In many occasions it is possible to extend the life time of a Urea Reactor. During normal operation of Urea Reactors common overall corrosion can be found on the internals as well as on the corrosion resistant liner on the reactor wall. While corrosion of the internals is not critical to safety, the corrosion of the liner is. After many years of operations the liner thickness eventually will become less than needed to form an adequate barrier against the corrosive ammonium carbamate. The life time of the reactor of course strongly depends on the material used for this protective layer.

This paper describes the possibilities and philosophies adapted by Stamicarbon to extend the life time of the Urea Reactor by partially re-lining the reactors during a planned shutdown period. The relining should be planned carefully and custom tailored based on the specific design of the Urea Reactor. Issues such as construction of the vessel, type and condition of C-steel used for the shell and head, form and shape of the hemispherical head, post weld heat treatment, construction of the corrosion barrier liners and/or overlay welding as well as the leak detection system layout are issues which must be considered before the start of a relining activity.

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Urea reactors designed for service in Stamicarbon urea plants are typically designed to have a lifetime of 25 years. Many urea plants operate their urea reactors significantly longer than 25 years.

The life of a Stamicarbon urea reactor is predominantly affected by corrosion which occurs in the top section of the vessel. The urea reactor is almost completely filled with liquid (NH₃, CO₂, carbamate and urea) up to 2 meters below the top tangent line. Above the liquid a gaseous phase is present.

At the transition between the liquid and gaseous phases, there is a splash area. It is in these areas the highest corrosion is normally found. Knowing this area to be the most corrosive, we can increase safe operation by renewing and enhancing the corrosion resistant layer in this area.
This paper describes the important considerations for relining urea equipment. These considerations are based on our experience in such relining projects.

**Design of Urea Reactors**

The design of the vessel, construction materials used, as well as the layout of the leak detection system, are to be considered before a re-lining job is undertaken. There are generally three main types of urea reactor vessels which are built as follows: solid wall, multi-layer, or multi-wall.

**Solid Wall Reactors**

The solid wall reactor consists of solid hot rolled plates. In these plates the areas for the future liner welds will be milled. At the milled areas a buffer layer (309 type welding consumable) will be welded to enable liner welding during the last stage of fabrication\(^1\). After the buffering, the plates will be rolled to barrels consisting of one longitudinal weld seam. The barrels are welded together with circumferential welds to become one cylinder of the desired length, and the welded vessel barrels will be post weld heat treated (PWHT). The length of the cylindrical sections will strongly depend on the manufacturers shop limitations with respect to handling and PWHT possibilities.

After PWHT of cylindrical parts the liners will be welded to the C-steel via the TP309 buttering. At the location of the closing seam(s), pre-rolled liner plates will be put into the vessel but not yet welded. After the final local PWHT of the closing seam(s) the final liners will be welded to the C-steel vessel wall via the TP309 buttering. It is necessary to fabricate in this order because, in general, the corrosion resistance of stainless or duplex stainless steel is limited with respect to potential sensitizing if exposed to elevated temperatures. Stress relieving PWHT temperatures normally range within 600 to 650 °C (1110 to 1200 °F), whereas the stainless steel parts are limited at 400 to 500 °C (750 to 930 °F) in order not to impair the final corrosion resistance of the plate material.

**Multi-Layer Reactors**

A multi-layered reactor vessel consists of a cold rolled ‘welder friendly’ inner core. This inner core is made from plate material; also here the buttering layers are welded prior to rolling the inner core sections to barrels. After the buffering (309 type) the barrels are rolled and the longitudinal seam is welded. The barrels or sections are PWHT, depending on manufacturer’s capabilities.

After finishing the inner core several barrels are connected to form the cylindrical shell of the urea reactor. In order to obtain the necessary strength the cylindrical part is reinforced using layer plates with a thickness of 8 to 10 mm (0.32 to 0.40 in) made from high strength steel. These pre-rolled plates are wrapped in several layers to obtain the thickness as designed. The cylindrical barrel is covered normally with a welder friendly material on the outer layer in order to weld attachments and/or insulation clips. The main advantage of fabricating using a multi-layer technique is the elimination of the PWHT. The heads are pre-buttered and heat treated before lining installation, and closing seams can be welded without PWHT. Figure 1 shows a multi-layer vessel under construction.

