1,297 MTPD). This Reformer has 4 rows and 42 tubes per row. Non-Johnson Matthey catalyst was installed.

During a routine visual inspection of the reformer, an individual catalyst tube hot spot was discovered. Johnson Matthey was then requested to perform an analysis of the entire reformer with the Reformer Imager to determine the operating temperature of that tube and all other tubes.

Upon further analysis of the data, a hot band across the entire row could be seen. Figure 4, which contains a Reformer Imager frequency plot for measured TWTs, shows an image of the hot band. While not visible in the reformer, altering the color contrast on a computer screen highlighted the issue.

Performing the Reformer Imager survey and analysis of the reformer led to an early awareness of the developing hot band allowing the facility time to properly prepare a turnaround for catalyst replacement.

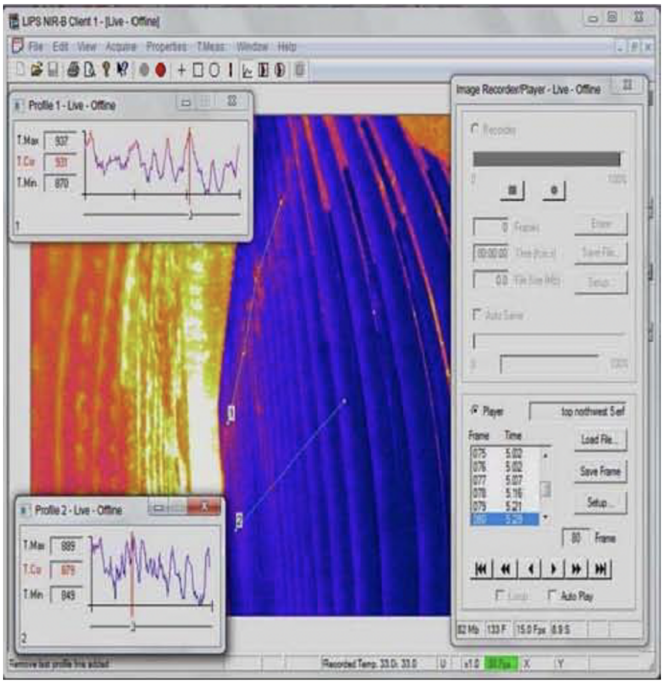

Figure 4. Frequency plot for measured TWT's with hot banding.

Case Study 2: Suspected hot tubes measure cooler than anticipated; Plant shutdown avoided.

The C.F. Industries Ammonia 1 plant at Verdigris, OK is an original 1,000 STPD (907 MTPD) Kellogg ammonia plant that is currently operating at 1,700 STPD (1,542 MTPD). The Primary Reformer is a top-fired design with 9 rows consisting of 42 tubes in each row. Most of the micro-alloy tubes were installed in 1992. Non-Johnson Matthey catalyst was installed.

Routine visual inspections of the primary reformer indicated hot tubes.

A full Reformer survey was conducted by Johnson Matthey in order to fully assess TWTs. During this survey the Reformer Imager was employed at the upper and lower view ports between each tube row. Figure 5 is a frequency plot for two primary reformer rows with TWT trends.

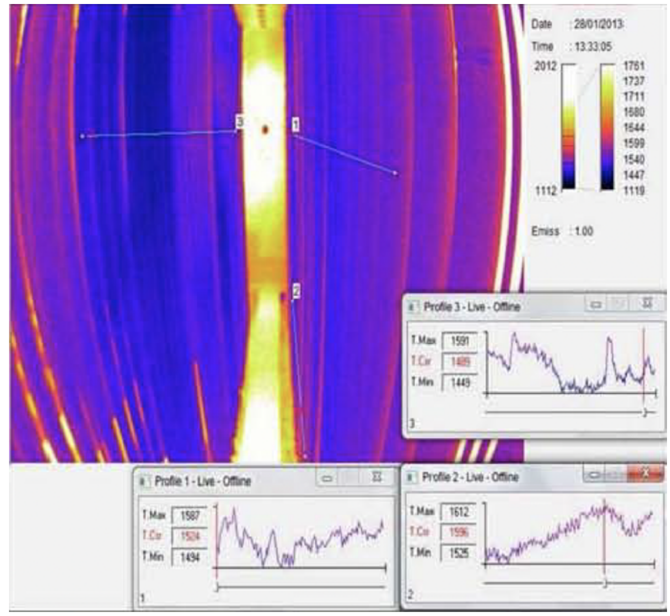

Figure 5: Reformer image of two primary reformer rows with temperature trends.

Once all catalyst tube rows had been assessed, an analysis took place of the overall primary reformer tube wall temperature profile. Figure 6 is a three dimensional representation of the overall TWTs taken at the upper viewport level after correction for background radiation. The tubes are numbered such that the tube No. 1, row 1, is in the Northeast corner of the furnace, and tube No. 42, row 9 is in the Southwest corner.

