Reformer performance and tube life management

The steam reformer is widely accepted as being the most complex and energy intensive part of any ammonia, methanol or hydrogen plant, and as such, it is important to ensure that it is operating and maintained under the best possible conditions. This will enable the operators to produce the maximum achievable levels of product, extend reformer tube lives and increase energy efficiency.

Catalytic steam reforming of hydrocarbons in tubular reformers is the most common process for production of synthesis gas. The reforming reactions are highly endothermic, and the heat provided by combustion of fuel gas in a furnace box is transferred to the catalyst tubes mainly by radiation.

Tubular steam reformers are divided into four categories depending on the location of the burners (Fig. 1).

Depending on the design, the furnace box may contain a single row of tubes or multiple rows. Catalyst tubes in top-fired and bottom-fired reformers are arranged in several parallel rows with the burners located between the tube rows either in the top or the bottom of the furnace box. Tubes in side-fired and terrace wall-fired reformers are arranged in single rows between two opposing furnace walls. Accurate temperature measurement is difficult in any reformer configuration, but is particularly so when the tubes are arranged in multiple parallel rows.

Catalyst tubes continuously degrade due to the harsh environment of the furnace box from the moment they are commissioned. The upper limit of tube wall temperature is primarily governed by the tube design temperature. If the temperature is too high, there is a high risk of premature creep damage and coke formation, resulting in tube failure and process flow restriction. Continual operation at temperatures just 20 degrees higher than the design temperature will cut the tube lifetime in half. On the other hand, too low temperatures lead to decreased production output and profit losses. Operating variables that determine the optimal tube skin temperature include fuel consumption, steam-to-carbon ratio, and feed gas rate. In general, for a plant to optimise tube lifetimes and production, operating temperatures should be kept as close as possible to the design temperature.

Accurate TWT monitoring is crucial to maintain operation near design temperatures. Common temperature measurement methods include imagery, direct contact, infrared thermometry, and calibrated eyeball. The factors that determine which of the available methods should be used include accuracy, cost, reproducibility, feasibility and simplicity. One simple option is a thermocouple, welded on the tube surface or embedded in the tube wall. These can provide accurate, continuous measurements, are low in cost and are simple to use. However, the lifetime of thermocouples is short under the harsh conditions of the reformer furnace, and the method of attachment to the catalyst tubes often compromises the inherent accuracy.

The performance of the primary reformer is of crucial importance to plant efficiency and production because of the reformer’s role as the single largest consumer of energy. It is therefore extremely valuable to conduct regular reformer assessments that result in solutions aimed at optimising parameters for peak reformer performance.

Topsoe reformer management

Topsoe has recently improved upon its already extensive repertoire of services and tools used for assessment and optimisation. A primary focus of the improvements is on tube wall temperatures (TWT) due to the lack of precision when using conventional methods for measuring TWT. Results from extensive infrared pyrometer studies reveal why and when to use different pyrometer types, and this knowledge will help producers optimise their steam reformers by maintaining operation closer to design temperatures. Topsoe is also introducing a system for advanced reformer surveillance, which provides additional temperature data via continuous monitoring.
monitoring. With these advances in steam reformer services, Topsoe can better help customers adhere to design limits, identify bottlenecks, save energy, increase tube lifetime, and optimise operations.

Optical infrared pyrometry
Currently, the technique most commonly employed in the industry is based on IR pyrometry. The pyrometers are optical remote-sensing devices that detect the thermal radiation emitted by a target object. Benefits of this method include cost-effectiveness, relative ease of use, speed, and reproducible results. The disadvantages include frequent improper use and multiple sources of error.

Sources of error
One of the largest sources of error in optical IR pyrometry is derived from the uncertainty of the tube wall emissivity. Emissivity (ε) is by definition a number between 0 and 1, with 1 indicating a perfect emitter or backbody, and 0 a perfect reflector. All real objects emit only a fraction of the radiation of a blackbody. Objects with an emissivity less than 1 are partial reflectors of radiation, which means that radiation impinging on the tube from the surroundings will also contribute to the signal received by the pyrometer. The surroundings include refractory walls, floor, ceiling, flames, and other tubes, and are generally not uniform in temperature. Obtaining accurate TWTs therefore requires good knowledge of tube wall emissivity and contributions due to background temperature and reflection.

Most infrared pyrometers measure spectral radiance over a small wavelength range. The optimum wavelength is a balance between lower background and emissivity uncertainties at longer wavelengths and lower TWT measurement uncertainties at shorter wavelengths. Industrial thermometers typically operate in the infrared part of the spectrum. Since the flue gas in reformer furnace boxes also absorb and radiate infrared energy in selective wavebands, it is important to choose narrow pyrometer operating wavelengths that minimise the interference. Figure 2 shows the absorption and emission of flue gas (in the absence of soot), which is dominated in the infrared region by water and carbon dioxide. Given the minimum values at 1.0 μm and 3.9 μm, these are the two most common operating wave bands used for pyrometer measurement of reformer tube walls. It should be noted that the presence of soot should be taken into account when performing TWT measurements, since scattering of radiation by soot can also be a source of error.

Tube wall emissivity
General industry practice recommends an assumed tube wall emissivity of 0.85 for 1.0-μm pyrometers and an assumed emissivity of 0.82 for 3.9-μm pyrometers. However, one factor affecting the actual tube wall emissivity is the condition of the reformer tubes. New, clean reformer tubes have a rough oxide layer that gives them an emissivity as high as 0.9. As they age, reformer tubes shed their rough oxide layer and become smoother on the surface, which results in a lower emissivity. Proximity of reformer tubes to direct flame impingement also lowers the tube wall emissivity due to a faster aging process. If foreign material is deposited on the tube surface, emissivity can be further reduced to as low as 0.6. For example, for reformers situated in desert locations, a lower tube wall emissivity should be assumed.

New findings from a recent study show that actual tube wall emissivities also depend on a combination of operating temperature and wavelength. The study was conducted by Topsoe and the Technical University of Denmark on tubes at typical operating temperatures. Not only were actual tube emissivities found to vary as a function of temperature, they were also found to vary as a function of wavelength at different temperatures. It can be concluded from the observations that use of optical IR pyrometers should be accompanied by very careful consideration of tube wall emissivity assumptions.

