Improving reformer pigtails reliability

Previously reformer outlet pigtails were considered standalone components with a nominal 100,000 hour lifespan. With improvements in reformer tube metallurgy and manufacture, pigtails are now seen as a weak link and often require replacement before the reformer tubes and manifolds. There is a strong incentive to improve pigtail reliability and lifespan, taking into account all the key factors, from design to material selection, metallurgy, grain size distribution, quality control or inspection techniques, and all the major focal points during the life cycle of these components.

The steam methane reformer (SMR) is a major and critical piece of equipment in oil refineries, hydrogen plants, methanol plants and ammonia plants. Much attention is paid to the reliability and inspection of the catalyst tubes in SMRs, but equally important in ensuring the reliability and safe operation of a SMR is the outlet system. In most SMR designs, the relative thermal expansion between the catalyst tubes and the outlet manifolds is accommodated by tubes known as pigtails or hairpins, due to their often convoluted geometry. Pigtails carry the reformed gas from the catalyst tubes to the collection manifold. Failure of these outlet pigtails represents a common cause of plant downtime and potential risk to plant personnel.

The current industry standard material for steam reformer pigtails is Alloy 800H/HT (UNS 08810/08811) or proprietary equivalents, e.g. 800AT, Sanicro 31HT, Nicrofer 3220H/HP. These are iron-nickel-chromium alloys with additions of aluminium and titanium. Based on Alloy 800, the H and HT grades have tighter compositional limits on carbon, aluminium and titanium, plus a requirement for the grain size to be ASTM 5 or coarser. Other proprietary versions (e.g. Nicrofer 3220HP and Sanicro 31HT) may have slightly different compositional and grain size limits, but are still within the UNS N08810 and UNS N08811 specifications. Table 1 shows the variations in chemical composition and grain sizes between common 800H/HT variants.

Table 1: Alloy 800 variants commonly used in outlet pigtails

<table>
<thead>
<tr>
<th>Common or proprietary names</th>
<th>Alloy 800</th>
<th>Alloy 800H</th>
<th>Alloy 800HT</th>
<th>Nicrofer 3220H</th>
<th>Nicrofer 3220HP</th>
<th>Sanicro 31HT</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNS designation</td>
<td>N08800</td>
<td>N08810</td>
<td>N08811</td>
<td>N08810</td>
<td>N08811</td>
<td>N08810/N08811</td>
</tr>
<tr>
<td>Nickel, %</td>
<td>30.0-35.0</td>
<td>30.0-35.0</td>
<td>30.0-35.0</td>
<td>30.0-32.0</td>
<td>30.0-32.0</td>
<td>30.0-35.0</td>
</tr>
<tr>
<td>Chromium, %</td>
<td>19.0-23.0</td>
<td>19.0-23.0</td>
<td>19.0-23.0</td>
<td>19.0-22.0</td>
<td>19.0-22.0</td>
<td>19.0-23.0</td>
</tr>
<tr>
<td>Iron, %</td>
<td>39.5 min.</td>
<td>39.5 min.</td>
<td>39.5 min.</td>
<td>balance</td>
<td>balance</td>
<td>balance</td>
</tr>
<tr>
<td>Carbon, %</td>
<td>0.10 max.</td>
<td>0.05-0.10</td>
<td>0.06-0.10</td>
<td>0.06-0.08</td>
<td>0.06-0.10</td>
<td>0.05-0.10 (a)</td>
</tr>
<tr>
<td>Aluminium, %</td>
<td>0.15-0.60</td>
<td>0.15-0.60</td>
<td>0.25-0.60</td>
<td>0.20-0.40</td>
<td>0.30-0.60</td>
<td>0.15-0.60</td>
</tr>
<tr>
<td>Titanium, %</td>
<td>0.15-0.60</td>
<td>0.15-0.60</td>
<td>0.25-0.60</td>
<td>0.20-0.50</td>
<td>0.30-0.60</td>
<td>0.15-0.60</td>
</tr>
<tr>
<td>Aluminium + titanium, %</td>
<td>0.30-1.20</td>
<td>0.30-1.20</td>
<td>0.85-1.20</td>
<td>0.70 max.</td>
<td>1.20 max.</td>
<td>0.85-1.20 (b)</td>
</tr>
<tr>
<td>ASTM grain size</td>
<td>not specified</td>
<td>5 or coarser</td>
<td>5 or coarser</td>
<td>2 to 4</td>
<td>2 to 4</td>
<td>not stated</td>
</tr>
</tbody>
</table>

