Shortening of high pressure bimetallic urea strippers in situ to extend their operational life and improve reliability

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Along with the synthesis reactor and the carbamate condenser the urea stripper forms the core of the high pressure cycle of SNAMPROGETTI/SAIPEM urea process. Its performance and reliability is so critical for the productivity of the whole plant that any problem to this equipment is due to have a negative impact on the production rate. At the same time the stripper is the single most expensive process equipment of the HP cycle and the most stressed as far as heat and corrosion are concerned, which makes it also the equipment with the shortest operational life and more frequent need of replacement.

This paper outlines a method to improve the reliability and extend the overall operational life of degraded SAIPEM / SNAMPROGETTI bimetallic HP urea strippers by shortening the tube length and restoring the overall condition of the bottom tubesheet and the tube-to-tubesheet weld joints in situ.

1. Brief introduction of AXO WELDING.

AXO WELDING is an Italian company specialized in servicing, repairing, and modifying static urea and ammonia equipment.

Founded in 2004, we serve fertilizer plants in the Middle East, North and South America, Europe, China, South East Asia, India, and Bangladesh, and we are a trusted contractor of world-class companies such as PETRONAS, YARA, SABIC, OMIFCO, GPIC, STAMICARBON, IFFCO, SAIPEM, and many others.

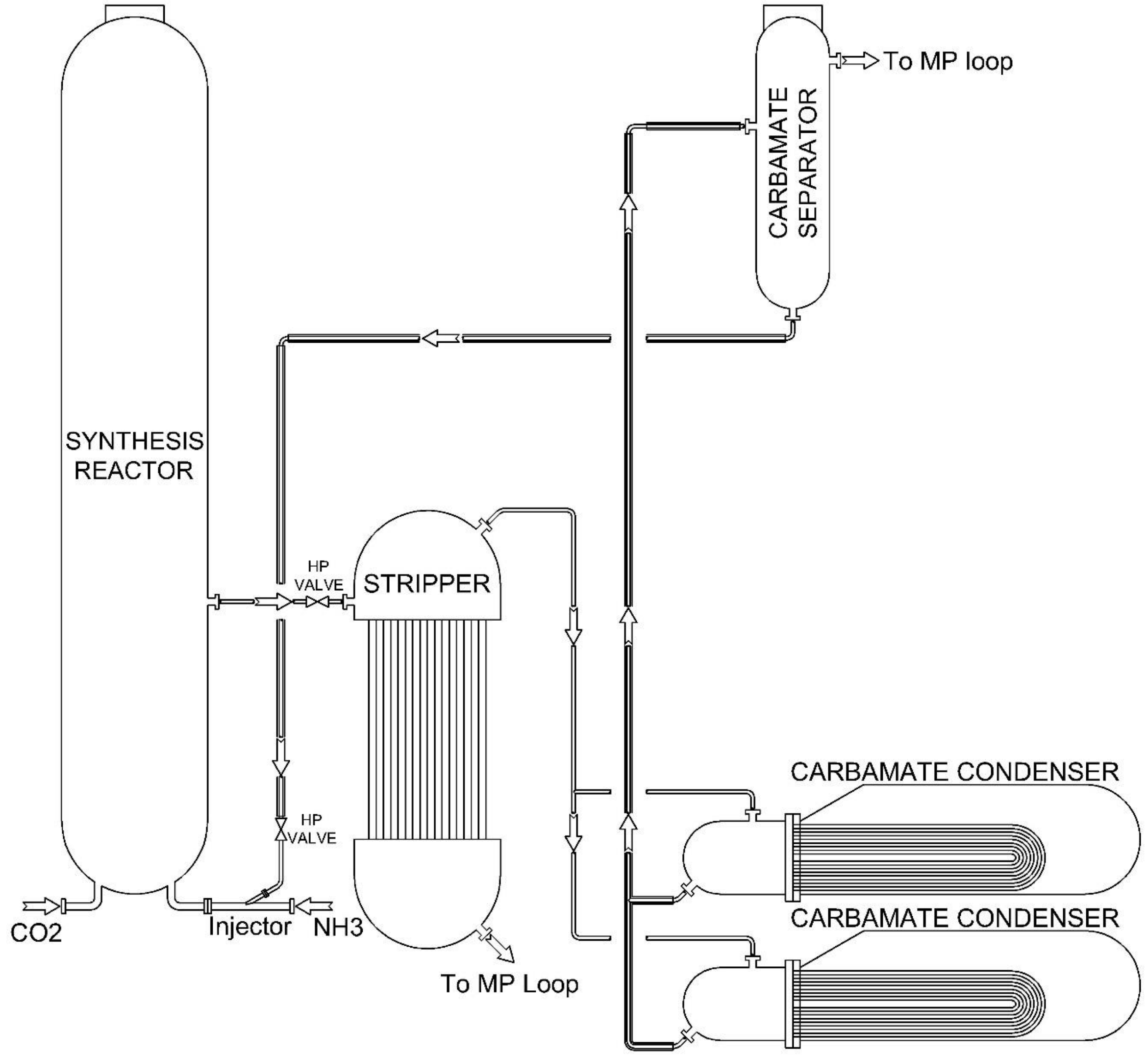
AXO WELDING offers a deep knowledge of the materials employed, of the manufacturing and welding techniques, and of the specific problems of the critical equipment.

