

# Steam reformer tubes; lifecycle and integrity management

Steam reformers are used in ammonia, methanol and hydrogen plants and are one of the most critical items of equipment in terms of the potential impact on safety and production in case of failure. Reformer tubes operate within the creep range, and thus their useful life is finite and highly dependent on the operating conditions. Knowledge and the rigorous application of sound practices are required to ensure the proper management of the tubes from design to fabrication, installation, inspection, and ending with safe retirement after the conclusion of their lifecycle.

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## Catalyst tubes design basis

Due to the severity of the operating conditions, reformer tube assemblies are fabricated from centrifugal cast materials. These provide a high potential to withstand the operating conditions, with superior stress-to-rupture strength at high temperatures. The latest trend is to utilise micro-alloys, which have a higher creep resistance. Figure 1 compares the average 100,000 hours creep resistance of several alloys used for reformer tubes.

The advantages of these micro-alloys are:

- Possibility of operating the reformer at higher temperature and pressure
- Reduced reformer wall thickness and subsequent thermal stresses across the tube wall
- Increased quantity of catalyst packing in the same space – this has been utilised advantageously for increasing the capacity and reducing the energy consumption of existing reformers

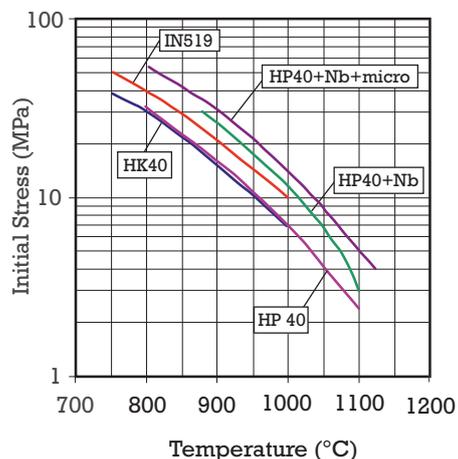


Figure 1. Creep resistance of several tube materials <sup>(4)</sup>

- These materials provide high resistance to metal dusting and carburisation through the formation of protective scales. Scale formation is supported by high chromium contents, medium silicon contents, and small grain sizes and induced surface deformation.

Catalyst tubes are designed to the rules of API 530 *Calculations of Heater-tube Thickness in Petroleum Refineries* with a typical design life for steam reformer tubes of 100,000 hours. Licensors and tube fabrication companies usually develop their own Larson Miller curves for the materials, particularly for materials such as HP micro alloys which are not included in API 530.

## Main damage mechanisms

Catalyst tubes continuously degrade due to the harsh operating conditions. The lifecycle of tubes is strongly affected by temperatures beyond the upper design temperature. Figure 2 shows the typical installation of the catalyst tubes in a top fired reformer. The primary damage mechanism for reformer tubes is the combination of thermal stresses across the tube wall and internal pressure stresses. This combination causes creep damage which typically develops at the inner diameter or just below the ID surface as illustrated in Figure 3.

Creep damage occurs over the complete circumference (or at least a large part of it) and over a longer (axial) part of the tube. The damage process results in diameter increase and creep damage (cavitation) on the inner diameter. Final rupture occurs

in a longitudinal direction as shown in Figure 4.

Another primary damage mechanism can be overheating due to catalyst degeneration or by operating upsets. Typically, catalyst degeneration results in creep damage over a small part of the circumference and a short (axial) part of the tube, resulting in bulging with the final rupture also occurring in an axial direction.

