

THE POWER OF PYROMETERS



James Cross, AMETEK Land, UAE, looks at the benefits, challenges and technologies for tube wall temperature measurements in the ammonia production process.

The rapidly increasing global demand for food, which includes an increased emphasis on consumption of protein-rich diets, is supporting agricultural growth and therefore the demand for ammonia and fertilizers. Ammonia is also being increasingly chosen over hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) as a

refrigerant, due to its cost-efficiency and heat transfer properties. This has resulted in significant growth in the global ammonia market, which is forecast to realise a compound annual growth rate (CAGR) of 5.85% (with fertilizers expected to produce a CAGR of 6.23%), and to reach US\$70.75 billion before the end of 2025.¹

This growing global demand for ammonia has placed an increased burden on producers to meet ambitious production targets, which generates additional demands on already highly utilised equipment, including the steam methane reformer (SMR). The SMR is used in the first phase of the ammonia production process to produce hydrogen before it is synthesised in the secondary Haber process.

The need for continuous production near or above the plant's nameplate capacity places an emphasis on running the SMRs near their thermal design limits, both during normal production and after shutdowns or incidents. This creates an increased risk of catastrophic material failures and unsafe conditions, as well as increasing the costs associated with maintenance and turnaround. The highest risk components in the SMR are the steel parts, including the burner nozzles and catalyst tubes, which are susceptible to progressive microstructural degradation when exposed to elevated temperatures or thermal shock.²

Traditionally, catalyst tubes are examined in detail during shutdowns or turnarounds through analysis of the tube's change in diameter. This is monitored over time to ensure creep progression does not exceed predetermined tolerances. Creep deformation itself is unavoidable, but it can be managed by limiting the service life of tubes, avoiding thermal shock and monitoring tube temperatures.

Monitoring the tube's temperature throughout its service indicates the tube's remaining life, but consideration should also be given to events which place higher thermal stresses on the tubes, such as emergency

shutdowns, start-ups, and process issues. Tubes are not usually continuously monitored during these events, so life can be shortened without the operator being aware.

The Cyclops spot pyrometer is used throughout the ammonia industry to perform temperature measurements, but other technologies can be used in conjunction with it to provide more accurate and comprehensive temperature data for the catalyst tubes and refractory. These technologies can include infrared pyrometers, the Gold Cup pyrometer, and thermal imaging borescope systems. Each of these methods uses infrared technology which, while providing repeatable temperature data, requires an understanding of some of the application's challenges in order to get the most from the data.

Benefits of tube wall temperature measurements

Monitoring tube wall temperatures (TWTs) provides the maximum level of catalyst tube life to ensure energy efficiency and productivity. High temperatures inside the furnace can cause expansion of the tubes, or even catastrophic tube failure, along with creep damage, coke formation and process flow problems.

The cost of not properly managing TWT can be extremely high, since the effect on tube life can be significant. At levels of as little as 20°C (36°F) above the design temperature, the lifetime of the tube may be halved, with higher temperatures having an even more dramatic impact (Table 1).

Having to rebuild a 400 tube reformer can cost millions in materials alone, while the impact of lost production can also be significant. Current data places a typical rebuild cost at more than £7 million (US\$9.2 million), or £14 million (US\$18.4 million) when labour and lost production is taken into consideration.

Unsurprisingly, many plants work on the side of safety when setting operating temperatures, to reduce the risk of this expensive tube damage. However, if the plant is run too conservatively in order to prevent tube overheating, it will not achieve full efficiency.

At low TWT levels, the production output is decreased. A reduction of 10°C (18°F) below the design temperature, for example, results in a 1% productivity efficiency loss that may translate to millions of dollars in sales. It is, therefore, critical to find and maintain the optimum temperature to deliver production efficiency while preventing damage to the tubes.

TWT measurements can also be used to ensure balanced firing within the furnace, with all tubes running to the same exit conditions. Obtaining TWTs presents a number of measurement challenges. The conditions are extremely hot and hazardous, with flue gases at the outer tube surfaces reaching approximately 960°C (1760°F). Inner-surface process gases can range from 450 – 900°C (842 – 1652°F).