2. The bimetallic urea stripper in SAIPEM process

Figure 1 shows the typical layout of the high pressure cycle of SAIPEM urea process (see saipem.com internet site). From the outlet of the synthesis reactor the process fluid passes through the HP stripper, where the ammonium carbamate and ammonia which were not converted are separated (stripped) from the liquid urea by evaporation, sent to the carbamate condensers, to the carbamate separator and reintroduced into the reactor via the injector, using the ammonia flow as a traction fluid.

While the synthesis reactor is heated by the exothermal NH_3 / CO_2 reaction to a maximum temperature of 188 °C and the carbamate condensers are kettles – where heat is transferred *from* the hot carbamate gas *to* water and the fluid maximum temperature is 155 °C – in the stripper steam is used to heat the process solution which flows top-to-bottom into the tubes. The bottom tubesheet of the stripper, hence, at 205°C is the hottest spot of the whole HP cycle and for this reason it's the area where corrosion attack is more critical.

FIGURE 1: SAIPEM HIGH PRESSURE CYCLE



The most common type of stripper installed in SAIPEM plants is the bimetallic stripper, which derives its name from the fact that the tubes' wall is made of a 2mm thick 25.22.2CrNiMo austenitic stainless steel layer on the outside and a 0.7mm thick Zirconium layer on the inside. The two layers are wrought together to guarantee a strong bonding between them, in a construction that combines the weldability and relatively low price of the austenitic stainless steel with the extreme resistance of zirconium to corrosion and erosion, two conditions which are both severe in the stripper tubes.

For the rest, the unit is a vertical tubular heat exchanger with a high pressure channel/tube side and a low/medium pressure shell side. The MOC of the pressure bearing part in usually fine-grain carbon steel with an applied liner in 25.22.2CrNiMo on the internal surface of the channels and a 25.22.2CrNiMo weld overlay on the tube-side surface of the tubesheets.

FIGURE 2: BIMETALLIC TUBE

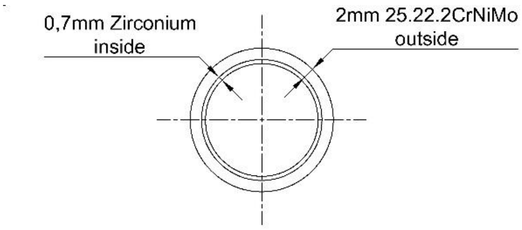
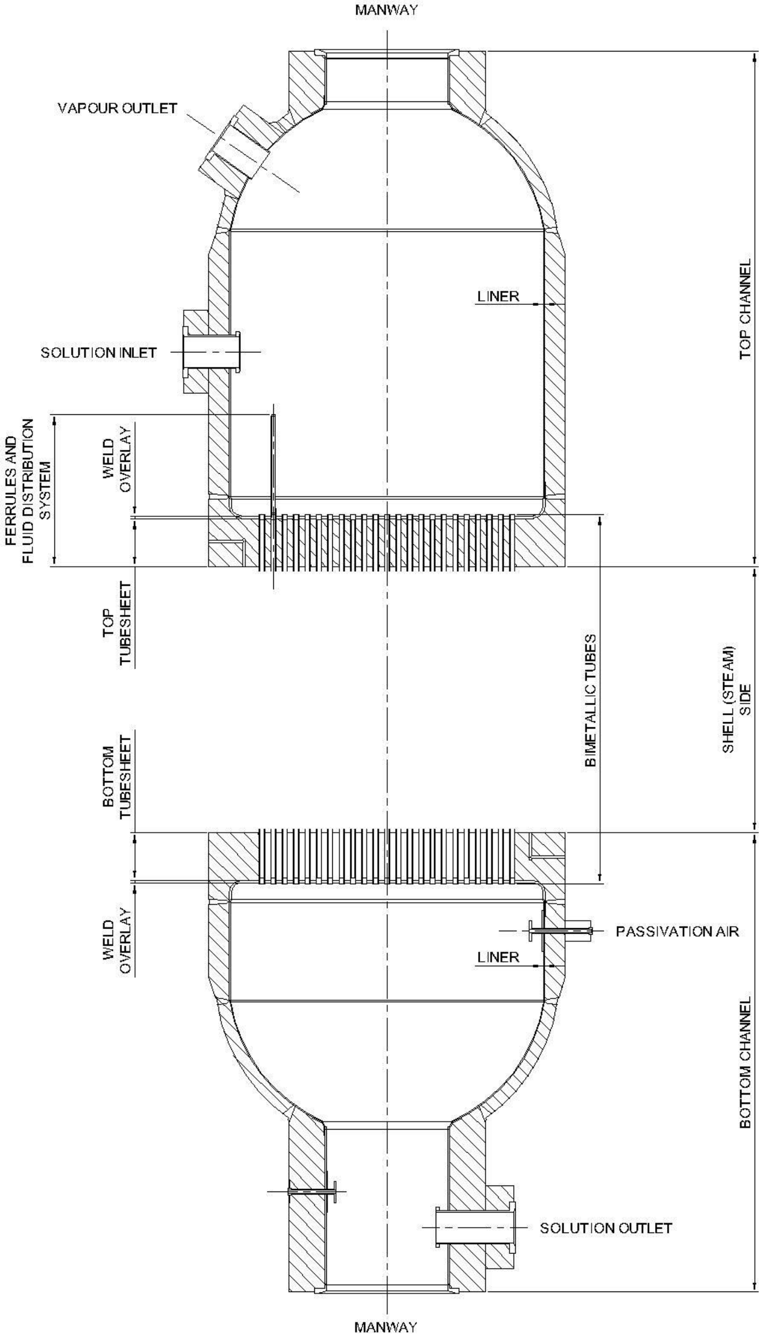