Uncertainties
It is important to have a sufficient understanding of measurement uncertainties involved in reformer temperature determination in order to minimise inaccuracies. As described by Saunders, there are three components of uncertainty. One is the uncertainty of the tube measurement itself, which is due to the intrinsic accuracy of the pyrometer and fluctuations in the furnace conditions. A second uncertainty is that of the emissivity. The value of this uncertainty is usually 0.05 at best, but it can be reduced by measuring a good set of tube samples. The third uncertainty component is the uncertainty in background temperature measurement and is generally the most difficult to assess. Results of Saunders’s uncertainty analysis reveal that the dominating uncertainty component depends on the actual operating conditions. For example, given an effective background temperature of approximately 880°C and low TWT, the largest uncertainty is from the emissivity component. For the same background temperature and high TWT, the TWT measurement uncertainty dominates. Performing an uncertainty analysis is therefore useful in determining which uncertainty component should receive the most attention in order to improve accuracy.

Comparison of 1.0-μm and 3.9-μm pyrometers
The 1.0-μm pyrometer has been used more extensively in reformers, with the
STEAM METHANE REFORMING

3.9-μm pyrometer only being introduced to the industry in the 1990s. The increased interest in the longer wavelength is partly due to its lower sensitivity to uncertainties in background reformer temperature and in tube wall emissivity. It is important to note that the sensitivity of the 3.9-μm pyrometer is lower only in the case where background temperature is higher than the target (tube wall) temperature, which is most often the case in reformers. However, when the background temperature is lower than the target temperature, the opposite is true, i.e., the sensitivity of the 1.0-μm pyrometer is lower.

The 3.9-μm pyrometer may be less sensitive to uncertainties, but it has also been observed to give less accurate TWT measurements. In one study, Topsoe inserted a target object between the tubes of an operating side-fired reformer and found that the 3.9-μm pyrometer consistently measured higher temperatures after correction than thermocouples placed in the object. The 3.9-μm pyrometer measurements were also found to be higher than predicted by reformer simulations. Reformer simulations, such as the proprietary simulation programs developed by Topsoe, provide optimum operating temperatures using detailed equipment information and actual operating data. As part of the simulation, advanced process modeling balances the reactivity in the catalyst tubes and heat flux along the tubes and finds the correct heat balance between the radiant furnace box and convection section. Further details of Topsoe’s simulation programs are provided in Jensen et al.8

In contrast to 3.9-μm pyrometers, 1.0-μm pyrometers have been found to measure temperatures in agreement with thermocouples in the same target object, and the TWT measurements were consistent with predictions from reformer simulations. However, the high sensitivity of the 1.0-μm pyrometer makes it less straightforward to use. In the absence of thorough training, the 3.9-μm pyrometer with its lower sensitivity should be used. The 3.9-μm pyrometer is also the more conservative choice, since the higher temperature readings generally lead to adjustments that do not exceed design limits.

**Preconditions**

Prior to measurement, the user must ensure that the plant is in stable operation and that sufficient draft is present to prevent overpressure in the furnace box during measurement. The user should also ensure that overpressure protection of the furnace box is in place.

**Cooling rate**

The vacuum inside the furnace box will cause cold air to rush into the furnace box when the peephole door is opened, which will cool the catalyst tubes. Evaluation of the cooling rate requires repeated TWT measurement of the same tube while the door is kept open. For example, measurements are taken every five seconds for the first 15 seconds, followed by measurements every ten seconds up to one minute. The peephole door must be kept closed for several minutes before this procedure can be repeated with the same or different tube. Since the tubes may experience significantly varying cooling rates, it is recommended to perform these measurements on two additional peepholes located at opposite ends of the reformer. The cooling rate is faster for tubes closer to the peephole doors but after about 120 seconds TWT does not continue to drop. In general, the cooling rate is low enough to allow a maximum open peephole time of three seconds.

**Reproducibility**

The reproducibility of the TWT measurements must be verified by consecutively measuring selected tubes five times, with at least one in front of and one away from the peephole. The peephole must be closed for a minimum of 30 seconds between measurements in order to avoid the cooling influence of outside air. A similar procedure can be used to verify the reproducibility of furnace wall temperature measurements. The deviation should generally be less than 2-3°C.

**Normal horizontal measurements**

The temperature measurements are performed in three steps:

- the tube wall temperatures are measured through all the side peepholes;
- the furnace wall temperatures are measured between the tubes from the opposite side;
- the appropriate correction due to furnace wall reflection is calculated and applied.

The pyrometer emissivity should be set to 1.0, continuous measurement mode should be selected, and the focus lens should be adjusted with respect to the distance to the tubes.

**Gold cup pyrometry**

Another trusted method of TWT measurement used in the industry is the gold cup pyrometer. With this instrument, the target object is surrounded by a gold plated hemisphere (gold cup) and effectively acts as a blackbody. Errors due to background contribution and inaccurate emissivity assumptions are eliminated, and the radiation measured by the gold cup pyrometer can be directly converted to the true temperature of the object. Due to its accuracy, the gold cup pyrometer is often used as a reference standard. A disadvantage of the gold cup pyrometer is its heavy and cumbersome weight. It also has a limit to the distance that it can be inserted into the furnace. Use is otherwise relatively simple, and minimal training is needed. This method is recommended as a supplement to regular and frequent measurements using optical IR pyrometers, and it is offered as part of Topsoe’s steam reformer assessment/optimisation services. Experts at Topsoe are well trained at providing the most accurate TWT measurements possible using a variety of methods and can use the gold cup to assess the effectiveness of other methods typically used at a plant.

In 2015, Topsoe performed a comparison study between gold cup measurements and measurements using optical IR pyrometers. The study was conducted on two side-fired reformers at separate plants that experience similar environmental conditions. All tubes were cleaned shortly before measurement. Results showed that
the 3.9-micron pyrometer measured consistently higher than the 1.0-micron pyrometer. They also showed that measurements from both of the optical pyrometers, after correction and the appropriate assumptions for tube wall emissivity, were typically higher than measurements from the gold cup pyrometer.

Differences between the gold cup measurements and the corrected measurements from optical IR TWT measurements were in large part attributed to inaccurate tube wall emissivity assumptions. A more accurate tube wall emissivity can be determined by adjusting it such that the corrected optical IR measurements match those of the gold cup.

The conclusion that assumed emissivities may often be too high is supported by a recent research project conducted between Topsoe and the Technical University of Denmark. Furthermore, findings from the joint project are in agreement with the distribution curve of adjusted emissivities obtained using the 1.0-μm pyrometer in this study. On the other hand, the distribution curve of adjusted emissivities for the 3.9-μm pyrometer is not in agreement with the literature and the joint project, and this approach of reconciling emissivities may therefore not be recommended for the correction of 3.9-μm pyrometer measurements.

