CASESTUDY

CATASTROPHIC FAILURE OF A HIGH-PRESSURE SCRUBBER

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NEXTCHEM Sustainable Technology Solutions

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SUMMARY

ABSTRACT

This paper investigates a catastrophic rupture of a high-pressure (HP) scrubber in a CO_2 stripping urea plant, which occurred in 1998 after 17 years of operation, highlighting the severe risks posed by ammonium carbamate corrosion in urea synthesis equipment.

The HP scrubber, designed with a multilayer carbon steel shell and a 316L UG stainless steel liner, failed two days after a maintenance shutdown, ejecting its dome and damaging surrounding infrastructure. Initial hypotheses considered an explosion from a hydrogen-ammonia-air mixture or mechanical deterioration of the dome.

Analysis ruled out an explosion, as gas composition was outside the explosive range, and instead identified severe corrosion of the inner carbon steel layers—caused by ammonium carbamate leakage through a defective fillet weld in a cover plate—as the root cause. The failure went undetected due to a plugged leak detection hole, a commissioning oversight that disabled the system.

Corrosion rates in such breaches can reach 500 mm/y, underscoring the vulnerability of carbon steel when protective liners fail.

This case illustrates the critical need for robust welding practices, effective leak detection, and diligent maintenance to prevent such incidents.

Stamicarbon' s standards aim to mitigate these risks, yet this event demonstrates that implementation lapses can lead to devastating consequences, emphasizing the importance of rigorous oversight in high-pressure urea plants.

1. INTRODUCTION

1 INTRODUCTION

In CO_2 stripping urea plants, ammonia and carbon dioxide react under high pressure to produce urea, with ammonium carbamate forming as a highly corrosive intermediate. This corrosivity poses a significant threat to carbon steel pressure vessels, necessitating protective barriers such as weld overlays or liners for all components exposed to the process, whether in liquid or gas phase.

Historically, Stamicarbon employed austenitic stainless steels like 316L UG and X2CrNiMo25-22-2 as liners, materials that rely on passivation air to maintain corrosion rates between 0.05 and 0.1 mm/y. Without this passivation, corrosion accelerates dramatically to 30 mm/y or more, and if ammonium carbamate breaches the liner, it can corrode underlying carbon steel at rates up to 500 mm/y, rapidly compromising structural integrity.

To mitigate these risks, Stamicarbon has developed stringent standards, including the use of corrosion-resistant materials, optimized fabrication techniques (e.g., welding procedures), leak detection systems, operational guidelines ensuring adequate passivation air, and regular maintenance protocols.

Despite these measures, failures still occur, as exemplified by the 1998 rupture of a high-pressure (HP) scrubber in a Stamicarbon plant after 17 years of operation. This paper examines this incident to illustrate the challenges of managing ammonium carbamate corrosion and the critical role of effective leak detection and maintenance in preventing catastrophic outcomes.

2. CATASTROPHIC FAILURE OF AN HP UREA SCRUBBER

2 RUPTURED HP SCRUBBER

The first case describes an incident in a Stamicarbon CO_2 stripping plant. The incident occurred in 1998 after 17 years of operation.

Two days after a normal maintenance shutdown, the high-pressure Scrubber ruptured at 04.30 hr. in the morning. The HP Scrubber, designed with a cylindrical dome (see figure 1) is located high up in the urea plant, see figure 2. The plant was running normal and fortunately nobody was present in the plant at the time of the rupture.

Stamicarbon was requested to assist in the root cause analysis of this failure.

The top part of the HP Scrubber was ruptured and completely disconnected from the vessel. One part of the rupture disk was found back outside the urea plant site. Also surrounding equipment, piping and concrete structure were damaged, see figure 3.

The function of the HP Scrubber is to remove inerts from the process gas. The ammonia and carbon dioxide are condensed and reused in the synthesis loop. The inerts are vented to the atmosphere. In the dome part of the HP Scrubber the presence of an explosive mixture of H_2, NH_3 and air is possible. Therefore, the dome part is designed such to avoid any loss of containment in case of an explosion.