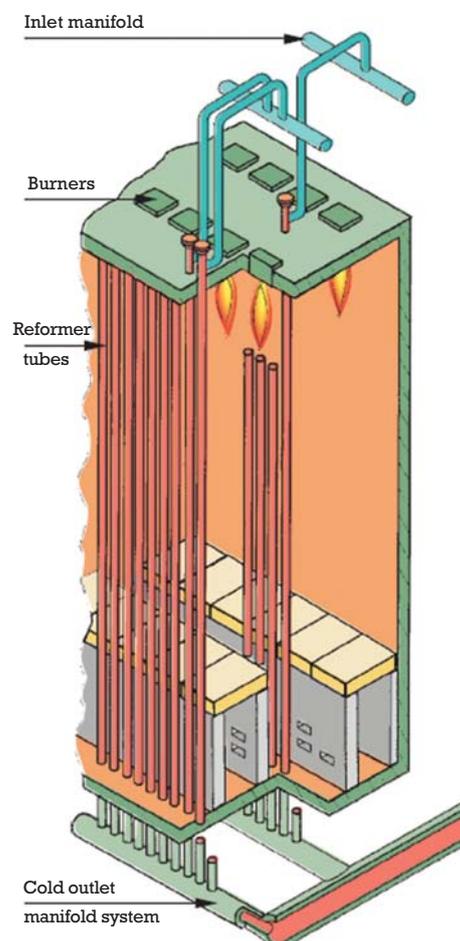


Figure 2. Top fired reformer <sup>(5)</sup>

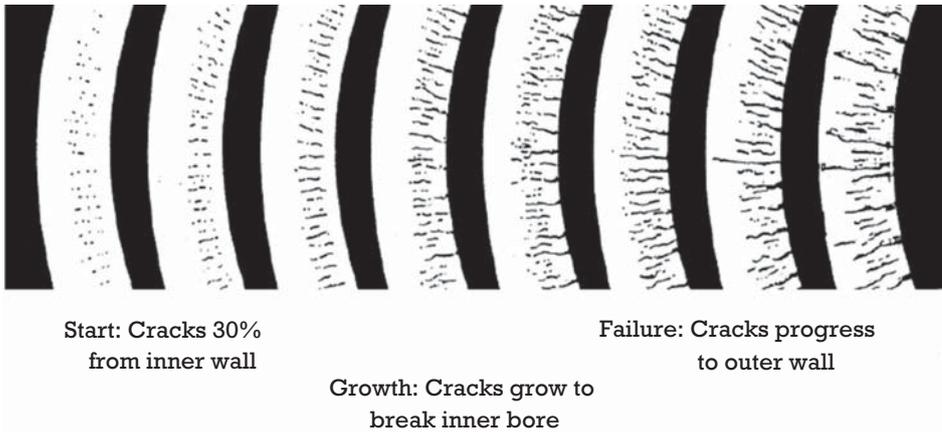


Figure 3. Creep growth in reformer tube<sup>(6)</sup>

### Catalyst tube lifecycle

Figure 5 indicates the catalyst tubes lifecycle starting from the design up to the safe retirement and replacement of the tubes after the full/extended service life; and the recommended actions for each stage to manage and maintain the integrity of the tubes.

### Tube metal temperature monitoring: TMT

Reformer tubes operate under creep conditions and any temperatures above the design temperature strongly influence their lifespan. Continuous operation at 36°F (20°C)<sup>[7]</sup> above the design temperature can halve the tube lifespan. Accurate temperature measurement is crucial to maintain the operating temperature within an acceptable limit. Following are common TMT measuring techniques. An **optical infrared pyrometer** is a remote sensing device that detects the thermal radiation emitted by a target object. Infrared pyrometers cannot distinguish between radiation emitted by the target tube itself and radiation reflected by the tube but originating from the walls of the furnace. As a result, infrared pyrometers tend to read high by typically 20 - 40°C (36 - 72°F) if left uncorrected<sup>[7]</sup> and the error can be as large as 60°C (140°F).

Obtaining accurate TMT requires good knowledge of tube emissivity and contributions due to background temperature and reflections.<sup>[8]</sup> The following points must be considered to ensure accurate measurement or to maintain minimum error:

- Implement a proven methodology to measure accurate temperatures in a repeatable process and cross-check

with other accurate measures using direct contact devices (gold cup).