**Topsoe Furnace Manager**

Other developments for improved reformer management include on-line measurement of TWT using a new Topsoe monitoring system called the Topsoe Furnace Manager (TFM), which is a permanent installation of an array of image collectors. The significant advantage of the TFM over hand-held methods is its remotely accessible and continuous real-time data of the furnace interior around the clock. Data acquisition does not require any opening of peephole doors, and operators can balance the reformer firing and respond to an alarm without direct interaction with the furnace box. This represents a major improvement in reformer performance and personnel safety.

Use of the TFM is straightforward and does not require extensive training. On-line flame and TWT monitoring results are presented via universally understood images and data for the entire lifetime of the furnace. Remote access to the data and images also means that off-site experts can participate in troubleshooting and furnace optimisation, engaging the entire...
furnace support organisation. In addition, logs of historical data are kept available, which easily provide benchmarks for training purposes and turnaround reference.

The many capabilities of the TFM make it very effective in helping plants avoid unwanted incidents. It acts as a safeguard against furnace overheating and works in parallel with existing safeguards, such as a BMS. It provides information facilitating process safety management and reliability, availability, and maintainability (RAM) evaluations, which leads to better knowledge of mechanical integrity, compliance audits, failure rates, failure modes, time-to-repair, and costs. Clients have found the TFM to be particularly valuable in maintaining safe and optimal reformer operation with older end-of-life catalyst tubes. The TFM has also helped a plant continue operation with a small process leak in the furnace box for over two years. Finally, the reliability of the TFM has also been demonstrated by a case in which after 45,000 hours of operation, all catalyst tube creep measurements were less than 1%.

The TFM is commercially proven in both side-fired and top-fired reformers. Its economic benefits include reduction of fuel consumption and efficiency improvements that could amount to a few hundred thousand US dollars a year and a similar amount in savings resulting from improvements in personnel productivity.

**Topsoe steam reformer assessment/optimisation**

Tube wall temperature measurement is one of the many steam reformer services that Topsoe experts can provide through the company’s four-level steam reformer assessment/optimisation service. The general scope of each service level is shown in Table 1. The aim is to help plants adhere to design limits, identify bottlenecks, save in energy and resources, increase tube lifetime, and optimise normal operations. The services are customised to each plant’s needs, and results are used to provide specific recommendations. Topsoe uses the detailed insight into the reformer’s performance to maximise its efficiency, stability and throughput. Figure 3 shows an example of TWT measurements before and after Topsoe improvements to the furnace. The top graph indicates high and fluctuating TWTs, while the bottom graph shows more consistent TWTs, which are necessary for optimal performance.

**Johnson Matthey improving reformer operation**

For a reformer to achieve maximum production in the most energy efficient manner, extending the reformer tube life and reducing trips and failures is something that needs consideration at all stages from the moment the catalyst is chosen, through its loading, start-up, operation and maintenance of the reformer. The right loading techniques, operation and process optimisation of catalysts can give world-beating performance, however they have to be considered as a whole and not in isolation.

In the following sections Johnson Matthey focuses on reformer operation prior to start up, during transient conditions such as start-up, steady state operation and even during a turnaround with the aim of highlighting best practice to improve the reformer’s performance and increase reformer tube lives.

**Prior to start-up**

Good reformer operation can be influenced even before the plant start-up and depends upon three parameters: the correct type of catalyst, an even catalyst loading and good quality reformer tubes.

It is important to determine in advance the correct catalyst combination for the process feed gas to the reformer. Special care must be taken to ensure that all components are considered in order to prevent future operational problems such as catalyst poisoning resulting in premature short lives. One example of this is alkalised formulations such as KATALCO™ 25-series in which low levels of potash are added to the catalyst. This is incorporated into the calcium aluminate support structure in a way that slowly hydrolyses, releasing alkali at the concentration required to ensure continuous carbon-free operation without loss of activity.

Another potential catalyst option would be to use the new Johnson Matthey CATACEL™ SSR which is a coated catalyst on a formed structure as shown in Fig. 4. Individual units are stacked on top of each other around a central axle assembly for charging the reformer tube. The structure is designed to direct the gas against the tube wall which results in a significant performance benefit compared to pellets. This benefit can be used to reduce tube wall temperatures, and as a consequence to increase production in the reformer.

As well as selecting the correct catalyst combination, the right loading technique is also essential. The loading must ensure that an equal amount of catalyst is dense loaded into each tube, hence ensuring an even flow of process gas, and therefore
In recent years it has become standard in Fig. 6 shows these issues could appear at the top of the reformer tube. The image must be installed so that catalyst does not result in localised “hot spots” on the tube life and therefore plant availability. Fig. 7 shows a tube that was found to have a boring defect during fabrication.

A baseline inspection of the tube internal diameter before the tubes are installed in the reformer, (or at the tube fabricators workshop), can determine any defects and hence allow replacement of the tube before installation.

During start-up

It is well known that large-scale steam reformers in syngas plants are vulnerable to over firing, especially during plant transient conditions. This vulnerability is due to the fact that external temperature instrumentation lags during normal operation, and that human monitoring cannot be conducted on a sufficiently frequent basis. The consequence is that, over the past decades, many of the catastrophic reformer failures documented have occurred during the most common transient operation – start-ups.

It is therefore essential that regular and frequent visual inspections of the reformer tubes are made during critical periods associated with transients as most reformer instrumentation is designed for monitoring and control of operation during steady state operation.

Case study 1 describes a failure during a start-up on a large plant and illustrates the damage to the reformer that can occur in a relatively short time period.

Case study 1: Top-fired reformer start-up incident

This case study is based on the actual experience of an operator of a large modern top-fired reformer. They suffered from significant tube failures during a plant start-up, resulting in losses running to US$ millions in terms of lost profits and down-time. This catastrophic failure was caused by over firing during start-up and was the result of a number of coincident factors.

At the time of the incident, the site had steam shortages and this led to pressure to conserve steam. In addition to this, the plant was under pressure to avoid a shutdown if at all possible due to low product stocks. The burners on their reformer usually received fuel from two different sources and these were mixed. One of the sources was of low calorific value, and the other a much higher calorific value. At the time of incident, the plant was unexpectedly receiving all of its fuel from the high calorific value source.

During the previous two years the operators had seen many start-ups and shutdowns for a variety of different reasons, and were therefore relatively familiar with the procedures. The plant tripped on loss of feedstock to reformer as a result of a valve failure.

