Catastrophic Fire in Ammonia Plant Compressor Room

On September 29th, 2011, 4 hours after the start-up of the ammonia plant at GPN Grand-Quevilly, a hydrogen leak followed by a fire occurred on a 1 inch synthesis gas line on the discharge side of the synthesis gas compressor. The plant was tripped immediately, the plant personnel were evacuated to a safe location, and the fire was finally extinguished about 90 minutes later, after depressurization and nitrogen purging of the synthesis loop. The damages to the compressor room were considerable, but no one was injured and there was no release of toxic chemicals or pollutants outside the plant. The fire could be seen several miles away, and there was a large media impact locally. The root cause of the leakage was the failure of the yoke bushing on a 1 inch forged steel manual valve. The cost of the reconstruction was more than 16 million € ($20 million USD) including implementation of additional safety measures. The total length of the shutdown was 11 months. The mother company of GPN, TOTAL, has performed a complete safety review of the plant.

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Introduction

GPN is the leading French producer of Nitrogen fertilizers. On the site of Grand-Quevilly, near Rouen in the North West of France, GPN operates one ammonia plant with a nameplate capacity of 1000 MTPD, two nitric acid plants with a total capacity of 2500 MTPD (2760 STPD) HNO_3, one ammonium nitrate (AN) plant with a capacity of 1700 MTPD (1870 STPD), and one calcium ammonium nitrate (CAN) plant with a capacity of 1800 MTPD (1980 STPD). The site also produces N+S and N+P fertilizers. The site of Grand-Quevilly is the largest fertilizer facility in France.

The Ammonia plant, known as "AM2", was started in 1978. It was engineered by HEURTEY, using Grande-Paroisse processes for reforming and ammonia synthesis and Giammarco-Vetrocoke process for CO_2 removal. The synthesis converter was revamped by Ammonia Casale in 1993, and the maximum demonstrated capacity was gradually increased up to 1170 MTPD (1290 STPD). The process is a conventional process, based on natural gas steam reforming, secondary reforming with air, shift conversion, CO_2 removal by activated potassium carbonate, methanation, medium pressure synthesis (20 MPag, or 2900 psig), and purge gas hydrogen recovery by pressure swing adsorption (PSA). The last turnaround was performed in 2008, and the next one is due in 2014.

The Incident

On Wednesday, September 28, 2011, the ammonia plant start-up was in progress after 10 days of cold shut-down for maintenance work. The synthesis gas compressor was started at 5:30 p.m., and the electrical start-up heater was activated at 7:00 p.m. Liquid ammonia product export to the storage spheres started at 4:30 a.m., the morning of September 29.

At 6:00 a.m., the morning shift operator and the shift supervisor did their routine synthesis gas compressor check. Nothing abnormal was observed.

At 8:30 a.m., the production rate was stable at 865 MTPD (954 STPD) and the team was preparing the start-up of the purge gas treatment unit. The plant was in steady state operation, and all process parameters of the ammonia synthesis section were normal.

At 8:33 a.m., three fire detectors located in the compressor room alarmed simultaneously. The alarm is reported both in the control room and in the site fire station. On the video monitor in the control room, the flames could be clearly seen, thus confirming the fire alarm (Figure 1). As far as it could be seen, the fire was located on the discharge side of the compressor.

At 8:34 a.m., the synthesis section emergency shut-down was activated manually from the control room. At the same time, the site fire brigade left the fire station.

At 8:43 a.m., as the fire was developing, the operators realized that there was a risk of extension of the fire. The plant was tripped completely and the natural gas cut-off valve was isolated. The control room operators started to depressurize the process gas through the vents.

Around 8:45 a.m., the emergency management team was set up in the administration building. On site, the firemen identified a very noisy, high pressure gas leak, located on the discharge side of the compressor, along the wall of the building. The firefighting strategy consisted of establishing water curtains to protect the machine and the piping inside the building in order to limit the extent of the fire. The civil fire service was called to support the site firemen.