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\(^1\) Older urea reactors might not have buffer layers present since the liner is installed as one loose sleeve from top to bottom.
Multi-Wall Reactors

Multi-wall urea reactors consist of a stainless steel inner core (the liner) that is usually rather thick (12 mm; 0.50 in) to withstand the manufacturing process. The first C-steel barrel is fitted around the inner core. The liner barrel is cooled and the C-steel barrel is heated up to 650 °C (1200 °F). The barrel fits via shrinkage to the inner core. The remaining wall segments are also shrunk onto the next. This method is rarely used nowadays since dimensional requirements on the separate barrels are high with no clear advantages.

Summary

In the above described manufacturing methods, the corrosion resistant surface is obtained by either plate material in austenitic and/or duplex stainless steel. Hemispherical heads can be covered by either liner plates and/or electroslag overlay welding. The fabrication method is an important consideration when developing a procedure for relining and extending the equipment’s useful life.

Typical Forms of Corrosion Found in Urea Reactors

The most common form of corrosion found in urea reactors is overall general attack. This attack leads to gradual thinning of the corrosion resistant surface over an extended time.

This corrosion mechanism is predictable and calculations on residual life are quite easy. Sometimes however, the overall corrosion attack is accelerated by so-called condensation corrosion. This type of corrosion occurs at those spots where carbamate gas condenses on the wall of the vessel. This condensing effect results in the oxygen (needed for the passivation of the stainless steel) becoming too low and accelerated corrosion will occur. This type of corrosion is generally found at areas with insufficient or bad insulation, or on so-called “cold spots”. Improving the insulation can stop or slow down the process.

The appearance of condensation corrosion, as shown in Figure 2, appears as a jigsaw-like pattern of oxide scales. No oxide scaling indicates the presence of gas and liquid phases at these spots.

Another failure mechanism that is sometimes seen after several years of operation is so-called
strain induced intergranular corrosion (SIIC), shown in Figure 3. This type of attack is a phenomenon that is found in the gas phase of the reactor. SIIC is an electrochemical corrosion mechanism in combination with deformation (strain).

![Crack propagation](Image)

**Figure 3. Cracks near circumferential welds made visible by dye penetrant examination**

The following conditions are a pre-requisite for occurrence of these cracks:

- The presence of an electrolyte as a result of condensation of ammonium carbamate in the gas phase. In cases where the liquid level in the urea reactor is extremely high, these cracks are also observed in the liquid phase (so electrolyte is always present).
- Plastic deformation (= strain) of the liner material. This deformation will always occur during pressure and temperature cycles (especially during cooling down of the reactor when high tensile stresses occur in the liner).

Other conditions that can enhance the failure are as follows:

- Inferior liner material and/or weld quality
- Presence of chloride and/or sulphur in the porous oxide layer
- An increased gap between the liner plates and the shell
- Large number of pressure cycles

Crack propagation is rather slow. Usually crack propagation only occurs during pressure (stress-strain) cycles (i.e., start-stop, blocking in of the synthesis, or draining of the synthesis section).

**Inspection of the Urea Reactor to Ensure Safety During Operation**

The minimum required remaining liner thickness depends on the liner material used, the inner diameter of the vessel, and the size of the area which is affected by the overall and/or condensation corrosion. With respect to SIIC, we allow a crack depth until a remaining thickness of 3 mm (0.12 in) is reached as acceptable since it is known that the crack propagation is slow and mainly occurs during starts and stops of the synthesis.

When the above failure mechanisms are found we recommend considering a relining job. In this respect it is important that the actual dimensions of the area to be relined be established. As well, the leak detection system layout must be checked. The data is required in order to prepare for the repair job during the next planned turnaround of the urea plant, therefore a good and thorough inspection of the Urea reactor is necessary.

