Thomas Fortinberry, AMETEK Land, UK, details fixed thermal imaging for steam methane reformers and how effective monitoring of process temperature data can provide better asset management.

A CLEARER PICTURE

Ammonia is one of the most common chemicals produced by industrial processes, coming second only to sulphuric acid. The market is growing by approximately 1.4% each year, with around 140 million t produced worldwide. The manufacture of ammonia from nitrogen and hydrogen takes place in two main stages: firstly, the manufacture of hydrogen and, secondly, the synthesis of ammonia (the Haber Process).

Within a hydrogen plant, continuous reliable running of equipment is essential for optimising production and reducing energy usage. Many plants choose to sacrifice production by running at lower temperatures. However, studies have shown that a 10°C drop in temperature can result in a 1% decrease in productivity. So, the challenge facing hydrogen production plants is how to maintain an accurate temperature to optimise efficiency, whilst ensuring the equipment is kept online at all times.

Steam methane reforming of natural gas is one of the most commonly used thermal methods for hydrogen generation. Growing worldwide demand for hydrogen has driven the increased use of steam methane reformers, backed by the desire to make the process as productive as possible. There is a simultaneous movement to enhance the inspection and diagnostics used in the creation of gases such as hydrogen, methane and ammonia, that is driven by many factors, including an increased focus on safety for operators, reduction of downtime and cost efficiency.

As part of the process, widely available and relatively inexpensive methane and water are reacted in the presence of a catalytic converter. During the production process, natural gas is combined with steam and heated at high temperatures (700 – 1000°C) under pressure in the presence of a catalyst. The result is carbon monoxide, hydrogen and a small amount of carbon dioxide.

In the next step, carbon monoxide from the reforming reaction interacts with steam, again using a catalyst, to produce additional hydrogen. Finally, carbon dioxide is removed, leaving pure hydrogen. Throughout the process, the heat resulting from the combustion of fuel gas from

burners in the furnace box is transferred to catalyst tubes by radiation.

Steam reformers used in ammonia, hydrogen and methanol plants are complex, energy intensive and expensive. The monitoring of tube wall temperatures (TWT) can help optimise catalyst tube life and ensure longevity, energy efficiency and productivity. As tubular steam reformers can be either top-fired or bottom-fired, catalyst tubes are arranged in parallel rows with burners between the rows at the top or bottom of a furnace box that is heated from 1000°C to 1100°C. Alternatively, tubes can be arranged in single rows between opposing furnace walls in side-fired and terrace-wall-fired reformers.

The reaction occurs through the tubes at 900°C, exiting the bottom. There are established TWT upper limits based on the design of the tube and the interior of the fire box, at which temperatures the tubes begin to expand.

Industry challenges

The most frequent challenges that plant operators face when controlling TWT are issues with the burner, fluegas distribution and the catalyst. All of these can directly affect TWT and lead to premature tube failure. To prevent failures, most operators tend to be overly cautious on TWT, and a plant can thereby lose valuable production output every year. Even when taking a cautious approach, tube failures can still occur, due to hot spots on tubes and hot areas within the convection box, so even producers running at a reduced rate are not guaranteed to have a balanced, reliable reformer.

Reformer tube failure and process flow problems result when temperatures are too high, costing a plant dearly. Even at temperatures only 20°C above the design temperature, a tube's lifetime may be cut in half. Maintaining optimum temperatures is, therefore, critical, and this can only be achieved effectively through continuous TWT monitoring.

The challenges inherent in a steam reformer environment range from the basic difficulty of obtaining TWT right through to the catastrophic failure of tubes. Adding to that difficulty is the extremely harsh environments in which fluegas at the outer surface of reformer tubes is around 960°C and inner-surface process gas ranges from 450 – 900°C.