- Understand the effect of the measuring factors: target tube's emissivity, target reflectance, flue gas effect, infrared. The condition of the tubes (whether there is refractory or other deposits on the tube surface), plus the angle of measurement, distance from the peep door, reflection from the walls and flame, etc.
- Pyrometer calibration and setting of wavelength and emissivity.
- Temperature correction calculations must be incorporated. Table 1 illustrates case studies indicating the measured error before and after corrections.
- Personnel performing Infrared (IR) surveillance should be knowledgeable and appropriately trained and qualified for IR scanning (e.g. ASNT SNT-TC-1A, PCN Condition Monitoring or owner-user standard or practice).<sup>[9]</sup>

Operations and inspection personnel should perform separate TMT measurements using different devices and keep these in separate monitoring records (sheets). Anomalies must be reported immediately and monitoring sheets periodically checked for any abnormalities.

### (a) Gold cup pyrometers

The gold cup pyrometer is a trusted method of TMT measurement (Figure 6). A gold plated hemisphere (gold cup) surrounds the target object, effectively acting as a blackbody. Errors due to background contribution and inaccurate emissivity assumptions are eliminated, and the radiation measured 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 is also limited by the distance it can be inserted into the furnace. Use is otherwise relatively simple, with minimal training required.

### (b) Online measurement

Online measurement includes:

- An internal array of image collector or direct contact welded thermocouples. However, due to the harsh environment in the furnace, the lifetime of these instruments is limited and relatively costly.
- In-tube process gas temperature monitoring; an instrument is inserted in the tube, and the readings used to calculate the tube wall temperature.

### Catalyst tube inspection

Proper determination of tube conditions and ultimate lifespan requires specific in-situ examinations. Reformer tube condition is assessed in-situ using various NDE techniques: visual inspection, eddy current testing, ultrasonic attenuation, laser profilometry, radiographic inspection, replication, wall thickness measure, dye-penetrant test, combined NDE technique 'H Scan.' Each technique



