The use of Heavy Plate in the fabrication of Urea Pool Reactor™

(by F. Foroni, F. Fusari, N. Maestri, P. Marangoni, F. Orlandi)

Abstract

One of the principal items of high pressure equipment in the design of a Urea process plant is the Pool Reactor. It consists of an external pressure bearing, Solid Wall vessel constructed from high strength steel material in the form of Heavy Plate. Due to the presence of severely corrosive media in the Urea process, an internal protection (usually of high alloy material) is applied to the vessel in the form of Weld Overlay or plate Lining. In order to overcome the problems posed by the different behaviour of the two base metals involved it has been necessary to adopt very demanding design and fabrication solutions.

This paper describes the main design and construction phases comprised in the fabrication of the High Pressure Urea equipment Pool Reactor™. The Pool Reactor forms part of the Stamicarbon proprietary Urea Process technology.

Equipment description

The Urea Pool Reactor™ consists of an external pressure vessel and internal Tube Bundle, which combine the required Reactor and Heat Exchanger process reactions, as shown schematically in Figure 1. The external vessel is constructed so as to resist the extremely high design internal pressure and temperature, while the internal protection in corrosion-resistant Duplex Stainless Steel (Weld Overlay or Lining) counteracts the corrosive media present in the production of urea.

Design

Design of the Pool Reactor has been carried out according to the AD-2000 Merkblatt Code, and to the applicable specific Stamicarbon design criteria. In addition, the particular configuration of the Pool Reactor was subjected to a Finite Element Analysis to verify that the stresses in the Tube Sheet were within the acceptable values. The Finite Element Analysis was performed using the computer program ANSYS®. The 3D model is shown in Figure 2. The resultant Total Equivalent Stress Distribution (MPA) for the design loading conditions (Shell-side design pressure) is shown in Figure 3. The results obtained satisfy the equivalent stress-based assessment and Stamicarbon service parameter requirements.
Fig. 1 – Pool Reactor
Figure 2 - General view of the 3D solid model and mesh detail
Figure 3 - Load Case 1 – Total Equivalent Stress Distribution [MPa]
Base material

A micro-alloyed steel type 20 MnMoNi4-5 (EN-10028) was selected for the pressure-bearing parts due to the Solid Wall solution adopted. Alternative solutions such as Multilayer or Multiwall techniques are sometimes chosen, but this generally because the necessary rolling machines and/or relevant experience are not available. There are contrasting opinions regarding the advantages or disadvantages for all solutions. However, it is not the purpose of this paper to discuss these issues, so we would simply state that the Solid Wall solution is still generally considered a wiser choice from a standpoint of quality and enables more reliable weld examinations to be carried out during fabrication and service.

The choice of 20 MnMoNi4-5 was based on its high strength and acceptable low hardening properties resulting in more favourable fabrication aspects. The main characteristics, chemical analysis and mechanical properties of 20 MnMoNi4-5 steel are shown in Table 1.

Table 1 – Base metal main mechanical properties and chemistry

20 MNMONI4-5

Chemical compositions

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>MN</th>
<th>P</th>
<th>S</th>
<th>Cu</th>
<th>Mo</th>
<th>Ni</th>
<th>Cr</th>
<th>N</th>
<th>AL-J</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.16</td>
<td>0.27</td>
<td>1.30</td>
<td>0.010</td>
<td>0.0006</td>
<td>0.027</td>
<td>0.48</td>
<td>0.52</td>
<td>0.038</td>
<td>0.0042</td>
<td>0.032</td>
<td>0.001</td>
</tr>
<tr>
<td>CEquiv</td>
<td>0.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mechanical Properties

After PWHT 610°C x 4h

<table>
<thead>
<tr>
<th>Tensile test (MPA)</th>
<th>Impact Test (AV= J)</th>
<th>Hardness HV (AV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>REH RM A %</td>
<td>At 0°C – 32 °C</td>
<td></td>
</tr>
<tr>
<td>RT 528 641 22</td>
<td>209 152</td>
<td>219</td>
</tr>
</tbody>
</table>

Since this equipment operates in severely corrosive conditions, the material chosen for the internal protection was a Duplex Stainless Steel called SAFUREX®. SAFUREX® is a high alloy grade ferrite-austenite stainless steel specifically developed from a collaboration between Sandvik and Stamicarbon.