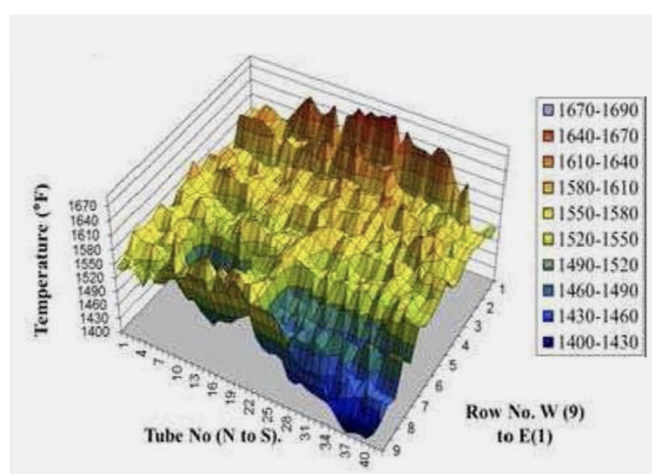

Figure 6: Overall TWT profile at upper viewport

There are two cold zones, most notably in rows 7,8 and 9 near the South end where many burners were pinched. There are also several hot zones; rows I & 2 and in row 9. Several burners were also pinched in these areas.

The maximum corrected TWT was 1,673°F, which is below design temperature of 1,700°F (927°C) for a 100,000 hour life. However, the temperature spread is 269°F, and the difference between the average and maximum temperatures is 128°F. These values are important when determining remaining catalyst life as it relates to carbon formation. The difference between the average and minimum temperature is 141°F.

Operational data was reconciled and used in a performance simulation program to provide a detailed assessment of the catalyst performance. The TWT profile predicted by simulation tools provided a good match to the temperatures gathered by the Reformer Imager as seen 10 Figure 7.

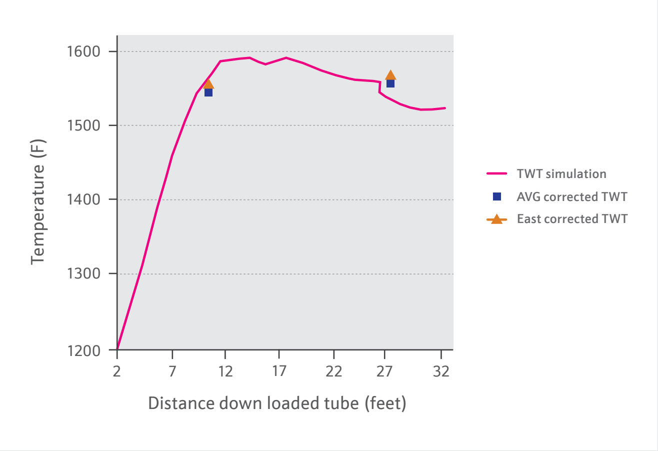

Figure 7: Simulated vs Actual TWT

The simulation model was also used to determine conditions at which carbon formation might occur. On the day of the survey, the average tube was found to be 89°F below the temperature at which carbon can form. Taking into account that many tubes are operating hotter than the average, the effective margin before carbon formation of the hottest tube is 23°F, indicating that several hot tubes may be just within the carbon formation regime. Further work shows that the temperature margin before carbon formation drops even further to 59°F as the catalyst ages an additional year.

More importantly no catalyst tube wall temperatures greater than 1700°F were being reached based on the Reformer Imager data. These calculations suggest that improved reformer balancing and more favorable operating conditions would need to be employed to prevent carbon formation from occurring. Based on this, and information from a metallurgist, the site had confidence to perform the reformer balancing and continue operation for 4 additional months, at which time both tubes and catalyst were replaced during a planned reharp project.

Case Study 3: Furnace rebalancing improves performance and prod uction.

C.F. Industries' Ammonia I plant at Donaldsonville, LA is originally a 1,000 STPD (907 MTPD) Kellogg plant that is currently operating at 1,700 STPD (1,542 MTPD). This MW Kellogg Process contains a top-fired furnace with nine rows of 44 tubes each. Johnson Matthey **QUADRALOBE**™ catalysts were installed.

Johnson Matthey performed a TWT survey using the reformer Imager. The general condition of the reformer was good with all tubes operating below the design TWT of 1,700°F (927°C). However, only 72% of the tubes were within a 100°F range of the average TWT, 1,529°F (831°C). Figure 8 is a frequency plot for measured TWTs. In a well-balanced reformer, typically over 90% of tubes are within this range. Further. 16% of tubes were more than 50°F below the average TWT, and 12% of tubes were more than 50% hotter than the average TWT.