Notes
- (a) N08810
- (b) N08811
- (c) on request

Source: Quest Integrity Group
Design and manufacture of pigtails

Pigtails are generally designed on the basis of creep rupture, e.g. using API 530. The physical geometry of the pigtails depends on the locations and methods of connection to and from the reformer tubes and manifolds. Figure 1 shows a number of typical pigtail geometries. It should be noted that the connections are not necessarily in the same plane, i.e. the pigtails can have 3D geometry. Pigtails can either be external to the reformer, with individual insulation on each pigtail, or mounted inside an insulated box containing all the pigtails, with no individual tube insulation.

Pigtails are normally bent from seamless tube to the required geometry, and then welded to connections (generally sockolets or weldolets) on the reformer tube and manifolds on site. Depending on the outlet system design, the pigtails may only be supported at the connections, or have mid-span support in the form of hangers, to help prevent sagging when in service at high temperature.

Figure 2 is a sketch of the dimensional features of a pigtail bend. The main features of a bent tube are:

- **Intrados** – the inner radius of the tube around the bend
- **Extrados** – the outer radius of the tube around the bend
- **Neutral axis** – the centreline of the tube around the bend
- **Inside diameter (ID)** – the internal diameter of the tube
- **Outside diameter (OD)** – the outside diameter of the tube

**Pigtail manufacturing process**

The first and most relevant step of the manufacturing process is production of the straight pipe, which involves several stages starting in the casting of the ingots, continuing with different forging steps, followed by heat treatment. The common sizes for outlet pigtails are 1, 1¼ and 1½ inch and the straight pipe is usually supplied in the “cold finished solution annealed” condition. The forging and heat treatment steps can be different for each producer, and thus the supplied microstructure is frequently different. This difference is one of the reasons why there is variation in the mechanical, corrosion and creep resistance properties.

The second step in the fabrication of pigtails is the bending process. During this step it is important to have appropriate control of the deformation, minimise ovality, and avoid scars or superficial defects. The extrados, or external part of the curve, is deformed in tension, and the internal part of the curve, or intrados, is deformed in compression. The neutral axis is the theoretical line which separates the compressive and tensile regions where no deformation, and hence no cold work, is created. A subsequent heat treatment is necessary to relax the strain induced during the bending process.

In order to improve pigtail performance it is recommended to perform a final annealing heat treatment. Since the bending process is done at room temperature and involves up to 15% strain, a degree of recrystallisation and grain growth will occur during this heat treatment. Since this step is the final step of the fabrication process, the structure obtained from the heat treatment is the one that defines the properties of the component, and therefore the behaviour of the component in service. Pigtail premature failures have been attributed to the omission of the final annealing step. Due to the fact that the curved material experiences varying amounts of deformation depending on the location in the bend, the microstructure of each area will show different amounts of recrystallisation and grain growth. The cold bending work has been shown to reduce grain size. If done correctly, the annealing should restore the grain size.
Grain size variability

Work performed by Schmitd+Clemens for Methanex during the manufacturing of a large number of outlet pigtails in 20Cr32Ni alloys and the study of the different parameters required to decrease variability of grain size throughout the processing route has resulted in several findings and recommendations for using additional reference standards and different techniques, such as electron backscatter diffraction (EBSD), to improve pigtail reliability and lifespan.

The industry requirement for pigtail materials regarding grain size is commonly found in standards and specifications as “average grain size 5 or coarser” according to ASTM E112. This specification does not, however, restrict the grain size distribution. It is known that the upper and lower tail of the statistical distribution has a large influence on mechanical behaviour of materials.

Schmidt+Clemens found that specification ASTM E1181 offers a more appropriate description of 800H/HT materials than ASTM E112. ASTM E1181 requires, in addition to the characterisation of the average grain size obtained by E112, the description of the minimum and the maximum grain size present in the inspected sample. Since the specification to be used is the prerogative of the purchaser, they must work with the pipe supplier and fabricator to achieve an acceptable grain size distribution. The grain size distribution cannot be guaranteed with the current industry practice of ‘ASTM #5 or coarser’.

Due to the austenitic nature of Alloy 800H/HT and the manufacturing process of the straight pipe, the microstructure exhibits a large number of annealing twins. This feature is relevant for the determination of the grain size, since the E112 standard requires annealing twins to be ignored in grain size measurement. These are easily recognised in optical microscopy as linear boundaries, often parallel to each other, or stepped and faceted. However, in practice it is often difficult to distinguish between grain boundary and annealing twin boundary with optical microscopic techniques, which can lead to twin boundaries being counted as true, and hence an incorrect grain size determination.