Fabrication Sequence

The fabrication sequence can be divided into four main steps:

- Fabrication of the external Shell vessel
- Assembly of the internal lining to the external Shell vessel
- Construction of the Tube Bundle
- Final assembly
External Shell vessel

The Shell vessel internal diameter was 3200 mm with wall thickness 105mm and, based upon the available Rolling Machine, rolling of the plates was carried out in the “Cold Condition”. Fabrication of each Shell Barrel was effected with one single plate as can be seen in Figure 4.

Figure 4 – Plate Rolling
The severest requirement for this type of equipment is to achieve the smallest possible gap between the external vessel and the internal lining in order to avoid problems that could arise to the lining welds in particular during the hydro test (and/or relevant process cycle).
In order to achieve this, extreme accuracy is required for the design and construction of the Shell Barrels involved, including correct plate rolling, longitudinal bevel design, optimized welding sequence and subsequent final barrel calibration, see Figure 5.

Fig. 5 - Barrel Calibration
Shell internal lining

Internal lining of the Shell was carried out with barrels in two halves assembled inside the external vessel, after PWHT. Of particular importance was the longitudinal and circumferential lining weld execution. A very specific welding design (welding thermal cycle and beads sequence) is required to limit the weld restraint that could induce deformation of the relevant lining close to the welding zone. Specific tools and fixtures are also necessary to counteract any potential lining deformation in the area surrounding the weld.

Tube Bundle

The Tube Bundle design is characterized by a Tube-to-Tube sheet weld joint of the Internal Bore Welding type. Such a weld design, while granting full design efficiency and not being subject to crevice corrosion, involves a very demanding execution, requiring a full control of the whole fabrication process. In particular, very tight tolerances need to be observed on the weld joint preparation in order to obtain the precise weld fit-up needed. Since the weld execution was carried out with the tube axis in the horizontal position as shown in Figure 6, the welding procedure needed to be very carefully elaborated in order to produce the required and uniform weld shape (See Figure 7). A Gas Tungsten Arc Process was selected, and to counteract the weld puddle gravity (out of plane position) a fully programmable computerized welding machine was used, able to adopt different weld parameters for the different weld sectors. Duplex stainless materials, due to factors in their chemical contents (e.g. Nitrogen) are prone to develop defects such as pores during welding. In addition to the selection of proper weld parameters, a dedicated shielding gas had to be designed in order to pass the required examinations, such as a 100% Radiographic test.

Fig. 6 - Internal Bore Welding (horizontal position)  Fig. 7 - IBW Macrosection
Final Assembly

The Shell construction was subdivided into several sections (left Head, right Head, left Shell section, right Shell section).

Separation of these sections was selected so as to allow the required Post Weld Heat Treatment (PWHT) execution, Tube Bundle fabrication and relevant intermediate and final inspection activities.

After Tube–To-Tube sheet welding the Shell sections were assembled with three closure seams (See Figure 8):

- right Head to right Shell
- right Shell to left Shell
- left Head to left Shell

SAFUREX®, as with other similar material, while guaranteeing a very high corrosion resistance, cannot be exposed to high temperatures.

Welding of the Shell Barrel and Shell-to Head closure seams included the execution of local Post Weld Heat Treatments (PWHT).

In order that the corrosion resistant material would not be exposed to detrimental temperatures, a preliminary Thermal Analysis was performed to support the local PWHT set up.

The object of the Thermal Analysis was to provide for adequate insulation on the zones nearest to the heat treating material, so that the external parts would be protected from a harmful temperature gradient and, at the same time, to check that the temperature of the Head lining was maintained below the critical point of 400°C.

During the PWHT operations the temperatures were constantly monitored by thermocouples connected to temperature recorders. Thermocouples were placed at the closing seam and closest to the lining to verify the maximum temperature of the SAFUREX® material during the PWHT.

The Finite Element Model and local PWHT arrangement are shown in Figures 9 and 10.

The results of the Finite Element Analysis and the temperature profile at the end of the holding time are shown in Figure 11.