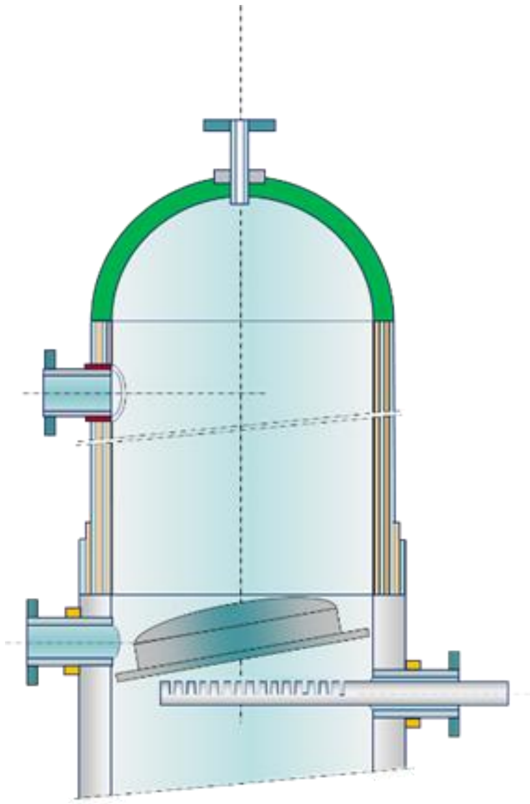

Figure 1: HP Scrubber with cylindrical dome in multi-layer design. Rupture disk closes the dome area at the bottom

Figure 2: Location of HP Scrubber

Figure 3: Damaged top part of HP Scrubber and

3. ROOT CAUSE ANALYSIS & LEAK DETECTION FAILURE

3 ROOT CAUSE ANALYSIS

Initially two possible root causes were identified:

1) An explosion due to an explosive hydrogen/ammonia/air mixture in the HP Scrubber in combination with a loss of mechanical integrity of the scrubber dome.

2) Deterioration of the mechanical integrity of the scrubber dome and subsequent failure under operating conditions.

3.1 POSSIBLE ROOT CAUSE 1: EXPLOSIVE MIXTURE

The gas composition present in the HP Scrubber just before the rupture was analyzed and the mixture was not within the explosive range as is presented in figure 4.

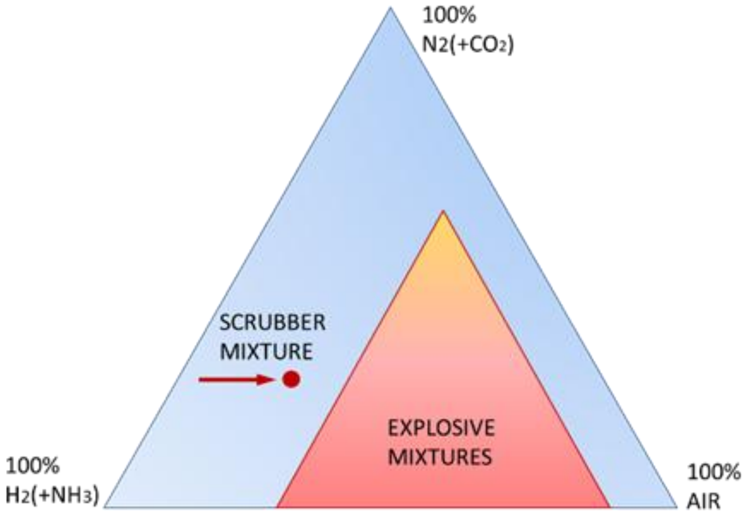

Figure 4: Gas composition in HP Scrubber just before the rupture; in the save range

Therefore, it was concluded that no explosion occurred because:

- Prior to the rupture the operating point is outside the explosion triangle
- The process condition was stable and normal
- No other plant disturbances occurred

3.2 POSSIBLE ROOT CAUSE 2: MECHANICAL DETERIORATION OF DOME

The dome part consists of a cylindrical multi-layer carbon steel pressure shell lined with 316L-UG liner (WT = 6 mm). The hemispherical part is a solid-wall design also lined with 316L-UG.

The cylindrical part is constructed of 4 layers of 9 mm K-TEN steel (K-TEN quenched and tempered steel with tensile strength: 62 Kg/mm^2 and a minimum yield strength of 45.3 kg/mm^2 at design temperature of 185 °C).

The cylinder part was ruptured in longitudinal direction; the three inner c-steel layers were through wall corroded, see figure 5, whereas the outer (fourth layer) was only minor attacked.