In their efforts to bring the plant back on line quickly, the feedstock to the reformer was not isolated adequately by a valve and the set point on the reformed gas pressure was not reduced. In addition to this steam introduced for the plant restart was at a reduced rate and all of the burners were lit (a deviation from the written procedure). According to the instruments in the control room, the reformer tube pressure remained at normal operating conditions of 16 barg. The reformer tube exit temperature also “looked normal” and throughout the incident never exceeded 700°C.

However, since all the burners were lit, there was nearly three times as much fuel going to burners than there should have been. In addition to this, the high calorific value fuel added an extra 15% heat release. When the first tubes ruptured, the radiant box high pressure alarm activated, but the plant did not trip as the high pressure trip was by-passed. The oxygen level in the flue gas dropped to zero and flames were seen coming from the reformer peep holes. Visual inspection of the reformer then revealed “white hot furnace and tubes peeling open” and the emergency shutdown was the activated.

The entire set of reformer tubes had failed, Fig. 8, and the incident from start to finish took less than 30 minutes.

One method which would prevent such an event is to use online temperature measurement, such as a relatively new in-tube temperature measuring technique, called the CatTracker™ (a trademark of Daily Instruments). CatTracker can be installed in steam reformers using a method patented by Johnson Matthey. The CatTracker is a multipoint thermocouple that is installed in the centre of the reformer tube amongst the catalyst and has been shown to have the following benefits:
The optical pyrometer is an instrument which most operators own and which has been proven over decades to provide good results when compensated for background radiation. However, using it 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 centre 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.

A gold cup pyrometer is an accurate measurement of tube wall temperatures when required. It is a direct contact pyrometer and therefore no correction is required for background radiation. However the gold cup pyrometer too, has its limitations. The method requires the gold cup to physically touch each tube; therefore measurement is limited to only a small number of tubes in each row for a multi-row furnace.

Johnson Matthey has another technique known as the Reformer Imager which is recognised as “best in class” for measuring reformer tube wall temperatures. It operates in the infra-red spectrum and captures significantly more information than the two techniques described above. The imager has a lens which allows a wide viewing angle therefore temperature readings are available for parts of the tubes that cannot be seen by the naked eye, e.g. the tops and bottoms of the tubes and tubes closer to the walls. The videos are recorded directly to a laptop and can be taken away for further analysis and can be used as reference to compare reformer performance over a given time period.

Any or all of these techniques can be provided by Johnson Matthey in the form of a reformer survey or used for reformer balancing on a customer plant. The reformer survey goes beyond straightforward TWT measurement and incorporates temperature correction and process engineering simulations to characterise a reformer performance, benchmarking against similar reformers and troubleshooting operational problems. This type of survey allows the operations team to make changes to the reformer balancing to improve reformer performance, often delivering significant value to the customer and improved plant production and efficiency. Johnson Matthey can also assist on site with reformer balancing to either increase production,
reduce maximum tube wall temperatures, improve energy efficiency or a combination of all three.

Case study 2 describes how a reformer survey with the reformer imager was used to diagnose and solve a plant problem that was previously not understood while case study 3 details how these techniques can be used for balancing the reformer.

Case study 2 – Reformer analysis and solution development

A top fired reformer on a methanol plant which had a competitor’s steam reforming catalyst installed, suffered from hot spots and hot bands on the tubes in its first three years of operation. Within a few months of operation of its second charge, two tubes had ruptured and additional hot tubes and hot spots developed after every plant trip. To manage the furnace, the operator trimmed the fuel to the burners in the problem areas of the reformer. Conventional temperature measuring devices such as an optical pyrometer were unable to measure the temperature of all tubes. Consequently, it was impossible to determine if the problems were caused by poor catalyst packing, carbon formation or poisoning.

The operator sought Johnson Matthey’s help with root cause analysis. Johnson Matthey engineers conducted a reformer survey using the reformer imager, temperature measurements were taken quickly and easily in all parts of the reformer. Conventional pyrometric devices were unable to measure the temperature of all tubes. Consequently, it was impossible to determine if the problems were caused by poor catalyst packing, carbon formation or poisoning.

With thousands of data points available, the exact location of the hotter tubes and hot spots could be pinpointed. With these data, Johnson Matthey’s experts determined the most likely cause of the problems was carbon formation as all of the hotspots were localised and well delineated. Hot tubes were consistently found at the end of rows, suggesting additional heat reflection from the refractory walls.

As a result of the survey, Johnson Matthey’s engineers made short and long term recommendations including amendments to the plant start-up procedures. The catalyst was also replaced with a Johnson Matthey catalyst that would not form carbon during operation.

Table 2: Summary of production increase

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refiner exit temperature, °C</td>
<td>800.6</td>
<td>798.9</td>
</tr>
<tr>
<td>Primary reformer methane slip, %</td>
<td>11.12</td>
<td>11.03</td>
</tr>
<tr>
<td>Production, t/d</td>
<td>1,633</td>
<td>1,637</td>
</tr>
<tr>
<td>Process gas flow, kg/h</td>
<td>31,047</td>
<td>31,059</td>
</tr>
<tr>
<td>Natural gas fuel flow, kg/h</td>
<td>2,869</td>
<td>2,850</td>
</tr>
</tbody>
</table>

Source: Johnson Matthey

The survey involved:
- The use of a reformer imager to capture images which were used to determine the temperatures of the reformer tubes
- Visual observation of the condition of the tubes, refractory and burners
- Recording of burner valve positions
- Collection of process data to model the performance of the primary reformer.

The survey indicated that the outer rows were hotter than the inner rows so the fuel header pressures were reduced on the outer rows in an effort to lower those temperatures. Following these adjustments, several further tube wall temperature surveys were done to assess the conditions of the reformer.

A summary of the process changes effected by the adjustments is shown in Table 2.

As a result of improving the temperature distribution within the reformer, fuel usage and methane slip at the exit of the primary reformer were both reduced,
leading to improved energy efficiency and a modest increase in ammonia production.

**Turnaround activities**

Good reformer monitoring does not end when the plant is shut down for a turnaround. Whether the catalyst is replaced or not, the tubes should be physically measured for creep growth during the last production run to back up the results of the temperature monitoring in terms of whether any tubes need replacement. If the catalyst is being changed out, it is always recommended to conduct an internal inspection of the tubes using a technique such as the LOTIS™ inspection to determine the diametrical growth of the tubes. If the catalyst is not being removed, the MANTIS™ inspection technique can be utilised (LOTIS and MANTIS are trademarks of Quest Integrity Group LLC).