The remaining wall thicknesses can be measured using ultrasonic equipment combined with pit depth meters. In case of SIIC, the crack depth can be determined by careful grinding whilst performing dye penetrant examination, but it is not the best solution. Grinding removes the protective oxide layer and removes excess material. Crack depth is better determined using a more sophisticated technique by eddy current technology. Stamicarbon uses specialized probes which compensate for the welding and protective layer. This technique can determine crack depth without removing the protective layer. The most severe spots can then be locally verified by dye penetrant.
Preparations for the Re-Lining Job

When inspection of the urea reactor indicates that a repair of the corrosion resistant surfaces will be due in the near future, as shown for example in Figure 4 a corroded weld overlay, it is time to prepare for this major repair.

![Figure 4. Severe corrosion on electroslag overlay weld (the red spots show increased Fe%)](image)

Based on the inspection results the area to be relined can be clearly identified. Normally the top part at the gas-liquid interface is the affected area. During the last inspection as-built dimensions should have been taken and compared to the original design drawings.

Stamicarbon recommends writing a vessel-specific relining procedure. In this procedure, the following issues and areas of special attention should be documented:

**General**

1. What is the magnitude of the repair?
2. What is the time window available for the repair during turnaround?
3. Use of local or specialized company or manufacturer of the vessel.
4. Manufacturer of existing vessel.
5. Type of construction.
6. Review strength calculations.
7. Design drawings available and readable.

**Dimensional**

1. Form of the spherical head, radius.
2. Inner diameter of the manway (check as-built dimensions).
3. Condition of the top sieve tray (weight of personnel and tools).
4. Layout and dimensions of leak detection system.

**Materials**

1. What liner material is present?
2. What is the material quality for relining (Safurex or austenitic stainless steel)?
3. Material of pressure bearing parts (hemi head, cylindrical part, man way or cover, if applicable).

**Welding**

1. Welding by qualified welders, qualified for the job.
2. Check corrosion resistance on test mock-ups.
3. Welding on base materials and/or loose strips.
4. Prepare for weld repair on C-steel type of weld consumables preheating, heat input, etc.
5. Pickling and passivation after welding.

**Pre-Fabrication of Liners and Sieve Trays**

1. Pre-form the liner segments for hemi head and cylindrical, as shown in Figures 5 and 6.
2. Inspection of pre-fabricated items recommended.
3. Check of material certificates and corrosion tests.
4. Replace top sieve tray with a new one in cases where necessary.
Removal of the Old Liner Plates

1. Define the cutting lines.
2. Define the sequence of cutting, cutting devices.
3. How to remove the plates / grinding debris.

Installation of New Liner Plates

1. Define maximum petal size.
2. Define starting point of relining in relation to leak detection system.
3. How to fit petals to wall.
4. Consider liner connections plate/ plate or plate C-steel.

Inspection and NDT

1. Prepare for hold and witness points during execution of the job.
2. Inspection of existing C-steel portion.
3. Tightness check of root run welds.
4. Fit of the new liner segments.
5. Check the finished welds for tightness and surface breaking defects.
6. Radiography of loose liner connections (if applicable).

Tools

1. Scaffolding, lifting equipment.
2. Grinding and welding equipment, welding consumables, gases.
3. Hydraulic tools and spanners for pressing liner to vessel wall.

Safety

1. Job to be done in confined space.
2. Oxygen, lighting, fall protection, ease of access.
3. Securing the vessel blinds etc.
4. Clean working environment.

The above lists do not pretend to be complete. Rather, they give an overview of the major issues that need to be taken care of before commencing a major repair like a relining. Every relining job is a specific one and a detailed procedure on how to perform the job can save time and money.
Removing Existing Liners

Removing the existing liner should be part of the detailed procedure. Marking the cutting line is the first step in removal of the liner plates. The first cut normally will be the circumferential cut in the cylindrical part of the vessel. Cutting must be done carefully in order not to touch the C-steel shell. Excessive grinding is needed to remove the liner plates as shown in Figure 7. One should take care that no dirt or debris can enter between liner and vessel wall. After the first cut, longitudinal cuts are made in such a way that the parts can be removed through the manway.

