Catastrophic Failure of Ammonia Synthesis Loop Boiler Feedwater Heater

On October 11, 2006, the ammonia plant at Mosaic Fertilizer’s Faustina facility suffered a catastrophic failure of its synthesis loop boiler feedwater heater when the inlet channel suddenly and completely separated from the body of the heat exchanger. The failure destroyed the heat exchanger and caused significant collateral damage to piping and equipment in the synthesis loop area. This paper presents the findings from the investigation into the cause of the failure, the subsequent testing of other synthesis loop equipment following the sudden depressurization of the synthesis loop, and lessons learned from incident.

Eugene R. Britton, P.E.
Mosaic Fertilizer, LLC

Introduction

Mosaic Fertilizer, LLC operates an ammonia plant at its Faustina facility in St. James, Louisiana. The ammonia plant was built by M. W. Kellogg and commissioned in 1968, with a nameplate capacity of 1,000 STPD (907 MTPD). The ammonia plant has been modified in several stages to its current capacity of over 1,500 STPD (1,361 MTPD). The Faustina facility also manufactures ammoniated phosphate fertilizers, including DAP, GMAP, and Mosaic’s proprietary MicroEssentials® products.

Background

Synthesis Loop Configuration

The basic ammonia synthesis loop configuration is the same as the original M. W. Kellogg design. Synthesis gas is dried in the synthesis loop using condensed ammonia and the moisture is removed via the ammonia product stream. The ammonia converter is the “Slim Jim” design, with four catalyst beds and temperature control by synthesis gas quench (no internal heat exchanger).

Synthesis Loop History

The system was upgraded in the 1970’s by installing a parallel low temperature ammonia chiller (119-CX) and a parallel ammonia converter feed-effluent exchanger (121-CX). In 1988 the ammonia converter was retrofitted to an axial-radial flow configuration using Ammonia Casale technology. The ammonia converter feed-effluent exchanger (122-C) and synthesis loop boiler feedwater preheater (123-C) were replaced with upgraded heat exchangers in 1990.

A sketch of the synthesis loop is shown in Figure 1.
Incident Description

On October 11, 2006, the ammonia plant was operating normally. Production rates were approximately 1,475 STPD (1,338 MTPD) and the plant operations were stable. The plant had been online for 315 days with no known mechanical or operating problems.

At 8:13 p.m., operators heard an explosion and observed a large fire in the synthesis loop area. The explosion was reportedly heard by citizens living as far as 6 miles (10 km) from the plant.

The operators immediately initiated emergency shutdown procedures, isolating the synthesis loop, stopping the major process compressors and shutting off feedstock to the plant. All employees on duty during the incident were accounted for and there were no injuries.

After the plant was safely secured, a fire continued to burn for some time in the area of the synthesis loop boiler feedwater heater (123-C). A nitrogen purge was established on the synthesis loop to clear remaining flammable gases. Following the incident, off-site air monitoring was conducted and no ammonia was detected.

Following the incident the local government emergency preparedness department was notified, along with other notifications required by law. Soon after the incident local television stations displayed a banner update stating that an explosion had occurred at the Mosaic Faustina plant, and a local news crew was on site prior to the 10:00 p.m. news broadcast. The plant manager was interviewed during a live broadcast.

After the synthesis loop was depressured and the fire extinguished, the inlet channel of the 123-C was observed to be completely separated from the body of the heat exchanger. A drawing of the 123-C is shown in Figure 2.
Chapter 3 - Incident Investigation

Figure 2. 123-C drawing

The channel was suspended in mid-air, supported only by the piping connecting it to the ammonia converter feed-effluent exchanger (122-C) as shown in Figure 3.

Figure 3. 123-C inlet channel

Incident Investigation

On October 12, 2006, a multi-disciplined incident investigation team was established to determine the root cause of the 123-C failure. The team collected process data prior to and during the failure, equipment history and mechanical integrity documentation on the 123-C, and interviewed the operating staff that was on duty at the time of the incident.

The heat exchanger was installed in October 1990, 16 years prior to the failure. A review of plant operating history revealed that when plant downtime was considered the unit had been in service for 14.0 years.

The review of process data confirmed that operating conditions were normal prior to the incident. There were no significant changes in the operating temperature of the ammonia converter effluent stream or in the synthesis loop pressures prior to the incident. The process data indicated that the synthesis loop depressured very rapidly. The pressure at the synthesis compressor recycle decreased from 1,950 psig (13,400 kPa) to 70 psig (480 kPa) in one minute. The synthesis compressor discharge pressure decreased from 2,206 psig (15,210 kPa) to 350 psig (2,410 kPa) in 30 seconds, with the pressure slowly dropping after that time. Note: the compressor discharge pressure did not accurately reflect the synthesis loop system pressure after that time, due to its location upstream of the synthesis loop emergency isolation valve. A plot of these pressures is shown in Figure 4.
The incident investigation team commissioned a finite element analysis of the joint between the failed heat exchanger’s inlet tube sheet and channel. The analysis indicated that the 123-C design was suitable for design operating conditions.

A metallurgical analysis of the failed components was commissioned as well. This study indicated that the channel to tube sheet weld failed due to a circumferential crack that propagated through the thickness of the weld causing the weld to fracture. The study also found that the fracture was due to hydrogen induced cracking. A photo of the failure site on the inlet channel is shown in Figure 5.

Due to the operating temperature and hydrogen partial pressure expected in the gas stream entering the 123-C, the inlet channel and tube sheet material specification is ASTM A182, Grade F11 (1 ¼ Cr, ½ Mo). The normal operating region is shown on a Nelson Curve in Figure 6.
The analysis of the 123-C inlet channel and tube sheet indicated that channel was manufactured from ASTM A182, F11 material. However, the inlet tube sheet material analysis was consistent with a standard carbon steel grade.