These techniques measure the internal or external diameter of the tubes, hence showing the creep growth during operation. Creep of reformer tubes is expected and tubes have a design lifetime of 100,000 hours if operated consistently well. Periods of operation at temperatures near or over design temperature accelerate creep growth and can lead to premature failures. The physical measurement will determine which tubes have the most diametrical growth and therefore may need replacement during future turnarounds.

If required, a remnant life assessment on the tubes can also be carried out using these diametrical measurements to determine the end life of each tube assuming operation similar to that previously experienced.

**BD Energy Systems tube overheat protection**

One of the most significant reformer incidents is overheating catalyst tubes to the point of failure. These events inevitably have a serious impact on the business with significant repair costs and loss of production.

Reformer tubes expand when heated to operational temperatures. The expansion is related to the tube temperature and is sufficiently precise that overheating conditions can be detected in time to avoid damage to the tubes.

Current on line detection of overheating relies on interpretation of process data from which tube temperatures are inferred either by the operator or an algorithm in the control system. These systems are not fool proof and fault tree studies reveal a number of ways they can fail to prevent overheating. However, by directly measuring the variable of interest, the tube temperature, via tube growth, these loopholes are closed and robust overheat protection is provided.

The Tube Growth Monitor (TGM) technology, which is licensed to BD Energy Systems and is available to non-methanol reformers applications, detects and alarms changes in reformer tube temperature before dangerous levels are reached earlier than current instrumentation. This makes possible an absolute protection against tube overheating incidents as long as the operators act upon the information promptly. The number of temperature monitors and the nature of the very visual display of the temperature indications and alarms from the TGMs cannot be missed or ignored.

Together with a robust protection against overheating, the TGM real time reformer temperature data allows multiple uses of this data to improve reformer performance and tube life management.

**Principle of operation**

All metals experience thermal growth due to temperature change that is characterised by a “linear expansion coefficient.” This is the fractional change in length per degree of temperature change from a reference temperature. The linear growth will then be measured as a temperature “inertia” to dissipate, without over-correction in order to avoid damage to the tubes. There is limited time available for analysing data and making a decision during an overheating incident. This understanding comes only with time and experience but is a critical need to enable operators to make correct decisions quickly and to avoid damage.

To avoid placement of such a heavy burden on plant operators, many plants have adopted some type of automated overheat protection system.

**Current protection weaknesses**

Conventional operator supervised overheat protection practices and automated systems using process instrumented inputs have inherent weaknesses and limitations that must be understood.

Reliance upon operator supervision for overheat protection places a tremendous burden upon operators to understand the dynamic behaviour of a reformer furnace during non-steady state operations.

The time considered for action to stop a temperature increase to prevent an overheat event must be enough to allow the temperature “inertia” to dissipate, without over-correction in order to avoid damage to the tubes. There is limited time available for analysing data and making a decision during an overheating incident. This understanding comes only with time and experience but is a critical need to enable operators to make correct decisions quickly and to avoid damage.

To avoid placement of such a heavy burden on plant operators, many plants have adopted some type of automated overheat protection system.

Many conventional automated overheat protection systems are based on use of fuel firing limitations programmed into the control system. These firing limitations are based on correlations intended to limit the fuel firing rate based on a number of critical measured process operating parameters. The intent of such correlations is to avoid human error during non-steady state operations. However, a remaining weak conventional automated overheat protection relies upon the proper function of...
Multiple instruments that measure those critical process parameters.

Most of the published overheating incidents show root causes related to human behaviour or with a great influence of this factor. Hence, the probability of overheating incidents is always present as long as human action is part of the decision and operation process intended to avoid such an event.

A factor that greatly influences the human behaviour is the plant reliability. The reformer reliability and plant on-stream reliability has been improving over time. This means that there are much longer periods of stable operation time between unsteady state operations such as startups, shutdowns and the occurrence of serious problems like reformer trips. As a result, operators deal with unsteady conditions less frequently, making these events somewhat unfamiliar.

Another condition to consider is the retention of corporate knowledge that has been built up over many years when there is staff turnover due to retirement, promotion or job relocation.

Preventing reformer tube failures
Case study fault tree analysis and actual operations experience has shown that the probability of prevention of reformer tube failures related to overheating by reading the tube thermal expansion is “almost certain” for the following cases:
- Exotherm during steam out oxidation of catalyst.
- Incorrect burner light off sequence.
- Incorrect burner shut off sequence.
- Fuel gas header pressure relying on autoramping during rate change resulting in overshoot of temperature.
- Low steam flow or maldistribution of steam flow during steam out.
- High fuel gas header pressure during steam out as control valve manual bypass is open.
- Attempt to introduce feed gas with manual isolation valve closed. Programed protection system allows increase of fuel firing based on feed control valve % open.
- Incorrect trend graph loaded into automated ramping software for start-up control.

And detection and prevention of overheat with the TGM system would be “probable” for the following two cases:
- Collateral damage from end of life tube failure.

Conceptual engineering and real application
The Tube Growth Monitor (TGM) concept uses an instrument that is easy to install and set up.

The TGM system design must consider the location of burners and how the tubes are supported in the radiant box (springs or counter weight hangers). With this information a rather simple mechanical design can be developed for installation of instruments on each hanger to ensure that they accurately measure the tubes thermal growth.

The system configuration is adaptable to the needs of each furnace operator. It normally requires that a signal of the tube growth is sent to the DCS in order to allow the operators and engineers to have online data. Additional trending can be made if the data is available to the plant process historian.

Although it is possible to have a local reading only, this setup is not recommended when the final intent is to protect the tubes from an overheating event as it would require constant attention from an operator to detect changes.

In a top-fired design, the TGMs are normally installed on the tubes spring hanger or counterweight hangers and the signal is sent to the DCS for processing and distribution to other plant systems like data historian and CMMS (Computerised Maintenance Management System), as a standard process data point.

A typical TGM setup for a top fired reformer can be seen in Fig. 11, which shows a series of TGM (battery powered) connected to the reformer spring hangers. The signals are sent wirelessly to a set of four antennas that receive the
signal and send it to four gateways that transmit the data to the system (DCS and data historian). The flexibility of the wireless devices allows for easy customisation according to the needs of the reformer operator.

There is also the option of a wired TGM installation, but more work and budget would be required for the wiring and accessories related.

The number of antennas and gateways determines the frequency of the scan rate for each TGM input and therefore the level of reliability and redundancy provided to the data management processing.