Some Urea reactors have hemispherical heads which are overlay welded by a combination of electroslag welding (ESW) and shielded metal arc welding (SMAW) or gas tungsten arc welding (GTAW). Repair of this type of overlay welding can be done locally using either SMAW or GTAW technique. ESW welding is not an option as this welding can only be performed in horizontal plane, welding position. (1G/PA)

In practice it is also possible to reline these overlay welded hemi heads by using liner plates. The first point of attention should be the form of the hemi head (true radius or not). Another point of attention is the fact that overlay welded heads have no leak detection system. The leak detection system needs to be designed in relation to the size of the liner petals and/or the connection to the C-steel portion of the vessel. Since buttering and/or post weld heat treatment is not necessary, liner welds can be made directly to the stainless steel overlay welding. The starting point and the layout of the petals strongly depend on the condition of the overlay welding in general.

Inspection of C-Steel Vessel Wall

After the removal of the existing corrosion protection (old liner plates) Stamicarbon always advises to perform a thorough visual inspection of the existing reactor wall. This inspection should be extended by magnetic particle inspection. Points of attention are in general overall corrosion by carbamate leakage through the old liner (see Figure 8). Although Stamicarbon opposes cleaning of the leak detection system by live steam, we are aware that it was common practice in the past. Using steam for cleaning leak detection systems might introduce cracking in the C-steel portion of the vessel. Cracks, as depicted in Figure 9, are not allowed and should be removed by grinding. The TP309 buttering layers should also be checked.
After removal of the old liners it is also possible to check whether the C-steel vessel wall was hit by the grinding wheel when removing the old liner. An inspection of these spots and their depths, in combination with the strength calculation, might lead to the repair of the vessel wall by welding. The detailed procedure should also cover the aspects of this repair welding just in case. The base material of the vessel wall and the design/fabrication code might dictate the repair procedure with respect to weld consumables, heat input, interpass temperatures and/or, pre-heating. PWHT is in general not an option during relining due to temperature restrictions of the existing liners and/or overlay welds, so damage due to grinding should be avoided as much as possible.

Cracking in the C-steel vessel wall might lead to early replacement of the vessel. These cracks can hardly be predicted and the seriousness depends strongly on the actual findings, crack depths, etc.

**Installing the New Liners**

The fit-up of the new liner plates should always start from the existing liner to obtain an optimal fit to the remaining liner. Depending on where the initial first cut was made, the connection to the old liner can vary. When the cut is made at the location of an existing buttering, the new liner can be welded directly to this buttering (Figure 10). When the cut is made in the middle of an existing liner segment (most common) in general, a leak detection communication needs to be made between the old and new liner segments.

The existing liner as well as the new liner is welded to a loose backing strip to avoid welding to the carbon steel vessel wall. Depending on the base material, the longitudinal weld can be made directly to the C-steel vessel wall using TP309 weld consumable or via a loose backing strip. The number of segments to be welded depends on the corroded area and the size of the manway opening.

In cases where the top head is removed (this might be possible with a multilayer design because no PWHT necessary) bigger segments can be installed, as shown in Figure 11. Also the relining of the hemispherical head then becomes much easier as it can be done in the 1G position in a work shop using welding manipulators.
In many cases, however, the top head is not removed, thus the relining parts should fit through the existing manhole. The transition of the hemispherical head to cylindrical part is welded directly to the existing TP309 butter layer.

The installation of the petals in the hemi head is the next step. The location of the existing buttering as well as the manway size dictates the size of the petals to use.

The manhole typically is relined in the same way as the cylindrical part of the vessel. The barrel is welded to a backing strip or directly to the nozzle reinforcement, depending on material. If the liners are removed in the top channel, it is possible to make a buffer layer and perform a local PWHT on the manway nozzle reinforcement. The top cover can be relined using the existing buttering and leak detection system. For convenience the cover may be transferred to a work shop for relining.

The welding scheme of the liner segments should be developed to minimize weld shrinkage. An example is shown in Figure 12. Shrinkage causes the gap between liner and C-steel wall to increase. This weld sequence strongly depends on amount and sizes of petals and segments and should be discussed prior to the re-lining job.