At 8:57 a.m., the roof of the building, partly consisting of transparent polycarbonate plates, began to burn producing a heavy, black smoke. The smoke could be seen several kilometers away. The fire then propagated to the process gas vents located nearby.

Figure 1. The roof of the building on fire

At 9:00 a.m., the west wall of the compressor room, made of concrete blocks, collapsed, and the gas fire, which up to now was contained inside the building, escaped outside, threatening the main pipe rack. All the plant personnel, with the exception of the firefighting team, were evacuated and sheltered inside the blast-proof control room building.

At 9:06 a.m., the civil fire brigade arrived on site and up to 70 firemen were prepared to support and replace the site firemen, if necessary.

At 9:17 a.m., the site firemen established fire hoses outside the building to protect the main pipe rack.

At 9:24 a.m., the synthesis loop residual pressure was less than 1 MPag (150 psig). At this point a 2 MPag (300 psig) nitrogen hose was connected to the loop in order to inject inert gas.

At 9:55 a.m. (1 hour and 22 minutes after the incident start) the fire was totally extinguished. The action of the civil fire brigade was no longer required.

The Damage

The following is a description of the damage to the plant equipment and property:

Damage to the Building

- The wall in front of the compressor collapsed from top to bottom.
- The steel structure of the building was damaged and thermally affected.
- The roof plates above the compressor were damaged and partially burnt.
- The outside wall covering in Eternit was destroyed and broken into small pieces, which were sprayed all over. Because this material contains asbestos, all the debris had to be cleaned up before the investigation and repair work could be started, causing about three weeks of delay.

Damage to the Syngas Compressor

- The instrument and lubrication lines were damaged by the fire and the debris.
- The control cabinet was totally burnt.
- The floor grating was distorted.

Damage to the Piping and Valves

- The main compressor discharge line was apparently intact, only the small bore piping was damaged. Two small process lines were broken (see Figure 2).
- The piping in the main pipe rack was impacted by the fire but had not failed (except for small steam tracing and instrument air lines).

Figure 2. View of the west wall of the building in front of the compressor showing the origin of the fire

Damage to the Instrumentation

- Inside the building in the compressor area, control valves with their actuators were damaged or destroyed, and transmitters and their connecting cables were destroyed.
- Inside the building in the compressor area and in the main pipe rack in front of the building, cable trays were impacted by fire and partly destroyed.

Origin of the Fire

The origin of the fire was quickly identified. It was a 20 MPag (2900 psig) high pressure synthesis gas leak on the 1 inch by-pass line of the synthesis compressor discharge valve, as shown in Figure 3. This line was completely bent, as can be seen in Figures 2 (above) and Figure 4, and ruptured just downstream of a manual block valve (154UH102). The 1 inch manual valve itself was severely damaged as well.

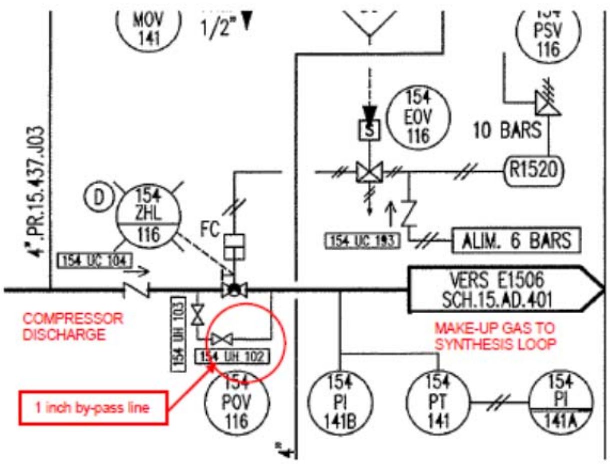

Figure 3. Section of P&ID showing location of the failed valve and its purpose

Another ¾ inch instrument line located above (154PI141B) was also ruptured. The investigation concluded that this was a consequence of the main failure.