Figure 4. Tube creep rupture<sup>(6)</sup>

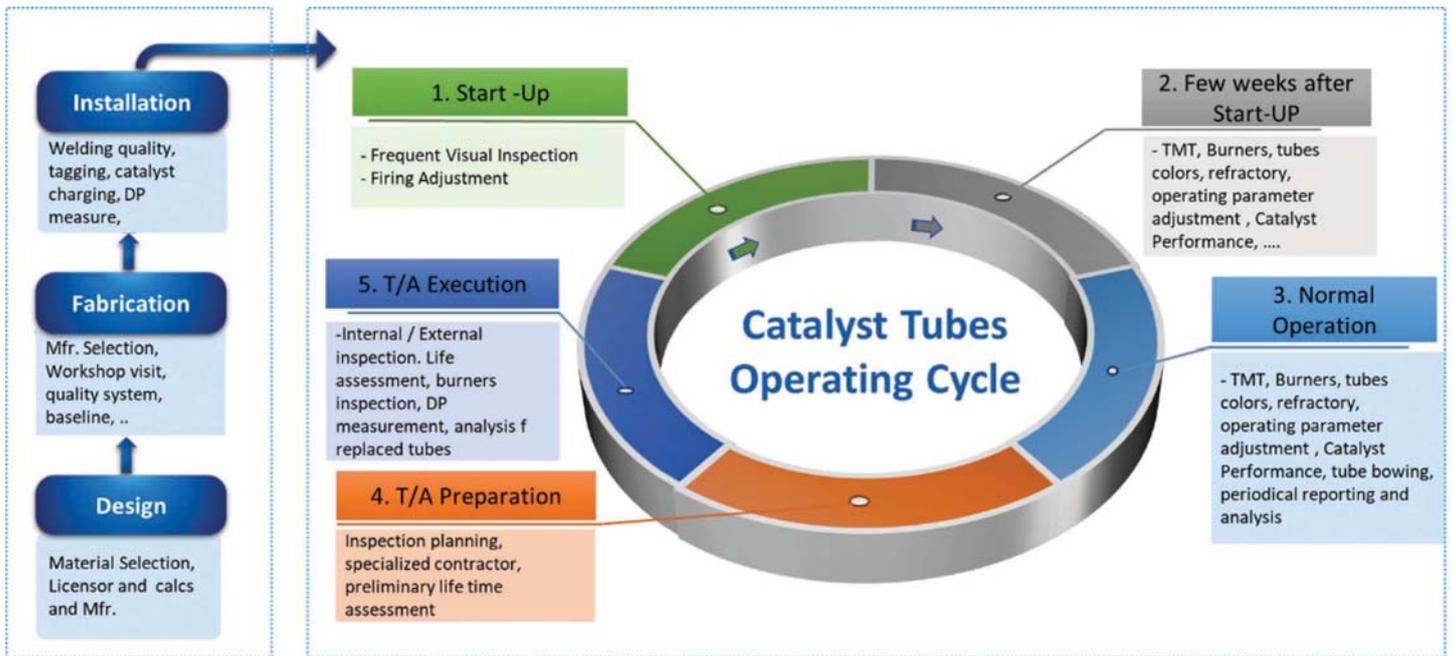


Figure 5. Catalyst tube design, fabrication, installation and operating lifecycle

has its limitations which plant personnel should be aware of, and tube conditions cannot be determined conclusively by one stand-alone technique.

**Tube expansion monitoring**

The effect that high temperatures have on the tube is reflected in the overall thermal expansion, which is detectable on the suspension systems. It is essential to maintain the tube suspension systems (spring hangers or balanced weight) in good condition to ensure the proper support of the tubes without hindered expansions and excessive loads. The cold and hot positions of the suspension systems must be marked clearly, with safe

access for inspecting, to indicate axial tube expansion.

**Tube growth monitor (TGM)**

TGM measures the thermal expansion of reformer tubes, giving accurate information regarding operating conditions relative to tube metal temperatures and providing feedback to the DCS. An alarm is triggered when expansion correlates to a tube temperature approaching the design temperature. TGM is effective for cases of hot tubes (temperature increases for the full tube length or the majority of the tube length). However, for cases of temperature increase in portions of the tubes (hot band, tiger tailing, giraffe necking) the reflection

in the tube expansion is relatively small and may not alert the TGM alarm values.

**Tube life assessment**

The two most common methods for calculating the remaining creep life of a component are the Larsen-Miller method and the Omega method. The Larsen-Miller method has been around for decades and is used in API 530, *Calculation of Heater-Tube Thickness in Petroleum Refineries*. The Omega method is used by API 579-1/ASME FFS-1, *Fitness-For-Service*.<sup>[20]</sup> In both methods, the inputs are material-specific constants, stress, and temperature. The result is time-to-failure or end of design life. Accurate material properties and operating history must be used.

Table 1. Case study for measured tube wall temperatures<sup>[7]</sup>

Description	Gold Cup	IR Pyrometer Corrected	IR Pyrometer Raw Data	IR Pyrometer Raw Data
Pyrometer Emissivity Setting	NA	1.00	1.00	0.85
Upper Peephole °C	721	733	793	882
°F	1330	1351	1459	1620
Middle Peephole °C	810	806	847	903
°F	1490	1483	1557	1657
Lower Peephole °C	890	890	912	943
°F	1634	1634	1674	1729

**Process monitoring & control**

Monitoring the operating parameters of the reformer within the acceptable safe limits and the developed Integrity Operating Windows (IOW) is essential to maintain safe reformer operation. Continuous monitoring and trending of the data are also necessary to show early indications of changes in parameters values before they become critical. While monitoring and control of the operating parameters is the role of the operator, the involvement of the process engineer for trends and periodical reports on the reformer performance is also required.