Non-Destructive Testing During Relining

During the relining operation Stamicarbon recommends non-destructive testing at several steps of the relining job. After removal of the existing liners a unique opportunity is given to inspect the carbon steel vessel wall from product side. We advise that a magnetic particle inspection, UT thickness measurements, and visual inspection be done on the vessel wall. The butter layers should be checked using a delta or dual scope, and the ferrite content can be checked by a ferrite meter. In case there are doubts about the bonding of the TP309 buttering, an ultrasonic test can be performed to check for disbonding. After the acceptance of the C-steel portion, which should be a hold point for QA/QC, the liner installation can proceed.

In some cases loose liner connections (plates joined together with 1 – 2 mm, 0.04 – 0.08 in, pre-opening) are necessary after insertion of the first liner segments. A dye penetrant and radiographic check should be included.

After installation of the petals and segments are tack welded to the vessel wall (TP309 buttering or loose strips), we recommended a hold point for QA/QC to check the gap between stainless steel liners and C-steel vessel wall. Also, the
quality of tack welds and distance between the separate segments can be checked. The gap between the stainless steel liner and the vessel wall can be checked by delta or dual scope, in combination with an ultrasonic thickness gauge. Gaps of 5 to 7 mm (0.20 to 0.28 in) are considered acceptable. The distance between the two liner segments should be minimum 7 mm (0.28 in) to enable good root run welding.

After acceptance of the fit-up, the roots can be welded by manual GTAW. The root welds are also considered a hold point for QA/QC. Root welds should first be checked by dye penetrant (DP), as shown in Figure 13, and repaired when necessary. Finally, a leakage test should be performed. This test is done by pressurizing the leak detection system up to 0.3 barg (4 psig) using air. Subsequently the welds can be checked by a water-soap solution. A pressure relief safety valve should be used to avoid deformation of the liner plates. When the leakage test is done with acceptable results (no leakages) the item can be released for completion of the liner welds.

After completion of the liner welds we recommend a DP test prior to the hydrostatic test.

A hydrostatic test should be done up to the design pressure with water (chloride content less than 1 ppm) using the high pressure flush pump to fill the vessel. If aluminum scaffolding is used, it is not necessary to remove this scaffolding during the hydro test. The pressure should be raised in steps to allow the liner plates to yield to the vessel wall. Normally steps of 25 barg (360 psig) are used with holding times of 10 minutes to allow the liners to yield.

After completion of the hydro test all liner welds should be DP tested again. The final gap should be checked with a dual scope combined with ultrasonic thickness gauge. The gap shall be less than 1 mm (0.04 in) after the hydro test.

We recommend an ammonia leak test to check the final tightness of the liner welds. Ammonia is supplied to the leak detection system and the welds are checked by ammonia sensitive spray. A common mistake is that couplings used for the connection of the leak detection system show small leakages resulting in reaction of the ammonia sensitive spray all over. The couplings should be tested by air prior to the ammonia filling. If repairs are necessary, the ammonia test should be repeated.

After the ammonia leak test the leak detection system should be flushed with nitrogen for several hours to remove any ammonia from the system. It is important to remove the ammonia as it may interfere with leak detection systems during operations.

Cleaning and Boxing Up - Mechanical Completion

During the job great care should be given to cleanliness. Even so, it is important that the complete vessel is checked for remainders of grinding and liner parts. Scaffolding is to be removed and the downcomer is to be opened again. When the cover is relined as well, it might be necessary to re-machine the flange face surface to obtain a proper sealing.

The cover should be tightened using the specified bolt torques for operation.
Conclusions

The main conclusions which can be drawn from our field experiences are as follows:

1. Plant inspections should be performed at regular intervals.
2. Necessity of repair can be planned during a scheduled turnaround.
3. A good relining job needs careful planning.
4. A detailed repair procedure tailored to the actual vessel should be made.
5. Safe operations and extended life can be guaranteed after a relining, as shown in Figure 14.
6. If properly arranged a partial relining can be performed during a planned shutdown.
7. Stamicarbon can prepare a detailed tailor-made relining procedure for your Urea Reactor and prepare an offer for the execution of the re-lining.

Figure 14. Re-lined top section after several years on-stream time in good condition (relined part X2CrNiMoN 25.22.2)