For non-contact measurements, the emissivity of the tube wall surface is an important factor in temperature accuracy. General industry practice recommends an assumed tube wall emissivity of 0.85 for 1 µm pyrometers and 0.82 for 3.9 µm, but this can be affected by the

Table 1. Tube wall temperature related to mean tube life

Temperature (°C/°F)	Mean tube life
860/1580	10 years
880/1616	5 years
900/1652	2.5 years
925/1697	11 months
950/1742	4.5 months
975/1787	2 months
1000/1832	4 weeks
1050/1922	5.5 days

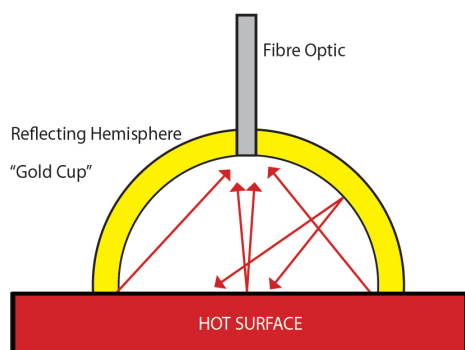


Figure 1. Gold Cup against hot surface of tube.

condition of the tubes, which may be 0.9 when new, but will decrease with use as they shed their thick oxide layer.

Despite these challenges, it is critically important to improve monitoring and temperature measurement of the tube walls, obtain an accurate reading and apply a suitable correction method to get the true TWT. A continuous and accurate monitoring solution delivers more data certainty, increasing the uniformity of heat through the furnace and homogeneity of tube temperature. This data allows temperatures to be increased safely, leading to a growth in productivity.

Temperature monitoring helps extend the life of both the tube and catalyst, while also providing early warning of any temperature increases. During start-ups and shutdowns, infrared thermal imaging allows the operator to easily identify hot and cold areas, unbalanced burners and the gas mix, allowing better optimisation. Three main areas of measurement can support better performance in the reformer: linear tube measurements, interior temperature measurements, and burner flame monitoring. A thermal imaging solution is the most effective way to monitor all three of these areas.

Reference measurements

The Gold Cup pyrometer, which is AMETEK Land's pyrometer for reformer tubes, creates near black body conditions at the measurement point to deliver a repeatable, reliable reference temperature.

As discussed, non-contact infrared measurements of TWT are affected by the emissivity of the target surface

and require a way to compensate for reflections from the hotter surrounding environment of the furnace. In addition, depending on the furnace firing method, there may be interference to these measurements caused by dirty furnace atmospheres. By using a hemispherical reflector (the 'gold cup' which gives the instrument its name), a measurement area is produced which is independent of emissivity. This is ideal when dealing with tubes of unknown emissivity.

The instrument has a narrow protective edge suitable for tube contact. This edge prevents reflected radiation from the hotter surroundings from entering the cavity formed between the tube and the cup (Figure 1).

The gold reflective hemisphere integrates the emitted and reflected radiation, producing black body conditions. This enhanced energy escapes through a small aperture in the back of the hemisphere, where it is measured by the pyrometer module's indium gallium arsenide (InGaAs) detector. The pyrometer module then transmits the temperature signal to the display unit.

The information from the instrument can be used to remove inherent errors and modify infrared thermal imagers and pyrometers. This ensures these non-contact measurements are more accurate, which leads to increased tube life and improved product yield.

How is it used

To obtain accurate reference temperature measurements, it is important to identify any errors caused by three key process variables: tube emissivity, background radiation, and sight path effects. The pyrometer achieves this by creating near black body conditions against the surface of the tube. Therefore, the measured temperature is considered to be the true surface temperature and the portable pyrometer's settings are adjusted accordingly.

The device consists of a 3 m-long water-cooled probe which is held against the tube surface. A fibre optic cable connects the pyrometer to the battery-powered digital display which displays the temperature. A thermocouple in the tip of the probe indicates the temperature of the Gold Cup to prevent overheating/damage to the instrument.

In practice, the instrument's probe requires a minimum of two operators. It is carefully inserted through the peephole and the hemisphere is rested against the tube, preventing sight path effects from hot furnace gases and incident radiation from nearby tubes and refractory surfaces. The temperature reading must be taken straightaway before the measured tube begins to cool down due to being sheltered by the cup.