The introduction of EBSD technology has allowed boundaries between adjacent grains that have a twin misorientation to be automatically identified and therefore automatically left out of the grain size calculation. Figure 3 shows how significant this can be, by comparing the optical image with the processed grain map. However, EBSD is not currently capable of automatically determining the interface plane.

Figure 4 shows an ‘incoherent’ twin boundary, where the adjacent grains’ misorientation is the same as an annealing twin, but the boundary plane is not an annealing twin. This boundary would be considered a twin boundary by the EBSD software unless further image processing steps are taken, and thus caution must be exercised when applying EBSD to measure grain size.

EBSD is a useful tool for automating grain size measurements to aid in the validation of new processing parameters but care must be taken in choosing EBSD parameters such as pixel size and twin identification algorithms to optimise the accuracy of the EBSD grain size measurement results.

An understanding and adequate control of the processing steps can help reduce grain size scatter.

It has been shown that the selection of the final heat treatment regime strongly affects the grain size distribution. Nevertheless, there are further improvement opportunities in the manufacturing of the straight pipe in order to reduce the scatter of the size of the grains.

---

Fig 3: Optical image compared to processed grain map

a) An optical micrograph of 800H.

b) An EBSD orientation map of the same area as a).

c) The effect of automatically eliminating twins using EBSD software. The scale marker is 500 µm.

Source: Schmidt+Clemens

Fig 4: The difficulty in identifying twin boundaries using EBSD

Source: Schmidt+Clemens
Pigtail failure mechanisms

Alloy 800H/HT and equivalent grades do not have any corrosion issues with most reformer outlet conditions. Above 905°C/910°C there is an increased risk of carburisation which makes the surface less ductile and prone to cracks. With time the carburisation goes deeper into the metal. High levels of carburisation are likely to make the pigtail unsuitable for nipping since it would cause it to crack and then to leak during nipping. Like all of the high alloy material, this material creeps, with creep rates increasing significantly as design temperatures are exceeded. It has also been established that creep is a function of grain size. Small grain sizes are likely to creep several times faster than larger grain sizes.

Alloy 800H/HT pigtails have demonstrated a range of failure modes. These can be grouped into four main categories:
- creep;
- creep fatigue;
- environmental attack;
- relaxation cracking.

Inspection strategies

The inspection strategies for pigtails need to be related to these damage mechanisms and selected based on plant design, experience and review of the original pigtail specifications. The industry standard approaches to inspection of pigtails are as follows:

Uniaxial creep

Diametral expansion due to creep is often measured, either directly (e.g. using pi tapes, verniers) or indirectly, using go-no-go gauges, set at certain expansion limits, e.g. 1%, 3%, 5%. Diametral checks normally have to be done during outages, as access to the tube surface is required, but some plants utilise methods that allow online gauging. If online gauging is performed, correction for thermal expansion across the tube diameter is required.

Pigtails that are swollen due to creep are a very good indicator of distressed catalyst tubes if they are within specification with respect to grain size. Over-temperature operation of the catalyst tube would be the most likely cause of such damage. Rapid creep at normal operating temperatures generally indicates an out of specification material (i.e. a too fine grain size).

Figure 5 shows an example of creep swelling due to different grain sizes.

Creep at bends

Detection of creep cracking at the bends of pigtails is dependant on the stage of cracking. Through wall cracks should be picked up during operation by inspection methods such as thermography due to leaking of the hot process fluid. Surface breaking cracks can be detected by dye penetrant inspection during outages, after removal of any insulation. However, cracking at the bends has been noted to being more likely at the inner diameter of the pigtail, and not detectable by surface methods.

Radiography techniques have been used to detect creep cracking at bends. It is not unheard of this to be done online and through insulation, if there is sufficient and safe access to pigtails during operation. This has the advantage of avoiding conflicts between radiography and other inspection/maintenance tasks during outages.

Creep fatigue and stress relaxation

Inspection of creep-fatigue damage is usually performed using conventional dye penetrant testing. The creep-fatigue cracks initiate at the surface of the pigtail tube, due to the thermal bending stresses at the connections, and are readily detectable when surface breaking. Such inspection requires removal of any insulation and careful preparation of the surface. The inspection should also be concentrated on connections to the outlet manifold where the thermal expansion effects are expected to be highest, e.g. at the end of manifold arms.