FIGURE 3: LAYOUT OF THE BIMETALLIC STRIPPER



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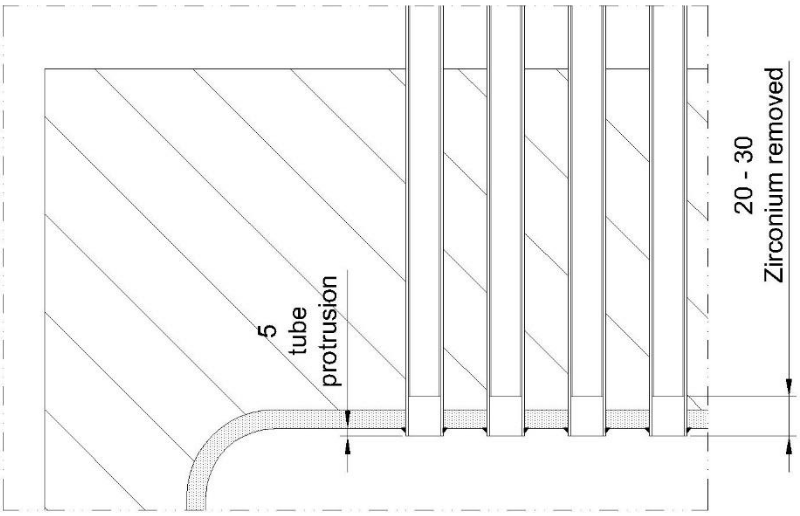
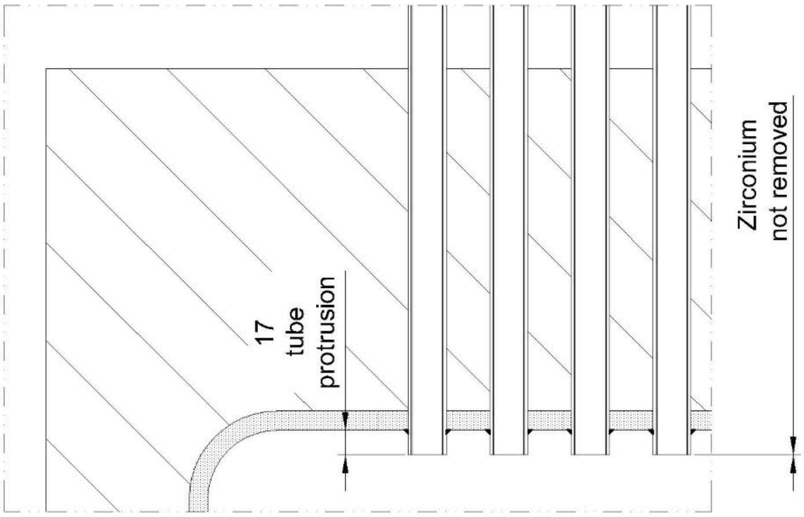
With the typical tube diameter-to-tube pitch ratio of the bimetallic stripper the minimum distance between the walls of two adjacent tubes is 6-7mm. With such a small clearance the welding technology available until the late 90s did not consent the tube protrusion to be higher than 5mm. Since the tubes are bimetallic though, the heat from the weld could determine a local disbonding (separation) of the two layers with the possible formation of a crevice that is absolutely detrimental in the working environment of the unit. To avoid this, the zirconium layer would be removed on an area of 20mm to 30mm at the end of the tube, as shown in figure 4:

FIGURE 4: LAYOUT OF THE TUBE-TO- TUBESHEET JOINTS UNTIL THE LATE 90S



Later on, new types of automatic orbital TIG welding machines were developed to make it possible to weld the joints with a protrusion of the tube from the tubesheet surface of 18mm or more. Such a long protrusion has proven to remove the disbonding problem, so that the zirconium layer can be left in place and protect the tube surface up to the tube end.