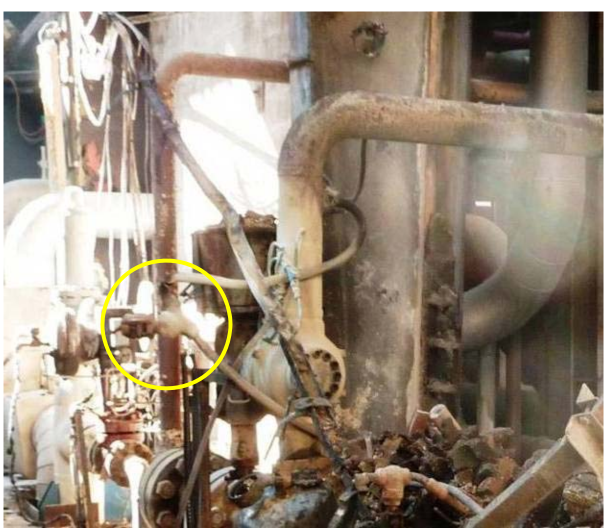

Figure 4. Main compressor discharge valve with ruptured 1 inch by-pass line

Root Cause Analysis of the Incident

Investigation

An internal investigation was conducted during the week after the incident by a team of 9 experts from GPN and from TOTAL (GPN is a subsidiary of TOTAL). External expertise in the areas of fire and metallurgy were also utilized. The following details what the investigation entailed:

- Several visits to site were conducted, and more than 200 pictures were taken and analyzed.
- Interviews of firemen, plant operators, maintenance engineers and members of the crisis management team were conducted.
- All plant operating data for the day before the incident, including process and machinery parameters, alarm log sheets and plant log book were collected and analyzed.
- Maintenance records and material inspection reports were searched and analyzed.
- Piping elements and valves were collected and examined thoroughly, including metallurgical analysis.

Immediate Cause

The immediate cause of the incident appears to be a hydrogen-rich gas leakage on a 1 inch ASME class 2700 lb, welded bonnet, forged steel valve (Figure 5) located on the by-pass line of the synthesis gas compressor main discharge valve. This manual valve is operated during each plant start-up in order to pressurize the synthesis loop.

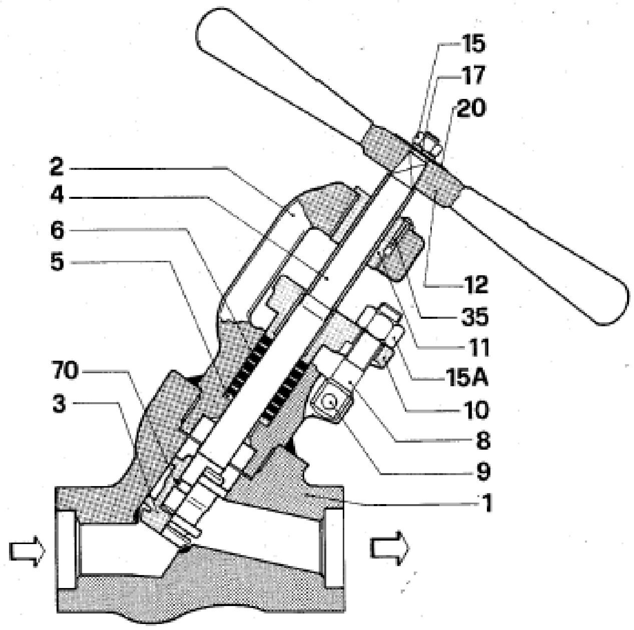

Figure 5. 1 inch welded bonnet forged steel valve, ASME class 2700 lbs

The valve was last visually inspected by the site Material Inspection Department in July 2011 (together with the main process gas line). It had been operated a couple of hours before the incident occurred. At that time no leakage or apparent defect had been noticed, except that the operators reported that the valve was unusually hard to operate.