For the real application described in this article, wireless communication TGMs were installed on each spring hanger of a top fired reformer, as shown in Fig. 12. Each TGM reads the thermal expansion of four tubes, as that is the spring hanger support configuration.

Finally once the information is contained in the DCS and data historian, the data is presented on proprietary software developed to display a representation of the radiant box plant view. This software is able to present a graphic display of the reformer in plan view showing a gradient of colours to indicate displacements of the TGMs installed on the hangers.

The software also presents statistical information about temperature showing the maximum, minimum, and average at different times as well as standard deviation and rate of change statistics. It also allows for taking images and saving events amongst other features.

In addition, the software allows for remote connection to the data making it possible to monitor the reformer condition at all time and from remote locations.

The data collected can also be exported to an Excel spreadsheet for further analysis and interpretation. This feature facilitates the development of life management strategies for the catalyst tubes.

Application
This technology is currently installed in two top fired reformers (spring hangers) and one terrace wall reformer (counter weight) with the first installation made in 2012 following the type of configuration shown in Fig. 11. The software developed facilitate the operators’ surveillance, and for data acquisition and analysis for engineers.

On one of the top fired reformer installations a total of 200 TGM are mounted on the tube spring hangers as shown in Fig. 12, the signal of each TGM is directed to the DCS and data historian.

There is one display representation for the DCS and another for the data historian.

Since the initial installation of the TGM system, a number of temperature excursions have been observed and damage was successfully averted by operator action. The data gathered, makes it quite clear that TGMs are the first alarms to indicate a temperature excursion.

Visibility to control room operators
To enable the TGM system to deliver the desired protection requires constant and clear visibility to control room operators. This allows for quick reaction time in case any temperature related problem occurs in the reformer.

Software displays are on 100% of the time and located next to the shift leader position and viewable by everyone in the control room.

The panel DCS view can be called up and is often used by operators.

Data quality
The TGM data is able to yield 5°C accuracy with 1,050°C of span. As explained this is a bulk or average temperature of the tubes supported by each spring or counter weight.

The scan rate for the data is set by the owner and is a trade-off between battery life and response time. A one-minute update rate has been found to be a compromise that gives reasonable battery life and good response time and data resolution.

Case histories
Since the installation of the TGMs in a real application, there have been numerous cases examples that have shown the value of these instruments.

The following cases show just two situations where the TGMs have given valuable information to the operators:

Local heating
Many tubes underwent a ‘hot banding’ episode after an instance of heavier feed gas. A reformer went from the condition shown in Fig. 13 to the condition shown in Fig. 14 over a period of 44 minutes.

With no change in operating parameters, the rise in temperature was detected by the TGMs and the field operator measured 1,000°C with the pyrometer but only over a 1 m length of tube.

As a result of the information provided by the TGMs, quick action was taken to increase process steam rate for a period of time until the carbon accumulation dissipated and tube temperature returned to normal. By acting quickly, more significant carbon accumulation and catalyst damage was avoided, potential significant overheat of the tubes was avoided, and production loss was limited.

Local hot spots detection and reformer instability
The TGMs are also valuable to detect individual tubes in the reformer or regions of tubes in the reformer that flip between hot and cold due to flue gas flow pattern instability. This is a phenomenon sometimes experienced in large-scale down-fired reformer furnaces. Figure 15 shows this condition in a reformer.
Chiyoda remaining tube life assessment

The life of catalyst tubes operated in steam reforming furnaces is affected by creep damage under high temperature and high stress level conditions and they finally crack. Usually the leakage is avoided by monitoring the remaining tube life. The progress of creep damage relates mainly to the exposed temperature condition of catalyst tubes. The outer surface condition of the tubes, especially colour and roughness, are changed by exposure to high temperature, and therefore it is possible to estimate the temperature based on the observation of outer surface colour and roughness. With this, the remaining life of catalyst tubes can be managed to maintain the safety and the reliability of the steam reformer furnace.

Chiyoda has assessed the remaining life of catalyst tubes since 1971. Two methods are applied to find the remaining life:

1. Destructive metallurgical examination, including creep rupture testing;
2. Non-destructive testing method consisting of UT attenuation, ET and dimensional measurements (this method, called ‘H’ Scan, was developed by ‘H’ Scan International Inc.)

Chiyoda selected three commonly used heat resisting cast alloys that it has supplied for catalyst tube materials which have the properties of improved creep rupture strength and stress relaxation properties: HK40 (25Cr-20Ni-0.4C) an iron base cast alloy supplied by Chiyoda since 1964; IN519 (24Cr-24Ni-Nb-0.3C) an iron base cast alloy, the most common material supplied since 1974; and HP microalloy (25Cr-35Ni-Nb-0.3Ti-0.5C) an iron base cast alloy, available since 1984. In 2015 more than 80% of catalyst tube material supplied by Chiyoda was HP microalloy.

From the result of destructive metallurgical examinations, the relationship between the changes of inner diameter, namely bulging and life consumption of catalyst tube by creep damage was found. The worst bulged area corresponds to the highest temperature portion. The skin temperature distribution of catalyst tube is estimated to measure the hardness along the tube length. The lower hardness indicates the higher tube skin temperature. The remaining life of catalyst tubes is managed to monitor the changes of inner diameter at the highest temperature area of the tube.

The temperature profile and the value of temperature are estimated from the result of hardness measurement and microstructure observation. These are destructive examination methods and it is better to find the information with a non-destructive method. The outer surface conditions, especially colour and roughness of used catalyst tube, relates to the exposed temperature and time and it is possible to estimate the condition or remaining tube life by monitoring the outer surface condition including the period of operation.

Figure 16 provides an example of the outer surface appearance for HP microalloy catalyst tubes in an actual plant. These photos were taken from the top level of the tunnel located at the floor in the furnace. The outer surface top and upper portion seem to be covered with reddish black scale and the outer surface of the middle to bottom portion was covered with blackish scale.

It is hard to observe the outer surface conditions from the floor level of the furnace. It is better to find the outer surface condition from a right angle.

Furthermore, not only colour and roughness information, but also spectroscopic information for outer surface can be obtained by using a spectroscopic probe.

A so-called ‘Surface Scanner’, consisting of TV cameras with lighting, encoder to measure the distance from the standard point, and an air motor to move along the tube, can be used to observe the outer condition of the catalyst tube automatically. The Surface Scanner can also be combined with H-Scan equipment developed by H-Scan International Inc.