FIGURE 5: CONTEMPORARY LAYOUT OF THE TUBE-TO-TUBESHEET JOINTS

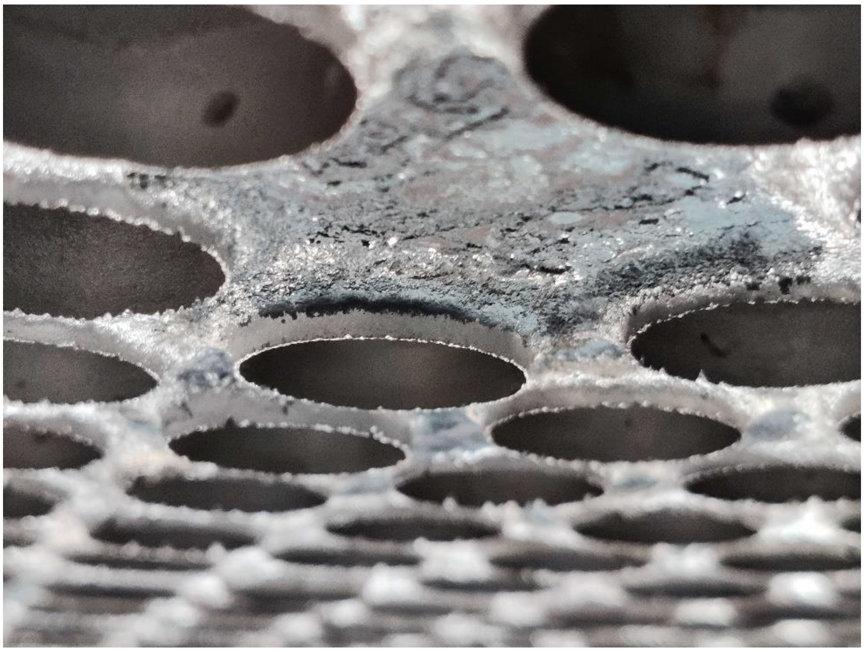


3. Aim of the shortening

When properly passivated the bimetallic stripper is quite a reliable piece of equipment. Even so, after the normal duration of its operational life the bottom tubesheet is in many cases the area that determines the decay of the unit and the need for its replacement, with the tube ends and the weld overlay being corroded and sometimes leaks developing in the tube-to-tubesheet welds, especially in units with the short tube protrusion.

In several of these instances of units with a degraded bottom tubesheet and a fairly good condition of the other parts, the procedure for shortening in situ that we developed has provided a significant extension of the equipment operational life and reliability and has consented to postpone the replacement of the equipment by several years.

FIGURE 6: THE BOTTOM TUBESHEET SURFACE IN THE CORRODED CONDITION



4. Preparation and qualification of the process

For the preparation and qualification of the shortening method and the welding procedure, in coordination with the Process Licensor we adopted the guidelines of SAIPEM specification SPC.CR.UR.528: «General specification austenitic stainless steels for urea plant - High Pressure Section - Tube to Tubesheet Weld Joints» (today SPC_ON-SCTON-EXE-ENG_MAT-528-E-R01), which is the same specification applicable to the manufacturing new strippers.

Based on that we prepared a mock-up of the tubesheet with the following features:

Base:

Material: ASTM A105

Width: 460mm

Length: 720mm

Thickness: 100mm

Weld overlay:

Welding process: SAW

Welding filler material: 25.22.2CrNiMo

PWHT after first pass: 610 °C ± 10 °C - Holding time 2:30 Hrs

Total thickness: 10mm

Bore:

Hole diameter: 26.9mm -0mm / +0.25mm

Hole pitch: triangular, 33mm

Tubes:

External layer:

O.d.: 26,5mm

Thickness: 2mm

Material: ASTM A213 UNS S31050

Internal layer:

O.d. 22,5mm

Thickness: 0,7mm

Material: ASTM B523 UNS R60702

Note: The external diameter of the mock-up tubes / bore diameter of the mock up piece holes was actually bigger than that of most of the strippers that we shortened because in time the manufacturing specification for stripper bimetallic tubes changed, new strippers have bigger diameter tubes and the older, smaller tubes are not available anymore on the market. This arrangement was accepted as representative of the welds in situ because the resulting tube wall-to-wall clearance was actually smaller than that of the tubes on site.

