Prevention of a Potential Catastrophic Failure of a High Pressure Condenser in a Urea Plant

This paper describes the findings of a High Pressure Carbamate Condenser installed in 1997 and operating in a Urea Plant located in Russia. Frequent leakages from the overlay welding in tubes ligament area were reported and Urea Casale was requested to inspect and provide solutions. The following inspection revealed improper repair attempts and corrosion related issue that could have led to potential catastrophic failure due to prolonged exposure of the tube-sheet Carbon Steel forging to the high corrosive Carbamate solution. Temporary specific repair procedure was agreed and implemented to allow plant operation to continue prior to equipment replacement. The lesson learned is, the importance of proper repair procedures that have to be implemented in the specific field of Urea production plants and the necessity of implementing preventive inspection and maintenance approach. The lack of these precautions may lead to catastrophic consequences.

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Introduction

Around June 2013 Casale was informed about the repeated leakages of a High Pressure Carbamate Condenser operating in a Urea Plant located in Russia. A meeting was immediately set-up to discuss the details and have a proposed path forward in positively determining the cause of leakages and develop effective repair plans.

The High Pressure Carbamate Condenser was commissioned in 1997; hence in operation for about 128,000 working hours. It is a horizontal kettle-type condenser with process flowing tube side and steam generating in the shell side. The tube sheet consists of a 270 mm carbon steel forging protected by 12 mm of AISI 316L UG corrosion resistant overlay alloy. The tube bundle contains 960 “U” tubes having the size of 19.05/2.11mm OD/thk and made of AISI 316L UG austenitic alloy. In the channel there is an internal partition plate designed to split the process flow into two passes. The process fluid is fed from the top half while the outlet side is located at the bottom one, as shown in Figure 1.

Figure 1. Original process fluid path
Background

Casale was informed that during the last 22 months of service, two leakages were experienced due to corrosion in the upper half (inlet side) of the tube-sheet overlay welding surface.

As reported, the mechanism of failure was apparently identical. In principle, accelerated corrosion pit-like indications developed in the course of service on the tubes ligament area.

The corrosion cavities propagated underneath the corrosion resistant overlay layer of tube-sheet. Due to the fast corrosion of the carbon steel the process product reached the annulus between tubes and tube sheet holes. In this way the high pressure mixture of NH3, CO2 and Carbammate started leaking in the water side and high conductivity in the condensate was detected.

Due to the prolonged period of service under this up-set condition and considering the fast rate of corrosion of carbon steel, it was considered most plausible that potential corrosion cavities occurred in the pressure bearing carbon steel portion of the tube-sheet.

Moreover, looking at the figure 2, which was submitted by the plant Owner at the early discussion stage, the root cause of leakages seemed to be from crack-like defect in the tube-to-tube sheet joints. As visible in the same figure, the crack-like indication also propagate in the tube ligament area.

Figure 2. Crack-like defect in tube to tube-sheet joint

The major threat associated with this type of leakage is the tube-sheet integrity as a pressure component. In fact, the carbon steel is prone to severe corrosion when exposed to high corrosive Carbamate solution and a long exposure can lead to potential catastrophic failure in worst case scenario.

The plant Owner had attempted to repair both leakages by building up weld overlay using AISI 316L Urea Grade consumable and plugging of tubes, as necessary.

The repairs result was not successful since the beginning. The welder was unable to seal welding the defect due to contamination product (see figure 3). The lack of expertise in the repair preparation and execution along with the extreme weather condition, ambient was around -10°C, were some of the limitations associated with this problematic repair.
As a temporary mitigation plan, tubes around the defective area were plug. The plug surface was then used as backing support for building up an overlay welding reinforcement in that area (see figure 4). The equipment returned to operation but high conductivity still persisted to indicate that the repairs were not successful.

**Inspection Findings**

On November 2013 the plant was brought down for inspection and repair. The foremost activities were major inspection to identify the leak source and preparation/execution of the repair job.

The visual inspection revealed that the overlay welding of the tube-sheet in the upper half (process inlet side) was generally corroded with pit-like corrosion marks. These pit-like marks were prominent in the central region located directly in front of the solution inlet nozzle. The tube ends were consumed on their heads and macro porosities were generally witnessed on the relevant tube to tube-sheet welding surface (see figure 5).

Due to the mild environment exposure, general condition of the overlay welding in lower half section (process outlet side) was significantly better than the upper half. Neither corrosion nor significant etching of tubes end was visible on the inner and outer surface including heads. The overlay welding surface was generally smooth with silver bright in appearance (see figure 6.)
The majority of the plugs which were installed based on tube wall thickness reduction analysis by Eddy Current examination were found badly corroded and the quality of the seal weld was generally poor (see figure 7).

Figure 7. Selective corrosion on plug base metal and seal weld.