Sequence of Events

The scenario of the incident can be described as follows:

1. Appearance of gas leakage on the packing.
2. Ignition of the gas, the jet fire impinges on the 1 inch pipe downstream the valve.
3. Pipe material overheats.
4. Creep failure of 1 inch pipe.
5. The gas leakage and fire intensity increases considerably.
6. Immediate rupture of nearby ¾ inch pipe.
7. 1 inch pipe bends, with a jet fire directed towards the wall.
8. Building steel structure overheats.
9. Wall collapses.
10. The fire escapes outside the building towards the main pipe rack.

Root Cause

The examination of the 1 inch valve revealed the following (see Figure 5 for reference):

- The valve had no mechanical defect.
- The graphite packing was still present and in relatively good condition.
- No component was damaged or distorted except for the stem (but this distortion was due to the valve hitting the main piping after the 1 inch pipe ruptured).
- The yoke bushing (#11) and its grooved rivet (#35) were missing.
- The thread in the bonnet was still intact, which means that the bushing was screwed off and not pushed out.

The investigation concluded the only possible failure mechanism was as follows:

1. Grooved rivet (#35) was missing.
2. Nearly complete unscrewing of the yoke bushing (#11) during operation of the valve.
3. Rupture of the last thread as a consequence of the internal pressure rise during the normal start-up process.
4. Vibration of the stem (#4) and loss of tightness of the packing.
5. Gas leakage and ignition.

This valve was installed in 1989, and was in service for 22 years, but was only manipulated once every plant start-up. What is not known is whether the rivet had ever been present (inadequate fabrication and quality control) or if the rivet had been removed in the past during valve maintenance and not reinstalled (incorrect maintenance). Even if the rivet was not present, a large number of manipulations are necessary to obtain the complete unscrewing of the bushing, which could explain why the failure did not happen before. Only a careful examination of the valve by a specialist could reveal that this very small part was missing.

Rebuilding the Plant

Identification of Damaged Equipment

The identification of the damaged equipment has been done according to API 579-I / ASME FFS-1 2007 Fitness for Service Part 11. Based on visual inspection, cartography of the temperatures has been performed and 6 areas have been identified. These areas have been classified on the temperature that the equipment had been exposed. For each area, the nature of the controls to be done was defined, depending on the material and the design temperature of each piece of equipment.

Figures 6 and 7 below show the isothermal curves inside the building according to API 579-I.

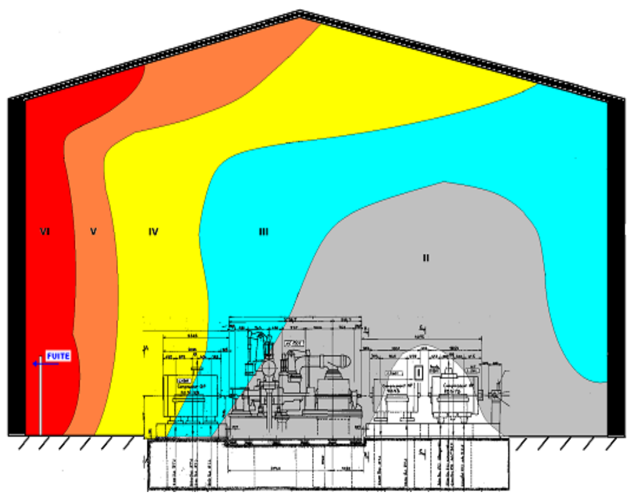

Figure 6. Isothermal curves (side view)

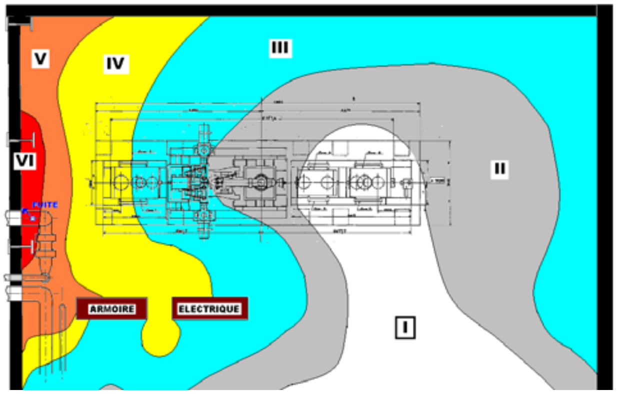

Figure 7. Isothermal curves (top view)

Legend (applies to both figures):

I: ambiant
II: < 80 °C
III: 80 °C - 200 °C
IV: 200 °C - 430 °C
V: 430 °C - 700 °C
VI: > 700 °C

In order to save time, it was decided to proactively replace all carbon steel piping and steel structures exposed to temperatures above 430 °C (areas V and VI) without further inspection.