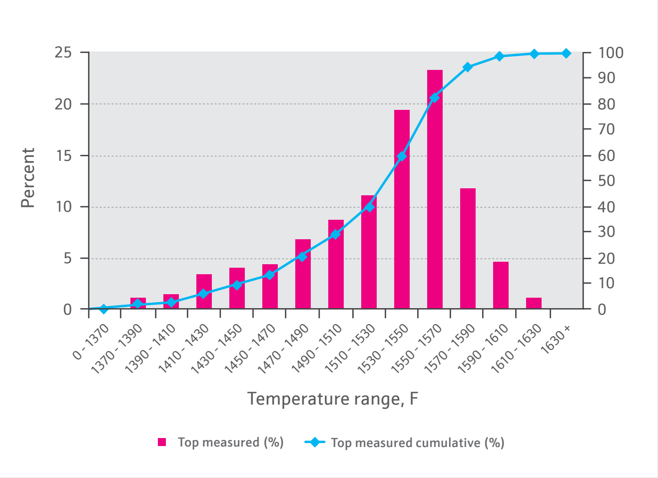

Figure 8. Frequency Piol for Measured TWTs.

From this initial survey. adjustments were made to the primary reformer to improve (reduce) the TWT distribution (spread) from 242°F to 185°F. Figures 9 and 10 show the reformer TWTs before and after the balancing.

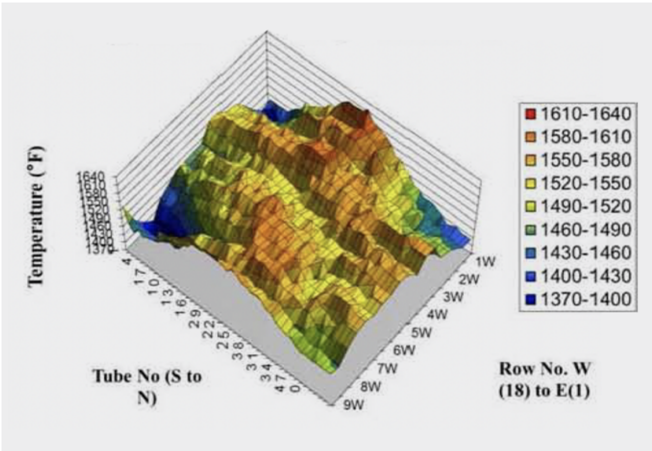

Figure 9. Donaldsonville Ammonia I upper TWT's prior to balancing

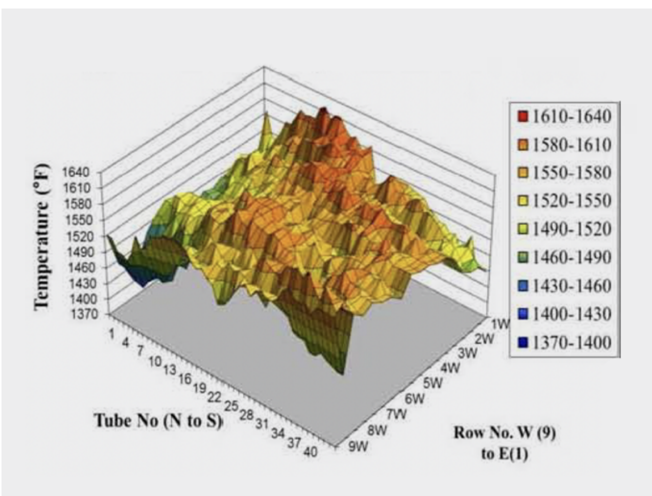

Figure 10. Donaldsonville Ammonia I upper TWT's after balancing

The improved balancing increased the margin before carbon formation, and will likely result in extending the catalyst life by one year. During this exercise, the methane slip decreased from 12.62 dry mol% to 12.39 dry mol% at a constant exit temperature. The improvements helped to lower the TWTs and eliminated the need for increased firing.

Conclusions

Reformers can suffer from a range of potential issues, and monitoring of the TWTs is critical to ensure safe and reliable operation. The portable Reformer Imager, provided by Johnson Matthey, captures significantly more data than prior TWT measurement methods of optical pyrometer and Gold Cup pyrometer, making review of reformer performance easy, and allowing for straightforward diagnosis of problems.

C.F. industries utilizes single point pyrometers and has used the Reformer Imager and service on several occasions recently within the fleet. Both of these TWT measurement technologies provide baseline catalyst tube harp TWT data, identifying and confirming high TWT and improving the overall safe and reliable operation of the Primary Reformer. The reformer Imager in particular has become a reliable tool and has the same ease of use benefits as the single point pyrometer.

References

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