FIGURE 6: MOCK-UP PIECE

When the mock up piece was ready, we organized a test welding session at our workshop at the presence of SAIPEM and Third Party inspectors, during which we welded 92 tubes on 8 rows. Then a group of No. 19 tubes was selected for metallographic/corrosion/macro testing and No. 4 groups of No. 7 tubes each were identified for flaw assessment/mechanical testing according to SAIPEM specification CR-UR-528. The position of the selected tubes is shown in the sketch in figure 4:

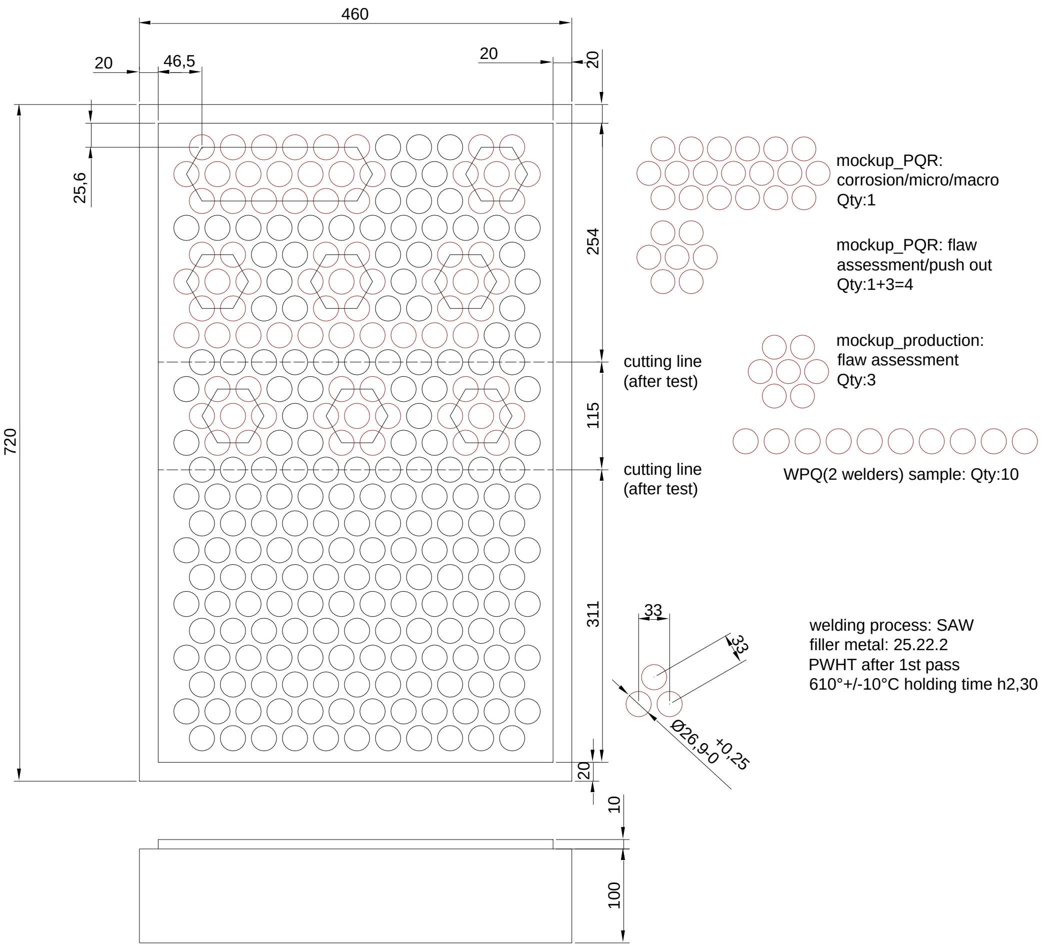
The mock-up tube-to-tubesheet welds were subjected to the following scope of testing:

a. Testing scope per ASME Code section IX:
   1. VT + PT
   2. Macrographic examination per QW193.1

b. Testing scope per SAIPEM Cr-Ur-528 Rev. 0 (Cr-Ur-510 Rev. 4):
   1. Metallographic examination
   2. Ferrite content
   3. Corrosion test: Huey test on No. 10 Huey cycles with measurement of weight loss
   4. Corrosion test: assessment of the maximum depth of attack
   5. Flaw assessment test
   6. Mechanical test: push out

Testing was performed at a SAIPEM accredited laboratory.

FIGURE 8: MOCK-UP PIECE TESTING SCOPE



Of the remaining tubes some had been welded before the testing session in order to set up the welding parameters and train the welders; and the rest we kept un-welded to be used on site for the mandatory production tests.

Finally we used the welded tubes which were not deemed part of the testing program as a sample to set up the tube protrusion reaming process.

Another important activity in preparation for a shortening job is the design and fabrication of two flanges that we install on the shell of the stripper before cutting the same. The two flanges are connected by 16 threaded bars which we use for lifting the bottom tubesheet.

5. Shortening method

We execute the stripper shortening through the following steps:

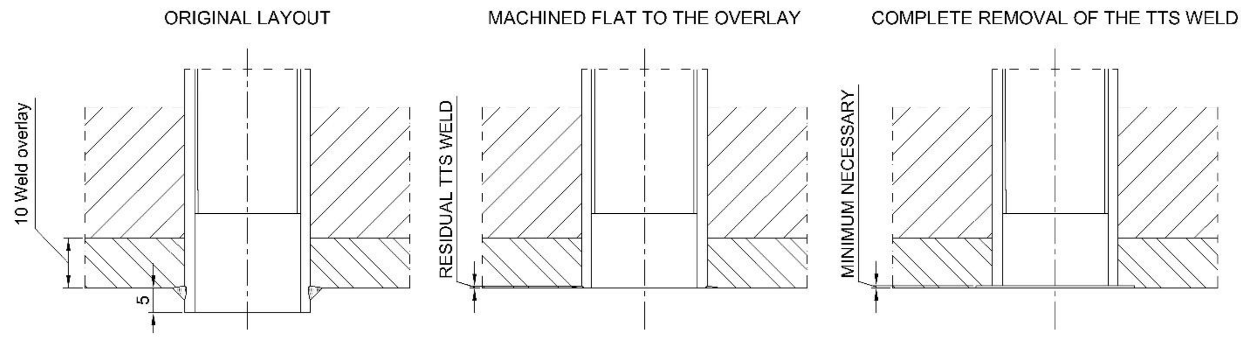
a. Remove all plugs from the plugged tubes.

b. Remove all tube protrusions and tube-to-tubesheet weld beads.

c. Machine further into the tube-to-tubesheet weld overlay to completely remove the penetration of the TTS welds into it and free the tubes from any bond to the tubesheet.

   This is an operation to be performed very carefully, in order to remove only the minimum quantity of weld overlay necessary to free the tubes and no more.

FIGURE 9: REMOVAL OF THE TUBE PROTRUSIONS AND THE TUBE WELDS



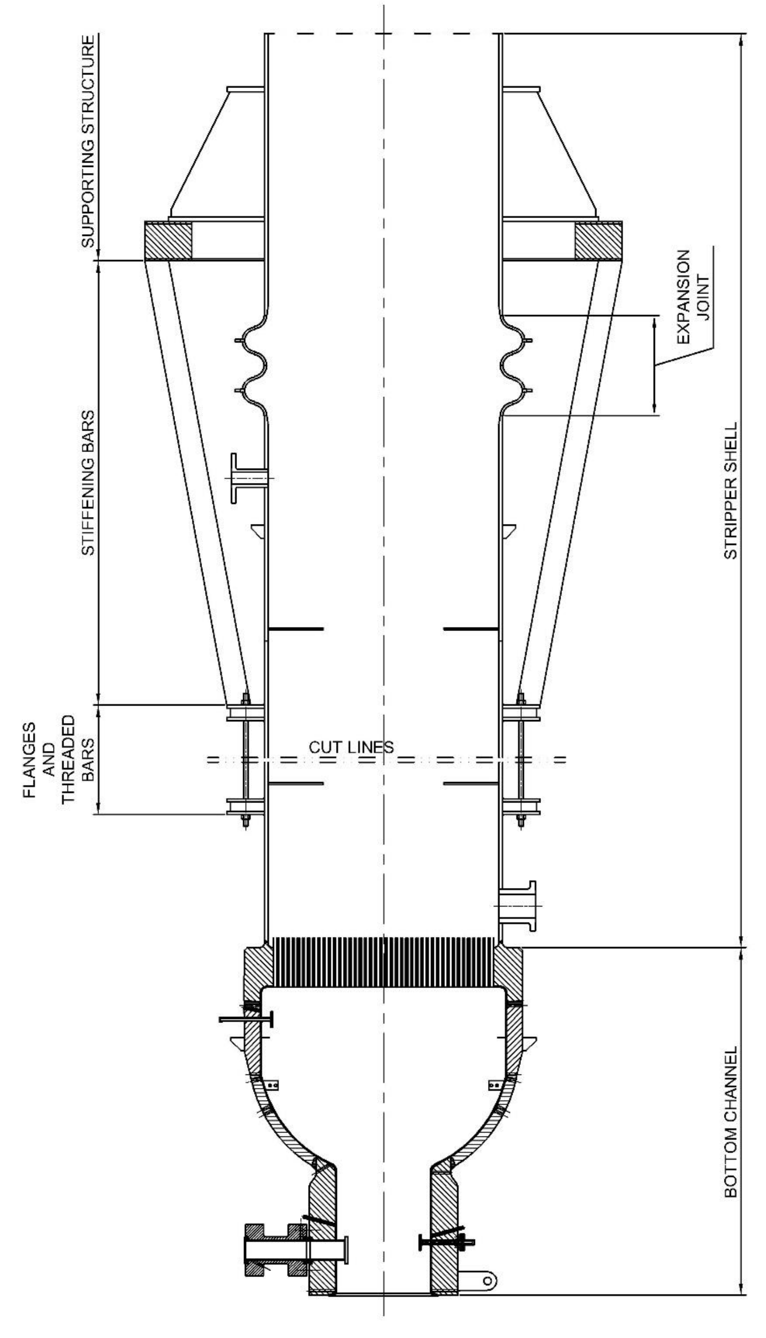
d. Perform a buffing of the tubesheet to clean out the layer of corrosion from the surface and make the surface uniform in preparation for the new welds.

e. Install and weld the lifting flanges on the shell, install the threaded bars

   To compensate for the different thermal expansion of the tube material, the stripper shell is provided with an expansion bellows. When lifting the bottom channel the expansion bellows must not be stressed and, for this reason, we link the top flange to the support structure by means of No. 8 stiffening bars that we temporarily weld in position, as shown in figure 10.