Repair Work

It took nearly two months, from the beginning of October to the end of November 2011, to prepare for the required repairs. This preparation involved making the plant completely safe, removing all debris and all traces of asbestos containing material, completing the investigations and controls, organizing the work, and placing the orders for the parts to be replaced.

The reconstruction work started on November 28, 2011, and employed up to 250 people. It was completed on May 10, 2012.

The major activities in the reconstruction work were as follows:

- One third of the compressor room building, from the floor to the roof, was dismantled and rebuilt, including replacement of the steel frame. During the construction work, a temporary structure was installed to hold the rest of the building together and protect the equipment from the weather.
- A complete overhaul of the synthesis gas and the refrigeration compressors, including auxiliaries, was performed. The low pressure case of the syngas compressor, which was exposed to temperatures between 200 °C and 430 °C, was dismantled and completely inspected. It showed no internal damage, and only the bearings and the gas seals required replacement.

- All electrical, instrumentation cables, and cable trays from the control room building to the compressor room were replaced. In total 40 km (25 miles) of cable was installed.
- All the synthesis gas compressor instrumentation, including sensors, control cabinets and turbine governor were replaced. A total of 210 sensors were replaced.
- The damaged piping and valves were replaced or repaired depending on the results of the inspections. A total of 150 m (500 feet) of piping (up to 40 mm, or 1.6 in thick) was replaced.

The total cost of the reconstruction and repair was 5.3 million € ($6.9 million USD). Of this total, 3 million € ($3.9 million USD) was paid by the insurance company. Figure 6 shows the reconstructed compressor building.

Figure 8. View of the compressor room after reconstruction

Preventative Safety Measures

Inspection of Flammable Gas Lines

The analysis of the incident has shown that the root cause of the fire was the failure of a 1 inch manual valve on a flammable gas line. Because of its small size (< 2 inches), this valve and the connecting piping were not part of a routine inspection program; only the main process line (6 inch or greater) was inspected on a regular basis. The first decision taken was to include all flammable gas lines, regardless of size and operating pressure, in the plant inspection program. In addition, it was decided to perform a complete inspection of these lines before start-up. A total of 183 lines with a diameter < 2 inches are now controlled as part of this program.

Inspection of Manual Valves

A complete visual inspection of all manual valves on flammable gas lines was also performed. This inspection was conducted together with a valve specialist, a pressure vessel inspector, and a plant operator. A total of 1290 manual valves have been inspected as part of this program. The items reviewed in this program include the following:

- mechanical integrity,
- external corrosion,
- condition of packing, and
- operability.

Every valve has now been identified with a tag number, and a report sheet has been completed for each valve. During the initial inspection, no other manual valve was found with a rivet missing or bushing partly unscrewed. The inspection was, however, quite valuable as 187 valves were repaired and 69 valves (mainly < 2 inches) showed various non-conformities and were replaced.

Furthermore, a check-list of all valves mentioned in the plant operating manual has been built. After each plant shut-down, every valve on this list is now checked systematically for mechanical integrity.