In conclusion, the results of destructive metallurgical examinations and non-destructive inspections for HK40, IN519 and HP micro catalyst tubes have proven the following:

1. The temperature profile of the catalyst tube can be estimated based on the measurement of hardness along the tube length. The lower hardness portion of catalyst tube in the furnace corresponds to the higher temperature portion where the progress of creep damage is faster than other lower temperature portion.
2. The temperature of the catalyst tube can be estimated by observing the microstructure compared to the standard microstructure which is prepared under known various temperatures and aging periods. The effect of temperature and time is evaluated with Time, Temperature Parameter (TTP). The Larson Miller Parameter (LMP), a familiar TTP, is applied to HK40, IN519 and HP micro-alloy materials.
3. The outer surface condition, especially colour and roughness, of catalyst tube indicate the tube skin temperature condition. Reddish brown and reddish black colour means low temperature, less than 1000 K, on the other hand blackish colour means high temperature, more than 1000 K. Smooth surface means the higher temperature, more than 11 70 K.
4. It is useful to observe the outer surface condition for the whole catalyst tube in the furnace since the distribution of tube skin temperatures for whole tubes, clarifying the higher temperature portion, corresponds to the severe creep damage portion.
5. The equipment necessary for observation of the outer surface condition of catalyst tube has been proposed. It was applied to actual catalyst tubes in a steam reformer furnace.
6. When areas of blackish surface, especially smooth surfaces, are found, it is necessary for the catalyst tube to be sampled and the remaining life estimated quantitatively by creep rupture testing.
Yara life cycle management of reformer tubes

The implementation of a best practice for the life cycle management of reformer tubes is an enterprise-wide goal for Yara International. Yara management recognised that they operated a large number of steam-methane reformers (reformers) globally and the management of these assets was not uniform and could be improved. The number and frequency of tube failures occurring at some of the sites was indicative of the improvement opportunity. More efficient, safe and reliable operation of these assets was viewed as critical to the company’s success and reason for the focus on a specific best practice. Quest Integrity was recognised by Yara for their reliability expertise in the ammonia and broader syngas industry, specific service and technology for reformers, and as a provider of world class products and services.

Together, Yara and Quest Integrity developed a project scope and a plan to provide training for operators and reliability groups, implementation of tube temperature management, and reformer performance and reliability surveys of this global set of assets. These best practice program elements of reformer care were implemented for all of the Yara International reformer assets during the time span of mid-2013 to early 2015.

Overview of Yara reformers

Yara has 12 operating ammonia plants located worldwide. These ammonia plants and reformers vary in process technology, reformer design, capacity, and age as well as production efficiency and reliability. The reformers are a combination of top-fired, side-fired and terrace wall designs. The oldest reformer in the system is the Yara Le Havre, France, reformer commissioned in 1967 and the newest reformer is the Yara Tertre, Belgium, reformer commissioned/rebuilt in 2010 following a firebox explosion. There are a total of 3,180 tubes in these 12 reformers located in eight production complexes around the globe. The oldest tubes were installed in 1977 in Porsgrunn, Norway, and Ferrara, Italy. The average age of the installed reformer tubes is around 20 years.

Basic elements of Yara catalyst tubes management best practice

Reformer catalyst tube reliability involves the whole production facility organisation (inspection, production, and maintenance) in order to systematically address all the phases of the tube life-cycle. Yara’s approach to the life cycle management of reformer tubes, as detailed in the best practice document Yara BP63 (BP63), involves training of personnel at both an operating and management level to ensure that they have an understanding of materials, common damage mechanisms, and inspection and monitoring techniques. This knowledge is used to evaluate manufacturing or fabrication deficiencies, deterioration or damage in service and the life cycle effects of operation deviations. The goal is to make optimum use of the reformer tubes (plus the pigtails and headers) over the expected life and avoid untimely and costly premature failures.

Specific steps are defined and accomplished to manage reformer tubes over each operating cycle for the reformer. The operating cycle is defined as the period of time between two consecutive turnarounds, typically four or five years. These asset management steps include an initial survey of the reformer conditions during operation soon after start-up, continuing visual inspection and tube temperature surveys on a regular basis, life assessment of reformer tubes and components prior to a scheduled turnaround, inspection and assessment during turnarounds, and careful observation and execution of start-up and commissioning. The cycle of the activities is then repeated.

Reformer survey and cost-benefit analysis

In 2013, two years after the development of BP63, Yara performed a survey on all of the reformer assets. From the survey, Yara recognised that the management of these assets was not uniform and could be improved. The catalyst tubes failure history data included in the survey determined that an average of eight tube failures every three years were occurring (not including tube failures due to incidents/trips). It was also clear that the areas with the greatest room for improvement were the temperature monitoring program and the residual life assessment of the catalyst tubes.

During the 2013 survey, a cost-benefit analysis was performed to estimate the potential benefit of a full and uniform implementation of BP63. This analysis was executed according to API 581 calculating the tube probability of failure due to creep in the following two conditions:

- Full implementation of Yara BP63: “highly effective” inspection, monitoring and assessment program;
- 2013 basis or actual situation: “fairly effective” inspection, monitoring and assessment program.

The result of the analysis showed a significant potential benefit.

Based upon the 2013 reformer survey and the estimated potential benefit, Yara selected Quest Integrity to assist with the global implementation of BP63 through a specialised program of “reformer care” with the ultimate objective to reduce the number and frequency of catalyst tube failures.

Reformer care

Quest Integrity’s Reformer Care includes data analysis, remaining life assessment, and engineering solutions. These services can be applied individually to address a specific issue or may be grouped to together to apply to a wide range of integrity issues. These services offer a unique solution to attain operational safety and reliability goals, enable proactive decision making, eliminate premature harvesting of reformer tubes, improve knowledge of turnaround requirements and reduces costs with proper planning, increase the understanding of reformer operation and limitations, and addresses all reformer systems.

Yara selected a sub-set of these Reformer Care services or program elements to assist with their global implementation of BP63. This set provided Yara with a specialised program of Reformer Care to assist with the strategic management of the 12 reformers.

These key elements included:

- training for operators on visual inspection of reformers including tubes conditions,
- burner operation, and general condition;
- training for operators on tube temperature measurement practices Implementation of reformer tube temperature correction procedures;
- recommendations for maximum allowable tube metal temperatures;
- reformer performance monitoring to evaluate the current condition in service and identity and recommend performance and reliability strategies for improvement.