   When the job is complete the stiffening bars are removed (usually by the Client), while the lifting flanges remain in place since they do not interfere with the operation of the equipment and their removal is unnecessary.

FIGURE 10: INSTALLATION OF THE LIFTING FLANGES



f. Cut the shell.

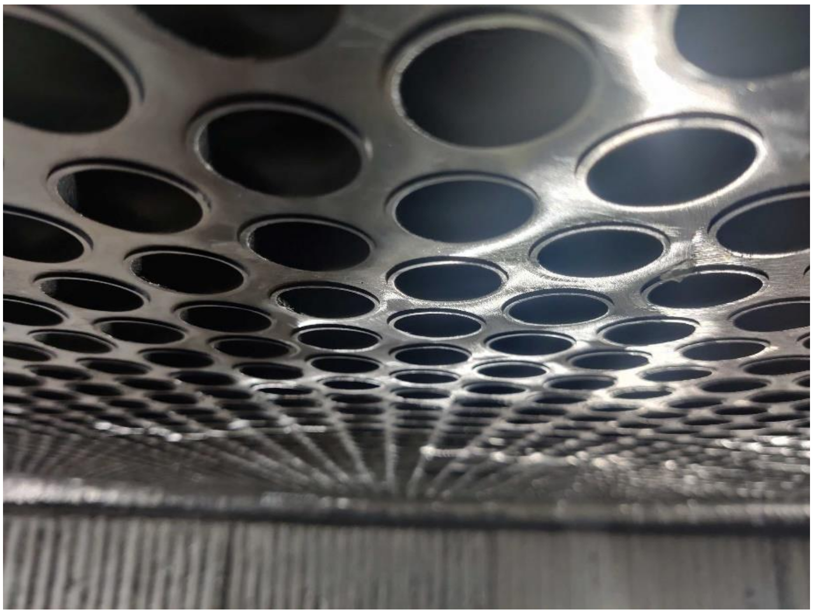
We cut the shell by manual grinding and, in order to gain accessibility to the shell surface, we remove the threaded bars in sequence, always leaving enough of them in place to support the load of the bottom channel. In order to avoid the debris to enter the shell space we introduce a small overpressure inside it by blowing compressed air through one of the nozzles and blinding the others.

g. Lift the bottom tubesheet and channel.

To avoid excessive friction between the tubes and the tubesheet and in order not to introduce unwanted strains on the tubes, the bottom tubesheet should be kept perfectly flat while lifting it. To make sure of that we monitor the lifting movement at 0°, 90°, 180° and 270° by means of 4 comparators and we tighten the bars following a defined sequence.

After lifting the bottom channel by 5-6mm we make a visual examination of the tubesheet surface to check if there are any tubes that do not slide into their holes and free them.

FIGURE 11: ALL THE TTS WELDS ARE REMOVED, THE TUBESHEET IS POLISHED AND THE TUBES START TO SLIDE DOWN WHILE THE CHANNEL IS LIFTED



h. Bevel, weld and NDE the shell joint.

i. Trim the tubes to a protrusion of 18mm

We calculate the width of the cut in the shell and the extent of channel lifting in such a way that – after trimming away the damaged section and the zirconium-free area – the tubes protrude 18mm from the tubesheet surface.

j. Weld the new Tube-to-Tubesheet joints

At the beginning, mid-way and before completion of the welding activities, in accordance to the requirements of SAIPEM specification we weld each time a group of No. 7 adjacent tubes on the mock-up piece. This welds are then subject to flaw assessment on site at the presence of a third party inspector.

k. Plug the tubes that could not be properly restored.

Usually the strippers that we shorten have experienced some leaks at the bottom tubesheet and have some plugged tubes. Some of this tubes may be restored, but in most cases they cannot and must be plugged again after shortening. In addition to that, often the carbamate solution from the leak seeps into the interstice between the tube and the tubesheet hole of some nearby tubes *and – when the stripper is cooled down – solidifies. During welding this solidified carbamate is heated up and expands rapidly, damaging the molten pool of weld metal and the tube wall. The tubes thus damaged must also be plugged.*

6. Testing before commissioning

When the shell and all the tube-to-tubesheet joints are welded and before commissioning again the equipment, in cooperation with the client and the process licensor we submit the equipment to a scope of testing that includes:

a. 100% PT examination;

b. Air-and-soap leak test;

c. Ammonia leak test;

Air and ammonia pressure is applied on the shell side and the soap solution / ammonia developer are sprayed on the tubesheet surface.

d. Hydrostatic test of the shell side;

e. Hydrostatic test of the tube side;

f. Air-and-soap leak test;

g. Ammonia leak test.

7. Problems encountered and lessons learned

The biggest recurring problem of this job is that after removing all TTs joints and cutting the shell the bottom channel does not rise because some tubes are jammed into their holes due to fouling in the interstice between the tube and the tubesheet.