Leak Detection Systems

Because a flammable gas leak cannot be totally excluded, it is important that it is detected as soon as possible when it occurs. After extended technical exchanges with the other companies of TOTAL and several other members of Fertilizer Europe, the following actions have been accepted and implemented:

- Nitrogen commissioning of the plant - after each major plant shutdown, a pressure test is performed with 2 MPag (300 psig) nitrogen on the front end, and 10 MPag (1500 psig) nitrogen on the synthesis loop. All valves on flammable gas lines are tested for leakage using a bubble-test.
- Leak testing with portable gas detectors - after each plant start-up, each manual valve which has been operated during the start-up (those listed in the operating manual) is tested for leakage with a portable gas detector. A check-list is used to ensure no valve is missed.
- Leak detection with fixed gas sensors in the compressor room - the existing 3 gas sensors have been complimented by 6 additional gas sensors, with automatic synthesis compressor shut-down (2 out of 3 voting).
- High pressure flanges leak detection - each high pressure flange on the synthesis gas compressor and on the synthesis loop has been fitted with a leak detection system consisting of a closed box, with a vinyl hose connected to a bubbling bottle. Operators can immediately identify a leak during their rounds. A total of 509 flanges have been equipped with such a system (See Figure 7).

Figure 7. Example of leak detection system on high pressure flanges (each individual vinyl hose is connected to a flange, and identified with a metal tag. The tag number is referenced on the plant drawings).

Safety Survey

Objectives

Independent of the preventive and restorative measures listed above, TOTAL mandated a comprehensive safety review of the plant. The study was conducted by a team of 27 experts, both internal and external, divided in 4 working groups referred to as Task Forces 1, 2, 3 and 4.

No major breach or violation of the internal rules or good industrial practice was identified that would have prevented a safe restart of the plant. Even so, 259 recommendations were made, including 57 to be completed before start-up. Some of these recommendations are listed below:

Mechanical Integrity

The objective of the Task Force 1 (TF1) was to verify that the material condition of the plant, including pressure vessels, piping, electricity and instrumentation, rotating equipment and structures were in good condition and would allow a safe restart and operation. TF1 made 69 recommendations, including 23 to be completed before start-up. The recommendations were mainly concerning the following:

- Non-conformities to the engineering standards and specifications of the plant.
- Refurbishment of some piping and valves, including steam tracing and insulation.
- Replacement of 50% of the refractory of the primary reforming furnace.
- Anticipation of corrective actions following periodic inspection of pressure equipment.

Operability

The objective of Task Force 2 (TF2) was to evaluate the quality of the organization, particularly the ability of the plant personnel to operate the plant safely. TF2 made 31 recommendations including two that had to be completed before start-up. The two that had to be completed prior to start-up concerned small improvements to the management of change process.

Process Safety

The objective of Task Force 3 (TF3) was to evaluate the quality of the safety study and the suitability of the risk management devices. TF3 made 53 recommendations including 19 to be completed before start-up. The recommendations were mainly concerning the following:

- Evaluation of additional incident scenarios.
- Verification of the efficiency of some preventative and mitigative safeguards.

Fire suppression equipment in the compressor building was not considered, for the following reasons:

- Extinguishing a gas fire without stopping the gas leak would lead to the formation of a flammable gas cloud and potential explosion, which can be more destructive than the original fire.
- Fire protection of the equipment in the compressor room (e.g., by sprinklers or foam deluge) was considered inefficient because of the size of the building.

Conformity

The objective of Task Force 4 (TF4) was to check the conformity with the applicable legislation and operating permits. TF4 has made 95 recommendations including 13 to be completed before start-up. Most of these recommendations concerned the anticipation of actions already planned.

Conclusion

All the work associated with the reconstruction and repair of the equipment impacted by the fire, the corrective and preventive safety measures, and the actions following the safety survey were completed by the end of April 2012. The internal start-up permit was signed on May 4, 2012, and the final start-up, authorized by the authorities was delivered on June 8, 2012. The commissioning of the plant, which was started on April 10th, was completed by end of May, including nitrogen leak testing of all the process lines.

During the start-up of the plant the HP steam superheater failed, causing additional down-time for repair. Ammonia was first produced on August 10, 2012, but continuous stable operation was only achieved on September 7, 2012. The total cost was 16.7 million € ($21.7 million USD), including 11.4 million € ($14.8 million USD) for the implementation of all safety measures. The cost does not include 11 months production loss.