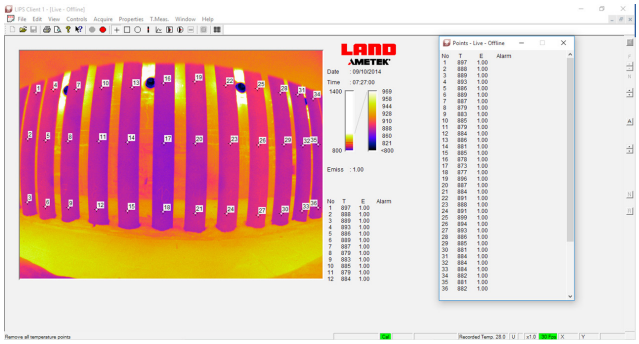

Figure 1. NIR-B 3XR thermal image of reformer tubes inside a furnace.

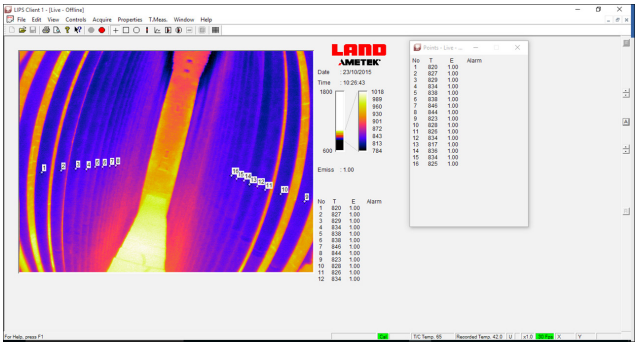

Figure 2. Thermal view inside and reformer tube furnace with data points.

Temperature-related issues with reformers include creep damage, stress cracking, extrusion rupture and overheating. A thermal gradient through the tube wall is more significant at the bottom or close to the bottom of the tube, causing differential creep strain, which is a primary cause of damage. A fifth of all incidents involve tube cracking.

Human error, however, is the main reason for catastrophic failure. Operators need to have an in-depth understanding of a reformer's behaviour, which includes being able to analyse data and make rapid decisions when faced with catastrophic failure.

Significant operator experience is necessary to fully understand basic reformer construction, process flow, heat transfer principles, background radiation, and emissivity, along with the cooling effects that occur when the peep door is opened. Regular opening of the peep doors can result in increased stress on the tubes and potential cooling of the tubes by up to 30°C directly in front of the peep door. With that in mind, operators need data on the TWT that is accurate, repeatable and reliable.

As tubes age, if they are not balanced, some tubes will gain more heat and therefore need replacing before other tubes. This creates issues as the new tubes and catalyst will perform differently to the older tubes left in the reformer, making it more difficult to balance the reformer. Asset management is therefore critical and can only be done by having an effective method of temperature measurement for reformer tubes.

By continually monitoring readings, the operator will receive an early warning of increasing tube wall temperatures, which can then be used to counteract potential catastrophic failure. Continuous monitoring also allows the operator to safely and confidently increase temperatures, with a view to increasing production.

Measurement methods

What is clear is that to meet the demands for greater production, efficiency and safety, continuous monitoring is required. While several different temperature measurement methods are available, the most effective are:

- Hand-held spot pyrometers: these enable routine spot measurements to be taken. Pyrometers are highly accurate and are considered an industry standard for measuring tube wall temperature. They can be used to optimise steam reformers by maintaining operation closer to design temperatures and, in many situations, can provide adequate accuracy. However, with pyrometers, the operators are only able to view a local spot on the tubes and may miss hot spots in other locations.
- Fixed thermal imaging: this provides more accurate and repeatable results than hand-held pyrometers as they are less liable to human error and enables optimisation of the TWT to ensure a long tube life. Here, thermal imaging cameras are inserted into the reformer, with the end of the imager 0.25 in. from the inside reformer wall refractory. Imagers are water- and air-cooled to ensure accuracy in the hot atmosphere of the reformer. This method improves efficiency and minimises the risk of catastrophic failure.