Based on this finding, the incident investigation team determined that the cause of the heat exchanger failure was improper material of construction for the heat exchanger’s inlet tube sheet.

A review of fabrication documentation and inspection reports from the heat exchanger manufacturer, including material test reports and heat numbers, indicated that tube sheet was fabricated with ASTM A182, F11 material. However, at the time the heat exchanger was built, positive material identification was not routinely used to verify mill reports and other material sourcing data sheets.

**Damage Assessment and Repairs**

Several options to replace the damaged 123-C heat exchanger were evaluated. Two similar heat exchangers were available from other ammonia producers, one was a spare unit and one was from an idled facility. Both units were physically smaller and slightly different designs from the failed heat exchanger. A process and mechanical evaluation of these units was performed, and once one was determined suitable for our needs, negotiations began to purchase the heat exchanger.

While these commercial negotiations progressed, a full inspection (including positive material identification) was performed on the heat exchanger. A finite element analysis was also conducted on the new heat exchanger to ensure an appropriate design was used for the new piping connections. Replacement pipe and fit-
tings for the damaged synthesis loop piping was also sourced during this time.

The 123-C failure and subsequent explosion caused a substantial amount of collateral damage in the synthesis loop area and to nearby buildings. Transite roofing and siding were damaged in structures in the ammonia plant, and windows were damaged in buildings several hundred yards away. Due to the fact that the damaged transite contained asbestos, the damaged transite was removed by a licensed asbestos abatement contractor.

The 16 inch, Schedule 160 piping, which connected the 123-C to the ammonia converter feed-effluent exchanger (122-C), was severely distorted. A piping elbow on this line was bent almost 270° by the forces generated when the inlet channel of the heat exchanger separated from the body. This elbow is shown in Figure 7.

![Figure 7. Damaged piping](image)

Other piping in the ammonia converter area, including some of the quench lines supplying the converter, were damaged as well. A thorough inspection of all piping in the immediate area was conducted to determine which lines required replacement due to physical distortion or heat damage from the fire that followed the heat exchanger failure.

There was also concern that equipment in the synthesis loop may have suffered internal damage due to the rapid depressurization of the synthesis loop. Areas of particular concern were the ammonia converter feed-effluent exchangers (121-C, 121-CX, and 122-C) and the ammonia converter basket and internal components. These heat exchangers are designed for a relatively low pressure differential, and are normally protected by a rupture disk bypassing the 122-C inlet throttling valve. Another concern was that high gas velocities, which likely occurred during the event, could have damaged the ammonia converter basket or internal components.

The decision was made to pressure test the 121-C and 121-CX heat exchangers. Field testing showed there were several leaking tubes in the 121-C and 121-CX heat exchangers. These leaking tubes were later plugged.

Plans were also made to open the ammonia converter to determine if the catalyst must be removed for a thorough inspection. Initially the bottom plug on the ammonia converter was removed to establish if the catalyst bed screens had been damaged. No loose catalyst was found in the internal return piping, but the converter plug was found to be damaged.

The plug in the bottom of the ammonia converter is a thin steel shell containing Kaowool insulation material. There are small vent holes in the steel to relieve pressure created if gas seeps into the plug. When the synthesis loop rapidly depressured the plug’s shell failed (Figure 8).
Some of the Kaowool was carried up the internal riser pipe in the ammonia converter, lodging on the internal tube sheet of the 122-C. A distributor plate located inside the 122-C inlet channel was dislodged by the gas rushing through the system (Figure 9). Based on these findings, the decision was made to remove, inspect, and repair the 122-C heat exchanger.

Due to the design of the ammonia converter, removing the 122-C heat exchanger requires an internal entry to the catalyst basket under inert atmosphere. During this entry the internal expansion joints on the quench piping, which are located in the ammonia converter’s annular space, were inspected. No damage was found to these expansion joints.

The 122-C heat exchanger was safely removed from the ammonia converter. Shop inspection found no leaking tubes. Several cracks were discovered in the tube to tube sheet welds on the inlet end of the heat exchanger, which were repaired.

The damage to the ammonia converter internal components was less severe than feared. It was hypothesized that this lack of damage was partially due to the fact that the gas velocity was somewhat limited by the deformation in the outlet piping. The flow was further limited by the 122-C outlet flange heat shield, which was found lodged in the deformed elbow of the outlet piping (Figure 10). Also, due to the location of the failure, the flow through the converter was in the correct direction during the incident, so the problems that could occur with sudden reversal of flow were not a factor.

While the ammonia plant was shut down all alloy piping and equipment components were identified and catalogued. Positive material identification was performed on these systems. No irregularities were found during these inspections.

**Conclusion and Lessons Learned**

The replacement heat exchanger was installed, damaged piping replaced, and equipment
opened for inspection was closed with no safety incidents. The ammonia plant resumed production on January 13, 2007, ninety-three days after the failure.

The following are several lessons learned from this incident:

1. Positive material identification should be an integral component of the inspection protocol for new equipment. In this incident, all fabrication documentation indicated that proper materials were used for the heat exchanger components, but one error in the manufacturing / procurement process led to a serious incident.

2. Existing plant components should be systematically inspected using positive material identification to ensure proper materials were used during fabrication.

3. Emergency response plans should include public relations and legal response strategies. In this case, the plant manager had received crisis management training, and was prepared for the interview with local news reporters. Also, significant equipment failures and plant incidents may lead to regulatory intervention or litigation, which will require detailed record retention and technical/cost data collection.