When we first met it we tried to address this problem by:

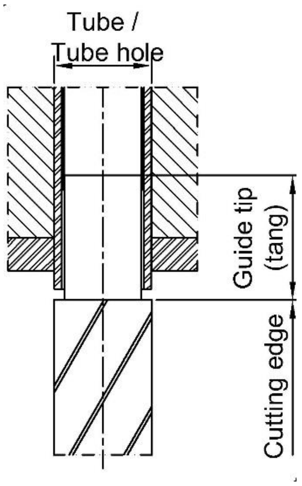
- Increasing the pull on the threaded bars. This freed a few tubes but it did not work on most, and it risks inducing an excessive strain, so we abandoned it.
- Cleaning the interstices by acid and by steaming, but both would flow through open tubes and have no effect where they were actually needed.

The first successful solution that we worked out was to machine the stuck tubes at the top tubesheet, so that rather than sliding down they would slide up. This procedure works, but it’s time-consuming and in any case it may happen that some tube is stuck in both tubesheets.

Upon the latest job we used instead a milling tool which we developed in cooperation with a specialist company. The tool has an o.d. similar to the internal bore of the tubesheet hole it’s guided by a tang at the tip. To drive the tool we use a magnetic drill but, since the surface of the tubesheet is nonmagnetic, we developed a special support to hold it in place.

The tool is capable of removing 150mm of the tube material from inside the tube hole, enough to liberate the stuck tubes without the need to machine the top tubesheet.

FIGURE 12: SCHEME OF TUBE MILLING



Apart from this, time after time we introduced many smaller, practical improvements to increase the productivity of the job. Some of the most significant are:

- PROVIDING OUR OWN, CUSTOM MADE SPARE PARTS FOR THE EQUIPMENT

  The original expansion shaft of the reaming machines, made of two segments, was subject to frequent breakdowns at the threaded link, with a negative impact on the time needed to remove the TTs welds and trim the tubes. Since the manufacturer of the machines would not provide any different solution we had our own spares fabricated on our specification.

- CLEANING THE INSIDE OF THE TUBES.

  On the first jobs we concentrated on cleaning the tubesheet surface and the welding area and – in order to save time – we did not perform any cleaning of the internal surface of the tubes beyond what is ordinarily made by the plant operation upon shutdown. A thin layer of solidified carbamate present on many tubes, though, would drop onto the welding head and would interfere with the welding, causing delay and loss of quality.

  On the latest jobs we added the activity of mechanical cleaning of 100% of the tube internal surface, using specific power brushes that we procure from the same specialized supplier from which we procure the milling tools.

- TRAINING OUR PERSONNEL TO REPAIR THE REAMING MACHINES.

  In a job like this the quality of the equipment is of essence for the success of the operation. Our reaming machines are made by GBC INDUSTRIAL TOOLS, an Italian world class manufacturer, and are quite reliable. In addition, we carry a redundant number of machines but, nevertheless, if we face a problem we do not have the possibility of asking the manufacturer to repair them. For this reason we organized a session of training at the manufacturer’s workshop for our technicians to learn to open, repair and assembly the machines.

- TRAINING OUR PERSONNEL TO REPAIR THE WELD HEAD.

  Same issue for the weld head. We use POLYSOUDE automatic orbital TIG welding machines, which are the same that most manufacturers of new strippers use in their workshop, but we operate far from home at our client’s site, so we cannot afford to rely on the manufacturer’s technician when we have a problem. We bring with us two weld heads, but we also had an expert technician from POLYSOUDE come to our workshop and train our workers in opening and repairing the weld head.

- PROVIDING THE EQUIPMENT AND THE EXPERTIZE FOR SHARPENING OUR TOOLS.

  With the amount of material removal that this job involves, tooling is one of the highest cost items. Replacing the tools as they lose their sharpness would be un-economical, and rely on the client's workshop too uncertain and time-expensive. For this reason we started to bring along our own bench grinder and grinding wheels and we set up a working position on site nearby the stripper manway to sharpen our tools.

8. One real-life example of operation after re-commissioning

One meaningful example of the results in operation of a stripper recommissioned after shortening is unit item No. 31-E-01 of plant IFFCO AONLA, which was the first unit on which we performed the procedure.

It was made by FBM HUDSON ITALIANA in 1995 and it had 1.677 tubes o.d. 25.4 x 6.000mm in length. Originally commissioned in 1996, by 2016 it had experienced a number of leaks and 57 tubes were plugged.

In May 2016 we reduced the length by 40mm and plugged a total of 145 tubes – the original 57, several ones which were jammed into the tubesheet and 2 tubes where we experienced welding problems.

After shortening and re-commissioning the unit was running at full plant load and attained a peak load of 115% the nominal capacity. All the running parameters were found normal and within the desired range, with average conductivity of LP steam at E-5 (carbamate condenser) less than 10 µmho cm-1.

The unit was replaced in the summer of 2023, with a total extension of its operational life of 7 years.