Environmental attack

Through wall environmental attack is best examined by conventional metallographic techniques on sampled pigtails. The presence and depth of nitrides, carbides and/or decarburisation can be easily quantified using visual and electron microscopy. This approach does entail a requirement to cut out and replace sections of pigtails, or whole pigtails. Examination for other damage mechanisms e.g. bulk creep damage can also be performed at the same time.

Surface replication techniques can be used to identify the surface condition, but provide little information on the condition of the bulk of the tube material.

Procurement strategies

Awareness of the in-service degradation mechanisms and associated fabrication characteristics allows the specification of replacement pigtail material and fabrication techniques to minimise damage during future service. Procurement of new or replacement pigtails should consider the following items:
- Control the grain size of the pigtail material to ensure the best compromise between creep strength and creep...
ductility. In effect this would be ensuring that the grain size is no finer than ASTM No. 5, but also not excessively large (e.g. no larger than ASTM No. 1) and with the maximum variability in grain size no more than 2 or 3 ASTM grain size numbers.

- Limit or exclude cold working during fabrication to help control grain size variability.
- Limit ovality of the tube cross section, and account for the allowable tolerances in design.
- Limit the amount of bending required in the pigtail. Experience indicates that long and therefore flexible, pigtails with minimal bends tend to have the least issues.
- Limit thermal expansion and related bending loads of the outlet system as a whole. For example, some designs have many short manifolds rather than one long one. Also ensure that manifolds and pigtails have the appropriate supports to minimise any system stresses.

Jacobs’ reformer pigtail design

Today the majority of Jacobs’ reformers follow the practice established at Humphreys & Glasgow (H&G) in 1962 when they licensed the ICI steam naphtha reforming process. At that time HK40 was the only available reformer tube material and the early naphtha reforming catalyst was relatively weak compared with today’s catalyst. Catalyst breakdown inevitably led to reactant mal-distribution with overheating of those tubes with the most broken catalyst. The weaknesses of HK40 meant that overheating would result in accelerated creep and premature failure. Without a nippable pigtail at the top and bottom of the tube this would require a lengthy shutdown to replace or isolate the tube.

All through the 1960s, town gas plants frequently maintained production by nipping the pigtails of any tube which developed a leak. The use of pigtails also helped with the general design of the reformer outlet system. In particular the design was able to incorporate the necessary flexibility which is required if you wish the tube bottom to be fixed.

H&G (now part of Jacobs through acquisition) introduced the idea of one outlet header for two rows of tubes. This leads to a long outlet pigtail (see Fig. 6). Initially, a long inlet pigtail was used to produce a high pressure drop to partly smooth out differences in tube pressure drops.

By 1970, the naphtha-based town gas boom was over and the reformer design was changed following a combination of theoretical and pilot studies. The new methods were first used in the design of two reformers for BASF. The methanol reformer, with an outlet temperature of 880°C, used a pigtail-less design similar to that used now by Uhde, since BASF felt that a design temperature of 910°C was too high for the pigtail material at the time, Incoloy 800.

An advantage of pigtails is that the outlet header can be multiples of short high alloy pipes of lower diameter connecting to a network of refractory-lined mains. These shorter lengths lead to a better reactants distribution than long headers, which take the full flow of a whole tube row.

In spite of the advantages of increased flexibility, smaller quantities of high alloy material, and the ability to isolate failed tubes by nipping without having to shut down the plant, the outlet pigtail is less strong than the reformer tube material. Since the pigtail is not subject to heat fluxes it has a design temp erature of 50°C to 70°C lower than the reformer tube. This permits the use of a high alloy material with acceptable strength and ductility.

Experience with large reformers

Jacobs’ first large reformer with 896 tubes started up in December 1982 in Edmonton, Canada. The reformer had 16 rows of 98 mm inside diameter tubes of 7.7 mm sound wall thickness. The pigtails had a design temperature of 905°C and were a semi-standard pipe size of 1.25 inch OD close to schedule 160 thickness. The plant was operated at 20%-25% above flowsheet for most of its life and the first set of tubes and pigtails lasted 20 years. Its twin for the National Methanol Company in Al Jubail had a first set which lasted 18 years in spite of being operated at 25%-30% over design for most of that time. The replacement after 18 years was only done then as a full set of spare tubes were available and the next turnaround was not planned for a further four years; failures in that period were likely to result in plant shutdowns to avoid the possibility of these very old pigtails cracking during nipping.