A corrosion cavity in the carbon steel tube sheet was explored and confirmed. Inspection holes were drilled out through the overlay welding layer to determine the extent of damage. The cavity in the carbon steel tube sheet was sized as 40 mm diameter and 50 mm in depth. It was evaluated that the cavity was small enough to not threaten the mechanical integrity of the tube sheet. Therefore a repair strategy was developed to protect the carbon steel components from further corrosion. It was decided to install a stainless steel patch placed over the defective area. This strategy avoided welding on the carbon steel material which is not suggested for large thickness carbon steel forging in critical service, where Post Weld Heat Treatment is not possible. In this context, welding on Carbon steel post weld heat treated high thickness components is always a risky operation, which should be avoided whenever possible, since high residual stresses and possible brittle phases are likely in this situation. Post weld heat treatment is not suggested on high pressure Urea equipment, due to the risk to impair the properties of the corrosion resistant liner, therefore when carbon steel welding is absolutely required special techniques like half-bead, which reduces the risks described before shall be considered. Specific experience and preparation is anyway required.

Repair Process

Preliminary air/soap water test was performed to search for all leaking source but nothing obvious was found with the visual inspection. The ammonia sensitive leak test could not be performed because the area was contaminated by heavy fugitive ambient ammonia. It was than agreed to proceed with the removal of all the existing plugs regardless their integrity appearance. This job was handled with special care since there was evidence of product entrapped in the “U” tubes due to the tube to plug seal welding failure. The air/soap water test was repeated but again no leak was found.

A patch plate 16 mm thick made of solid 25Cr22Ni2Mo austenitic alloy was cut and prepared to be installed over the central region of the tube where the leakage was experienced and caused the cavity in the tube sheet. The patch plate was shaped to the proper contour prior to installation using a template. Some tubes were ground flush and the back base support for the patch plate sealed by welding build-up (see figure 8).

Figure 8. Surface preparation by welding build-up in progress.
The patch plate was then installed and tacked into place properly. The fit-up and welding jobs took approximately 12 hours.

Dye Penetrant examination on the root and final weld was good. A final ferrite content check was also successful.

The complete welding profile between patch plate and tube sheet is visible in figure 10.

After repair, cleanliness was provided as necessary to prepare the equipment for the ammonia sensitive leak test. All tubes were washed and purged with air before admit ammonia in the shell. Visual inspection did not reveal anything after approximately 12 hours soaking time.

In parallel, as possible proactive approach, Casale proposed the installation of a new internal partition plate to modify the process fluid path. This is a consolidated maintenance practice that is really effective in terms of equipment life-extent when applied in due time.

After the fluid reversal the solution remains fed through the same nozzle – re-routing of piping is not necessary – but the fluid path is reversed to preserve the most affected tube sheet region (i.e. inlet side) from further deterioration.

The red highlighted arrows in figure 12, represent the process fluid inlet path and the blue arrows indicate the outlet path which are reversed if compared with the existing configuration (figure 1).
Unfortunately plate segments were not available at site in due size and the modification was not applied at that time.

**Conclusion**

Based on the inspection finding the reliability, efficiency and the operating working life of this equipment has been significantly affected or even compromised by the late understanding of the corrosion propagation mechanism and associated maintenance strategies.

The equipment is not fit for longer service at present condition and the recurrence of failures is the most probably scenario. Looking at a reliable, safe and efficient plant operation as a long term goal, the replacement of the equipment has to be planned without further delay.

In conclusion, a plant can remain reliable and safe only if it is properly maintained, a target that can be achieved by turning to professional experts and specialists with wide experience and knowledge. There are numerous reasons why a piece of equipment might require modification or repair: wear or corrosion in normal operation, damage, operational upsets, incorrect operation, or mistakes in the design or fabrication of the equipment itself. In any case, the first step for successful intervention is a full understanding of the causes leading to the faulty operation of the equipment. Only companies with deep and long experience and technical knowledge in the urea field can satisfactorily address all these issues where process, mechanical and metallurgical specific knowledge and experience are required. For this reason Urea Casale has put in place a specific program – PAMS (Pro Active Maintenance System) – as an opportunity to share CASALE experience and technical knowledge in the urea field to benefit plant owners directly in their operations.

It is a way to manage inspection and repair strategy in a cost effective manner. The prime objective of PAMS is monitoring of critical components against possible reliability and integrity failures and formulating the course of corrective action. To accomplish this goal requires the correct interpretation of failure, an understanding of the corrosion propagation mechanism, and planning effective maintenance strategies. Inspection and repair strategies developed are mainly focused on the following intents:

- preserve the pressure-bearing components from exposure to the highly-aggressive Carbamate environment;
- discern important findings requiring immediate action and consideration;
- extend reliability and life-integrity of operating components;
- ensure compliance with pressure system safety regulations;
- perform remaining life assessment;
- propose pro-active repair action to extend the expected operating life of the equipment;
- set up an equipment replacement planning program;

A close relationship and constant communication of the owners with urea specialists is the strategy to prevent costly failures in their urea plant: learn this lesson from the incident described in this paper.