Figure 5: Severe corrosion of three inner c-steel layers

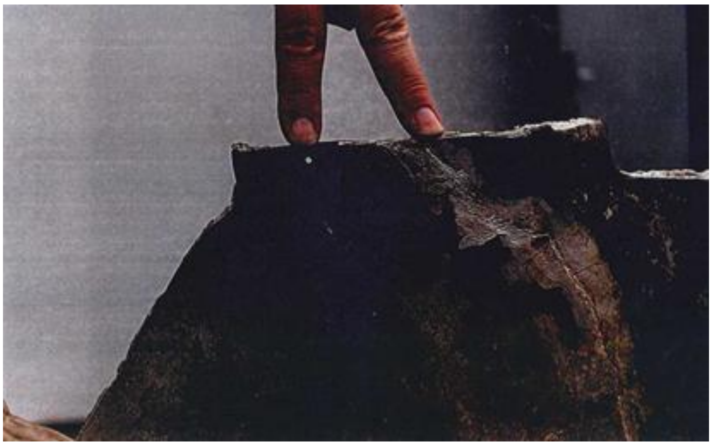

Figure 6: Backside of liner plate with carbamate corrosion

The corrosion is due to ammonium-carbamate leaking through the leak in the liner. Carbamate corrosion is visible at the backside of the liner, see figure 6. A cover plate was welded onto the liner at the location of the leak. The leak path was developed along a weld defect in the filet weld of the cover plate, see figure 7.

Figure 7: Leak path via fillet weld of cover plate and leak detection hole towards the multi-layered pressure shell.

3.3 FAILURE OF LEAK DETECTION SYSTEM

The HP Scrubber was equipped with a leak detection system. During transport from the manufacturer shop to the plant site the leak detection holes are plugged to avoid ingress of debris and moisture. However, during the commissioning of the HP Scrubber one of the leak detection hole was not opened and connected to the system, see figure 8. Therefore, the leak in the cover plate was unnoticed and corrosion of the pressure shell could commence.

Figure8: hemi-head part of dome with plugged LDS hole

4. SUMMARY & CONCLUSION

4 SUMMARY & CONCLUSION

4.1 SUMMARY

- The HP scrubber did not fail due to an explosion, but due to unnoticed corrosion of the c-steel pressure shell.
- Ammonium-carbamate corrosion occurred in the gas filled dome of the HP Scrubber. Due to improper insulation/tracing, condensation of the gasses created the corrosive solution on the inner surface of the dome.
- Corrosive ammonium-carbamate was leaking trough a hidden weld defect in a fillet weld of a cover plate on the liner.
- Hidden defects are likely to occur in fillet welds of cover plates. Stamicarbon is not in favor for installing cover plates, also not for local repairs.
- It is of paramount importance to have an effective, good working leak detection system in place as a last barrier of defense to avoid catastrophic failures.

4.2 CONCLUSION

The case study of the 1998 high-pressure (HP) scrubber rupture in a Stamicarbon CO_2 stripping urea plant, alongside the broader discussion of ammonium carbamate corrosion challenges, highlights the critical importance of robust design, vigilant maintenance, and effective safety systems in preventing catastrophic failures in urea production facilities.

After 17 years of operation, the HP scrubber's dome—constructed with a multilayer carbon steel shell and a 316L UG liner—ruptured not due to an explosive hydrogen-ammonia-air mixture, as initially suspected, but due to severe corrosion of the pressure shell caused by undetected ammonium carbamate leakage through a defective fillet weld in a cover plate. This corrosion, which penetrated three of the four 9 mm K-TEN steel layers, went unnoticed because a leak detection hole was inadvertently left plugged during commissioning, rendering the leak detection system ineffective.

The incident underscores the vulnerability of even austenitic stainless steels like 316L UG to rapid corrosion (up to 500 mm/y) when passivation air is compromised, or leaks allow ammonium carbamate to contact carbon steel. Stamicarbon' s standards—emphasizing corrosion-resistant materials like modern duplex stainless steels, optimized welding practices, and reliable leak detection—aim to mitigate such risks, yet this case illustrates that implementation failures, such as hidden weld defects or neglected maintenance, can still lead to disastrous outcomes.

The rarity of such catastrophic failures belies their devastating potential, reinforcing the need for rigorous adherence to design specifications, regular inspections, and a proactive approach to identifying and addressing vulnerabilities in high-pressure urea synthesis equipment.

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