Fixed thermal imagers

Accurate temperature measurement must take emissivity into account. Within the reformer environment, several objects can reflect off the surface. Hand-held pyrometers and visual inspection can wrongly interpret the reflections as real data, causing errors in temperature measurement. Thermal imagers, such as the hazardous area certified NIR-B 3XR borescope from AMETEK Land, are mounted strategically within the reformer and do not allow this to happen. The fixed thermal imager delivers a high-resolution image, with accurate real-time measurements of both the tube skin and refractory surface.

The image, combined with the 90° angle field of view, allows for multiple parallel tubes to be measured simultaneously. This can dramatically enhance efficiency and safety as well as provide for better asset management and furnace optimisation.

With the NIR-B 3XR, hot and cold areas within the furnace are easily identified and uneven heating becomes visible in real time. Burners operating incorrectly can be identified along with the effects of impinging flames. The use of a short wavelength minimises errors associated with varying emissivity, so that highly accurate temperature measurement data can be taken, stored and fully analysed over the lifetime of the reformer. Use of fixed thermal images also allows the plant to monitor temperatures during startups and shutdowns to optimise efficiency and reduce energy usage.

One of the major benefits of using fixed thermal imagers, such as the NIR-B 3XR, is the rapid response time. Using Land Image Processing Software (LIPS) provided with NIR-B 3XR, for example, the software will sound an alarm the moment the tube wall reaches maximum temperature in any region, identifying the problem region and allowing operators to take corrective measures to fix the issue. Fixed thermal images collect a huge amount of data that can then be used to create TWT trending charts to identify problem areas to be corrected during operation or repaired during a planned shutdown. Data

capture is also useful for conducting remaining life assessments on tubes or to help plan for tube replacement during maintenance work. Additionally, there is an option for alarms for use in control and automation as well as a playback facility of any pre-alarm event.

Some hydrogen producers are reporting a 2% increase in production, whilst still operating at a safe condition within their integrity operating window when continuous monitoring is introduced.

Ammonia plant TWT monitoring

Balancing tube wall temperatures has shown to be able to produce material improvements in overall energy efficiency, primary reformer methane slip and plant production.

In the case of an ammonia production plant in the West Indies, an agreed schedule of adjustments was made to fuel header pressure on individual rows, reducing and increasing the temperature as necessary. The result was that overall fuel usage decreased, production increased and methane slip was reduced. Owing to these adjustments, the average tube wall temperatures were effectively reduced in warmer rows or increased in cooler rows. A more detailed statistical analysis of the temperatures in specified rows revealed a marked improvement in the frequency distribution in the rows where adjustments were made.

Summary

The growth in demand for ammonia looks likely to continue. Further, there is the pressure on plants to increase production, while improving safety, controlling costs and reducing downtimes.

Continuous monitoring through the use of fixed thermal imaging cameras for continuous and improved temperature measurement of the steam methane reformer tubes is increasingly seen as the answer to improving production efficiency and reducing maintenance and repair costs. Asset management is an essential part of why continuous temperature monitoring is so important. Operating the process over temperature has proven to drastically reduce the lifespan and, therefore, increase operating costs. Similarly, the proper management of temperatures during startups, operation and shutdowns has proven to extend both tube and catalyst life, with less downtime and fewer unplanned tube replacements.

Fixed thermal imaging is a major new development in temperature measurement for industrial gas applications that has helped optimise efficiency and significantly improved process temperature monitoring. Using the NIR-B 3XR, for example, has led to increased productivity, greater asset protection and enhanced tube life. It has also reduced risks to operators, who are no longer required to be in hazardous areas to conduct temperature measurements on a regular basis. Monitoring the reformer on a 24/7 basis allows plants to run the reformer close to design limits, while still maintaining reliable conditions.

Due to the extremely challenging and complex nature of the reformer, fixed thermal imaging gives operators the tools to achieve better monitoring and enable them to make more informed decisions. The method goes a long way to enabling plants to overcome any issues they face with steam methane reforming, by providing accurate, rapid response data that helps them to optimise efficiency and maximise production output. WF