Jacobs’ more recent, large reformers have either 672 or 768 tubes. These tubes are 125 mm inside diameter and with the large flows the pigtails have a larger nominal diameter of 1.5 or 2.0 inch. At two of these reformers in Al Jubail cracks developed at the pigtail tube outlet weld after 14 years of service.

A more recent reformer with 768 tubes started having excessive pigtail creep problems after only five years of service. These pigtails have been extensively studied and now after eight years all of them have been replaced.

An extensive measuring program of all the pigtail diameters at numerous positions showed that a large number had grown by 5% while a lesser number had grown to a much higher degree with the
highest at 13.6%. None had failed. Surprisingly, the bulges were in the lowest straight section. Unused and bulged pigtails were tested independently. The ones with excessive bulging had a fine grain structure outside of the limits required by the project specifications. Operation at elevated temperatures does not convert to fine grain so it is deduced that they were put into operation with a fine grain structure.

Jacobs recommends that more testing for grain size should be done in future. Since this is a destructive test particularly if tests are to be done at various points along the pigtail it is impossible to test every tube. Care must be taken to ensure that the samples taken from each batch are truly representative.

So what has happened to shorten the pigtail life? No single explanation has emerged but several factors have been identified and are discussed in the next section.

**Influences on pigtail life**

The SMRs built in the early 1980s were up to three times the size of the earlier ones due to a rapid expansion in the daily capacity of many methanol, hydrogen and ammonia plants. Reformer tube material was being improved; HK 40 was replaced by HP 40 and subsequently by Microalloy. This permitted the use of larger diameter tubes which necessitated larger diameter pigtails. These were now available from a larger number of suppliers.

The two large reformers for Celanese and Ibn Sina (NMC) were among the last to use HP 40. This was a considerable improvement on HK 40 and, even at heat fluxes over 90,000 W/m², resulted in a very high tube life of around 20 years. At that time burners were selected for their compact flames but NOx levels were frequently in the order of 250ppm v.

Around 2000, designers came under pressure to reduce NOx to about half of the previous figure. This was achieved by either using staged combustion air or staged fuel burners. Both of these techniques resulted in less compact flames. These new flame shapes changed the size of the temperature zones in the reformer. At the same time Jacobs moved on from their earlier practice of accommodating the natural radiant heat distribution where the tubes near the side walls of the top fired reformer have 12% more heat. Previously, the heat gain was corrected by forcing 12% extra reactants into the outer rows. Since firing was designed to give a constant temperature to each level across the furnace the flue gas could flow vertically to the extraction ports in the outlet tunnels. This led to a very good temperature distribution across the furnace. However, the 12% extra flow resulted in about 25% extra pressure drop across the reformer.

To overcome this, it was decided around 1990 to follow the general industry practice of putting much smaller burners in the outer row and allowing some internal recycling of colder flue gas so as to even the heat pick up in the outer row tubes which now had the same flow as all the other tubes. Without doubt this had a deleterious effect on the temperature distribution. The low NOx burners appear to have compounded this effect. More recently ultra-low NOx burners with built-in devices to promote recirculation of flue gas has made temperature distribution even worse.

The original assumption made for radiation flow in a multi-row top fired furnace is that is the combustion zone at the top of the furnace is a perfectly mixed flue gas of even temperature across the whole width of the furnace. The depth of this zone is adjustable in the calculations but is initially taken as 30% of the tube heated length. This gas then flows vertically to exit via flue gas tunnels in the base of the furnace. It is this arrangement which leads to more heat being available to the outer row. In 4 row furnaces this is about 5% and is often looked after in the design margin. In 12 and 16 row furnaces it is 12% to 13%.

In order to correct this while having the same flow in all tubes the outer row flue gas must be cooler than that of the inner rows. Computational fluid dynamics (CFD) studies have shown that by firing just below the ratio of row widths in the outer row sufficient cooler flue gas recirculates from the base of the reformer. This even out the tube outlet temperatures. Due to the time taken for the CFD calculation, only a thin slice of the reformer is studied.

Better knowledge of tube outlet temperature would enable better control to avoid pigtails being subjected to excessive temperatures. Jacobs proposes to include a facility to attach a thermocouple to the base of every tube. At the moment, the company puts thermocouples into two tubes in each row. These would be used to calibrate the new thermocouples. In the future when the performance of the thermocouples has been evaluated, it might be possible to leave out the thermocouples.