The pyrometer must also be applied squarely against the surface of the tube. If it is not applied squarely, and if there is a gap between the tube and hemisphere,

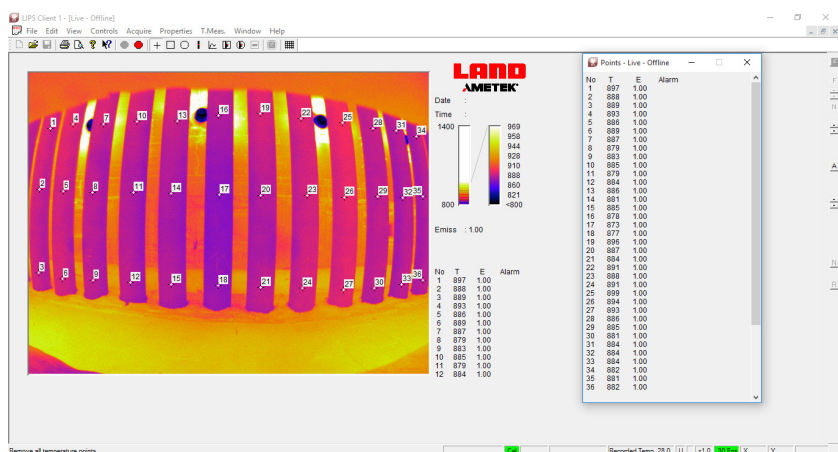


Figure 2. Thermal view inside reformer tube.

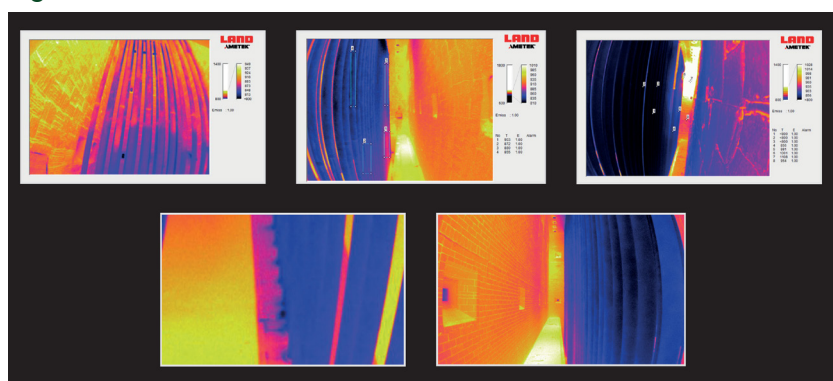


Figure 3. Thermal images showing reformer issues.

the reading will include radiation absorbed from refractory, nearby tubes, or carbon dioxide and water in the furnace: the black body effect is no longer achieved and temperature readings will be artificially high. The instrument has a measurable range of 625 – 1200°C (1160 – 2190°F) and is calibrated in a black body furnace from an ISO 17025 accredited infrared calibration laboratory.

Thermal imaging

To operate within an integrity operating window, there is a need for close, continuous TWT monitoring. Fixed thermal imaging provides a reliable method of optimising TWT to ensure long tube life. It provides an accurate, repeatable result independent of operator expertise, which improves efficiency and minimises the risk of catastrophic failure. Thermal imaging delivers a high-resolution image which identifies, in real time, the temperature measurements of the tube skin and refractory surface. Intelligent installation and a wide field of view should allow for multiple parallel tubes to be viewed simultaneously (Figure 2).

This image allows for easy identification of hot and cold areas within the furnace, making furnace issues immediately visible. In addition, advanced software enables sophisticated processing of the TWT profile data, allowing emissivity and background temperature adjustments to be made on each tube, or for each zone.

The continuous operation of thermal imaging provides an advantage over alternative measurement solutions. Alongside providing accurate, real time temperature measurements to extend tube and catalyst life, it allows

automated or remote operator-controlled temperature monitoring for early warning of rising heat levels. The measurements enable balancing of the reformer during general operation and at critical start-up and shutdown stages. It also allows data trending across weeks or months of operation, providing a greater understanding of the reformer process. By removing the requirement for an operator to make regular handheld spot measurements of the TWT, it also increases safety.

Reformer optimisation

The thermal images in Figure 3 show issues relating to reformer temperature balance, flame impingement, hot spots/band, and catalyst damage, and with associated temperature data help inform maintenance decisions.

Implementing these technologies with the necessary technical understanding ensures balanced, efficient reformers, and safer operations that operate near to their capacity without compromising asset integrity. **WF**

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