The Heat Treatment was performed in accordance with the theoretical analysis and showed a good correlation (refer to Figure 12).
**Fig. 9 - PWHT Transient Thermal Analysis: Finite Element Model & insulation layout**

**Fig. 10 - PWHT Transient Thermal Analysis: insulation layout and H.T. equipments position**
Temperature distribution at the closing seam - Holding temperature = 610 °C

Temperature distribution in SAFUREX® lining – Max Temperature = 357.4 °C

Fig. 11 - Thermal Analysis results: temperature distribution at the end of Holding Time
Theoretical temperature profiles [°C] VS time [sec] in seam zone and in SAFUREX® Lining

Calculated Max Lining Temperature = 357.4 °C

Recorded Max Lining Temperature ≈ 360 °C

Fig. 12 - Theoretical and actual temperature throughout Post Weld Heat Treatment
Weld Inspections

Non-Destructive Examinations are a fundamental part of the manufacturing process and guarantee high quality standards in the fabrication of the Pool Reactor from Heavy Plate.

They may be divided into two categories:
- Non-destructive examinations on Carbon Steel and low alloy pressure-bearing weld joints;
- Non-destructive examinations on Duplex stainless steel weld joints.

Non-destructive examination on Carbon Steel and low alloy pressure-bearing weld joints

Carbon Steel and low alloy pressure-bearing weld joints include:
- longitudinal and circular weld joints
- nozzle to shell barrels and heads weld joints.

All butt weld joints were all examined by Magnetic Particle Examination on the inner and outer surface and by Ultrasonic Examination, (Pulse-Echo technique, Time of Flight Diffraction technique and Phased Array technique) in accordance with the applicable standards (ASME Code Section VIII Div.1 or Div.2, AD 2000 Merkblatter). In addition to ToFD, and as required by AD2000 HP 5.3 Level C for welds thicker than 100mm, all pressure retaining welds have been examined by UT Tandem technique, to increase the Probability Of Detection for defects like Lack Of Side Wall Fusion in thick, multi-pass welded joints.

Belleli’s procedure for UT Examination with the ToFD technique (Figure 13 and Figure 14) has been demonstrated as reliable for all weld joint thicknesses from 40 to 375 mm, and Belleli has carried out ToFD examinations on Heavy Wall Reactors up to 328 mm thick. The ToFD examination can be easily repeatable on site during scheduled shut-downs using the technical set-up and calibration block supplied together with the equipment if so required.

Figure 13 - Shop Ultrasonic Examination (ToFD technique)
Non-destructive examination on Duplex stainless steel weld joints

NDE on Safurex material is mainly executed on corrosion-resistant weld overlays, weld joints of liner plates and Tube-to-Tubesheet weld joints. The weld overlay on the inner surface of Heads and Tubesheet weld overlays (for preparation of the Tubesheet for Internal Bore Welding) are examined by Dye Penetrant Testing and by high-sensitivity Ultrasonic Examination.

Liner plate weld joints are examined by Dye Penetrant Testing and Leak Testing (LT). LT consists of an Air test after the 1st pass seal weld and Ammonia Leak Testing on the completed weld joint; the latter is ordinarily performed after execution of the Hydrostatic Test.

For the Pool Reactor’s Tube-to-Tubesheet weld joints, Helium Leak Testing and Radiographic Examination are performed. Radiographic examination with gamma-rays is performed on the Tube- to-Tubesheet weld joints by means of an Iridium isotope utilizing a technique that can assure the detection of 0.5 mm rounded indications or 0.3 mm wide linear indications.
Conclusion

The fabrication of a Pool Reactor™, see Figure 15, represents a quite unique combination of demanding tasks:

- Elaboration of critical Engineering formulae including the Finite Element Analysis approach and Thermal Analysis.

- Construction of a thick wall external Shell with high strength material 20 MnMoNi4-5 in the form of Heavy plates.

- Construction of internal Tube Bundle with sophisticated material SAFUREX® and special Tube-to-Tube sheet design Internal Bore Welding.

- Severe weld examinations with full Radiographic Examination (IBW welds), UT ToFD (Pressure Plate), Leak Test and Ammonia Test for internal corrosion-resistant parts.

Fig. 15  - Pool Reactor ready for shipment