Reformer tubes are the subject of much scrutiny but experience shows that typically tubes are an order of magnitude stronger than pigtails. They are much more able to withstand temperature excursions than pigtails. In areas of high heat flux the inside temperature and material strength are much lower and stronger respectively than those on the outside. The pigtail temperature is the same all the way through. Relatively speaking, the pigtail has a much thicker wall than the reformer tube. This requires its temperature to be kept steadier than a reformer tube, otherwise cracks will grow every time the temperature is cycled. This can occur very often if there is a break in the insulation which allows the wind access to the pigtail surface.

As the pigtail is working close to its limit it is important that the full specification is fully complied with during manufacture. All out-of-specification batches, however slight, must be rejected.

**Uhde’s outlet manifold system**

There is no reformer design which can avoid exposing the reformer tubes to very high temperatures under full pressure. The process gas temperature required at the outlet of the catalyst-filled tubes is in the range between 800 to 900°C at a pressure of approximately 40 bars. Inevitably, the service life of components such as the reformer tubes and process gas header is limited.

Material deterioration occurs through the combined effects of creep, alternating thermal and mechanical stresses, external and internal oxidation and carburisation.

The design of the Uhde reformer (Fig. 7) available from ThyssenKrupp Industrial Solutions® avoids the need for hot pigtails and hot manifolds at the outlet and has therefore reduced the number of critical elements, which are subject to wear and tear, to the minimum. Only inlet pigtails, where process gas temperature is low, are required. Uhde first developed its cold outlet manifold system in the late 1960s and has since applied it to over 70 reformers. Due to the paramount reliability of the system, only small design improvements needed to be introduced during this long time of operation experience.

The main features contributing to a reliable and maintenance free outlet header system are:

- decoupling of high temperature and pressure bearing service (the lower tube end is subjected to the full pressure but not to the full temperature);
- avoidance of critical welds (the tube-to-manifold connection is a simple weld between two carbon steel materials);
refractory lined carbon steel pipe;
- protection of the lining with an internal metal sleeve;
- prevention of hot bypass streams by the installation of gas barriers;
- full access to the system for visual inspection and skin temperature measurements during plant operation;
- avoidance of weak parts like flexible connections or hot pressure bearing connections.

**Uhde’s top fired primary reformer**

Figures 8 and 9 show the design of the Uhde outlet manifold system. A removable catalyst grid is located at the bottom of the reformer tube. A thin Alloy 800 funnel and tube are welded to the grid support, the joint being gas-tight. This tube conducts the reformed gas down into the refractory-lined manifold. It can expand freely downwards and needs only to withstand the temperature. It is not subjected to pressure or external forces and, therefore, the tube wall can be thin, i.e. about 2 mm. The annular space between the gas-conducting tube and the pressure-bearing shell is filled with insulating ring-shaped bricks, which protect the pressure-bearing outer tube from high temperatures.

By separating high temperature service from pressure bearing service this tube to manifold connection got the same reliability as any other ordinary pipe in the plant. The skin temperature profile along the pressure bearing part of the lower reformer tube underneath the furnace decreases very fast down to a temperature suitable for carbon steel. The transition weld between the cast alloy and the carbon steel end is a shop weld. The assembly weld of the reformer tube to the nozzle of the manifold, which has to be performed at site, is a simple carbon steel weld.

The penetration of the reformer tube through the furnace bottom is sealed completely gas-tight by a flexible bellow. It prevents any ingress of air into the heated zone of the furnace and allows for the small thermal expansion of the manifold. The operating skin temperature of the manifold is as low as 150 to 200°C.

The manifold is refractory lined and contains a shroud (material Alloy 800H). It shields the refractory and conveys the reformed gas at a sufficiently high velocity. There are sufficient gas barriers provided in order to prevent any small hot side streams of gas from reaching the pressure retaining shell.

Temperature measurement at the end of each sub header eases furnace trim. There is no hot running work, no external insulation, there is an excellent accessibility for visual inspection at any time of operation. The manifold will be brought to site in sections, pre-fabricated and dried out.

**References**


* ThyssenKrupp Industrial Solutions is the amalgamation of ThyssenKrupp Resource Technologies (created by the merger of ThyssenKrupp Fördertechnik and ThyssenKrupp Polysius) and ThyssenKrupp Uhde. The previously separate plant construction companies in the ThyssenKrupp Group were combined in January 2014 to better utilise global market opportunities.