These elements were chosen by Yara to close the gaps (against BP63) identified during the 2013 reformer survey, with particular focus on maximum allowable temperature (MAT) determination, temperature monitoring and residual life assessment of the catalyst tubes.
The implementation of the “Reformer Care” services was accomplished according to a schedule developed by Yara. The schedule was based upon Yara’s evaluation of several factors including the turn-round timing of the reformers, history of operational and reliability issues, age of reformer tubes and planned replacements, and availability of site personnel.

The Yara Global Inspection Group had the overall responsibility for coordinating on-site training activities and coordination of information about the reformers to Quest Integrity ahead of the onsite work. Information exchanged included operating and design information, inspection results, and failure and replacement history. This information was used to develop specific training materials for each of the reformers, provide background information for evaluation of the reformers, and to customise the temperature correction software application for each reformer.

Site work and training was completed in 4-5 days per reformer.

Training
The on-site training for Yara personnel was accomplished in both a classroom and field environment.

Typical training attendance was 10-20 people and a mixture of operation, reliability, and inspection personnel. Quest Integrity senior engineers delivered the training, performed equipment field surveys, demonstrations and practical application of methods presented in the classroom.

The training classroom and field application portions of the work were accomplished in two days and split between reformer performance monitoring and reformer tube temperature measurement and corrections.

Reformer performance monitoring
The topics covered in the training included background information on reformer reliability, recognition and troubleshooting of reformer performance issues, reformer tube damage mechanisms and inspection, fitness-for-service and remaining life of reformer tubes, and how to recognise, troubleshoot and prevent common reformer tube failures. This training included normal and abnormal tube conditions, bowed tubes, hot spots, bulges, cold tubes, and conditions due to catalyst damage and poisoning.

Training specific to burners in operation was included to address burner characteristics and design, correct operation of the burner, adjustments, maintenance, and troubleshooting.

Practical training on tube and reformer visual inspection during operator rounds was discussed in the classroom and then practiced in the field by participants using specifically prepared check list.

Reformer tube temperature management
Accurate measurement of reformer tube-skin temperatures is a crucial input to a tube life prediction model (not directly based upon measured creep damage) and is also critical in optimising productivity and ensuring optimum reformer operation. Radiation thermometry is a practicable and reliable method for determining tube-skin temperatures in reformers provided certain measurement corrective practices are used. Radiation thermometry in reformers is prone to a number of errors arising principally from the effects of tube emissivity, reflected radiation and flue gas (Fig. 17). Radiation thermometer readings and thermal images must have corrections applied in order to obtain the true tube-skin temperatures. These corrections depend in a complex way on the geometry of the furnace, the emissivity of the tube material, atmospheric effects, and temperature corrections must be made to the thermometer readings based on the geometry of the furnace, the emissivity of the tube material, atmospheric effects, and knowledge of the operating characteristics of the thermometer itself. The correction of reformer radiance temperature readings (measured without correction) to corrected temperatures is accomplished using Quest Integrity’s CorrectIR™ software and method. The methodology and software is based upon the work of Dr Peter Saunders. Features of CorrectIR™ include:

- corrects radiance measurements for calibration, size of source effect, flue gas emissions and other instrument and environmental errors;
- calculates the uncertainty associated with individual factors;
- calculates the effective background temperature taking into account rigorous geometry for each tube;
- calculates the tube corrected “true” tube temperature and the total uncertainty.

Baseline reformer tube IR survey and tube wall temperature limits
As an element of the Reformer Care implementation, Yara implemented an IR temperature correction program to establish the actual reformer tube metal temperatures. In order to determine the true tube temperatures, corrections must be made to the thermometer readings based on the background information on reformer reliability, recognition and troubleshooting of reformer performance issues, reformer tube damage mechanisms and inspection, fitness-for-service and remaining life of reformer tubes, and how to recognise, troubleshoot and prevent common reformer tube failures. This training included normal and abnormal tube conditions, bowed tubes, hot spots, bulges, cold tubes, and conditions due to catalyst damage and poisoning.

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reformers. Quest Integrity has developed a unique creep material model for HP alloys that accounts for material aging and creep strain rate with respect to stress, temperature and time. This proprietary creep material model is called LifeQuest™ Reformer.

LifeQuest™ Reformer was used to define reliable and safe tube metal temperature operating limits for the Yara reformers. The main difference between the original design life estimates provided by the tube manufacturer or the furnace designer and the Quest Integrity service life estimate is that for the original design the tubes are assumed to have retained their original mean or lower bound as manufactured creep properties whereas the Quest Integrity model takes into account that the creep properties will progressively degrade. This information was also provided as a creep rupture life curve for each reformer.

The creep rupture life curve for the reformer tubes are used to assess the life impact from changes in operating conditions. With a corrected tube metal temperature (plus uncertainty) value above the safe limit, the creep rupture life could potentially be extremely short resulting in tube failure during the operating period.

Finally, during a reformer shutdown, the actual consumed creep life may be measured and calculated by utilising Quest Integrity’s proprietary inspection tools, LOTIS® and MANTIS® and the Level 3 LifeQuest™ Reformer assessment program.

Performance and reliability monitoring
Quest Integrity performed a reformer survey to evaluate each of the Yara reformers. The primary objective of the work was to observe the reformer in operation to assist with balancing the reformer firing and to deliver a reliability strategy to ensure the safe and reliable long term operation of the reformers. The survey and reliability strategy included the following essential elements to achieve optimum performance and reliability of the reformers:

- safety and environmental;
- operating performance;
- reliability issues;
- reformer tube condition;
- reformer mechanical condition;
- burner mechanical condition;
- recommended corrective actions for the reformers.

The issues found during the survey (see examples in Figs. 18 a-d) as well as other industry best practices were addressed by a set of corrective actions. Principled execution towards accomplishing these strategic actions will lead to a higher level of performance and reliability with respect to the reformer.

References
6. Roberts H and Sandy L: “Reformer balancing for optimisation of the PCS 02 primary reformer”.
7. Dean M and Briggs K: “The Value of Primary Reformer Temperature Balancing and Monitoring”.

Figs 18 a-d: Examples of issues found during surveys

a) Yara Sluiskilly H501 reformer: external scale on upper tubes.
b) Yara Sluiskilly H501 reformer: tube appearance as ‘hot’ due to external scale.
c) Yara Tertre B101 reformer: flame pattern with baking soda test.
d) Yara Ferrara B201 reformer: bowed tubes; uneven tube colour; flame impingement on tubes; tramp air entering from burners out-of-service with air register open.

Source: Yara