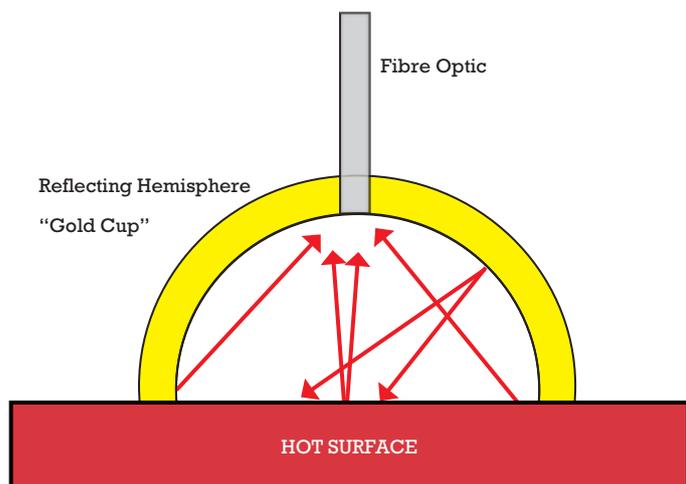


Figure 6. Gold cup pyrometer

Typical parameters to be controlled include:

- Pressure Drop, DP
- Carbon formation: S/C (steam /carbon) control and optimization
- Over-firing protection
- Operating temperature, pressure and flow rate
- Approach to equilibrium, methane slip
- Monitoring of the firebox vacuum, oxygen and temperature
- Firing parameters

### Safe operation

The role of the operator in maintaining the integrity and safety of reformer safe is crucial. An operator-driven reliability philosophy should be developed and endorsed. The operator needs the necessary knowledge and understanding of the reformer operation, design and potential failure modes and signs. The operator should know essential troubleshooting requiring simple, fast action.

Comprehensive SOP (Standard Operating Procedures) must be on-hand in a clear, simple format and should be developed for all operating scenarios including start-up, normal operations at different practical plant loads, shutdown and load change.

Operators should be involved in the TMT measurement and record all readings. Record sheet templates should be developed showing the tube maps and indicating date and time so that readings are recorded for the measured tube at the specified time. A clear checklist for field measurements should be developed as this will eliminate any confusion when used by different operators. A good example of that is the checklist provided in API RP 573.

References available upon request from the Editor:  
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### About the author

Baher Elsheikh is a Mechanical Engineer at SABIC. He has seventeen years of experience in the engineering, reliability, construction, commissioning and inspection management of pressure equipment, piping systems, fired heaters, and power boilers.

# Outokumpu enters Sustainability Yearbook 2020

In February, Outokumpu was included in the Sustainability Yearbook 2020, indicating that the company is now within the top 15% sustainability performers of the steel industry.

The annual Sustainability Yearbook showcases the world's best performing companies in terms of financially material environmental, social and governance (ESG) metrics. The yearbook is based on the SAM Corporate Sustainability Assessment, which identifies companies that are top of their industry in recognizing and responding to emerging sustainability opportunities and challenges.

"We are proud to have been included in the Sustainability Yearbook 2020 as it highlights our position as the leading producer of sustainable stainless steel globally. This is a result of the extensive work and continuous improvements in sustainability we have done during the past several years. We will continue to help our customers to design long-lasting solutions that help to fight climate change and other challenges facing our society today", says Kari Tuutti, President, Business Area Long Products & Group Sustainability.

During the past 15 years, Outokumpu has made substantial investments to build an environmentally efficient production system and to advance the sustainability of its products further.

### EcoVadis award

The company also recently received the a Gold level rating from supplier sustainability platform EcoVadis. The Gold level rating indicates that Outokumpu is among the top 5% of suppliers evaluated by EcoVadis.

EcoVadis is a leading sustainability rating provider which assesses companies in respect to environment, labour and human rights, ethics and sustainable procurement. EcoVadis has assessed over 30,000 companies and the criteria is in line with global standards such as GRI and UN Global Compact.

"This recognition is a result of the extensive sustainability work that Outokumpu employees have done during the past several years. We will also continue to work closely with our customers to help them design even more sustainable solutions", Kari Tuutti stated.

Outokumpu provides externally verified Environmental Product Declarations, making it possible for its customers to calculate sustainability performance over their products' life cycle.

