Case histories of

ATMOSPHERIC CORROSION

Case 1: Flixborough disaster

NTT Consultancy
Giel Notten
Senior Corrosion Engineer

Introduction

The Flixborough disaster was an explosion at a chemical plant in the village of Flixborough near to Scunthorpe, North Lincolnshire, England. The disaster happened on 1 June 1974. It killed 28 people and seriously injured 36.

The chemical plant was in operation since 1967. The plant produced caprolactam, a feed stock for the manufacture of nylon.

The process involved oxidation of cyclohexane with air in a series of six reactors to produce a mixture of cyclohexane and cyclohexanone. Some 8 weeks before the explosion a crack was observed in the number 5 reactor. It was decided to install a temporary 50 cm (20 inch) diameter pipeline to bypass the leaking reactor to allow continued operation of the plant while a new reactor was manufactured.

Although not directly related to urea processes, this case is an example of the same risks atmospheric corrosion can introduce in a urea plant

Description of the disaster

On Saturday June 1, 1974, the temporary bypass pipe, containing cyclohexane at 150 °C and 1 MPa (10 bar) ruptured. Within a minute about 40 tonnes of cyclohexane leaked from the pipe and formed a vapour cloud 100 – 200 meters in diameter. The cloud, on coming in contact with an ignition source

(most probably a furnace at a nearby hydrogen plant) exploded, completely destroying the plant. Around 1800 buildings within a mile radius of the site were damaged.
The fuel-air explosion was estimated to be equivalent to 15 tonnes fof TNT and it killed all 18 employees in the control room. Ten other site workers were killed as well.
Substantial destruction of property was recorded in Flixborough itself as well as in the neighboring villages. Significant structural damage affected Scunthorpe (some 12 kilometers away).

Cause of disaster (2 theories)

About the cause of the disaster there are two main theories.
One theory explains that there was first a leakage in a 8 inch pipeline causing a fire and a small explosion. Due to this small explosion the 20 inch pipeline was blown out causing the big leak followed by the big explosion.
Note: In the 8 inch line a 3 inch crack was found with Liquid Metal Embrittlement indications.
However the official inquiry into the accident determined that the bypass had failed due to unforeseen lateral stresses in the pipe during a pressure surge. The pipeline had been designed by engineers who were not experienced in high-pressure pipe work, no plans or calculations had been produced.

The officially accepted cause of the disaster is the mechanical failure of the "dog leg" 20 inch by-pass as shown in figure 1 and figure 2.

The "dog leg" by-pass consisted of three lengths of 20 inch pipes with flanges at each. The by-pass pipe was of smaller diameter (20 inch) than the reactor flanges (24 inch) and in order to align the flanges short sections of pipes with stainless steel bellows were added at each end of the by-pass. Under pressure these bellows tend to squirm or twist. It was not appreciated that the pressurized assembly would be subject to a turning moment imposing lateral (shear) forces on the bellows for which they are not designed. The assembly as constructed was of unknown strength and did not comply with the British Standard.

Figure 1 and figure 2 also show the position of an 8 inch pipe connecting two separator vessels.

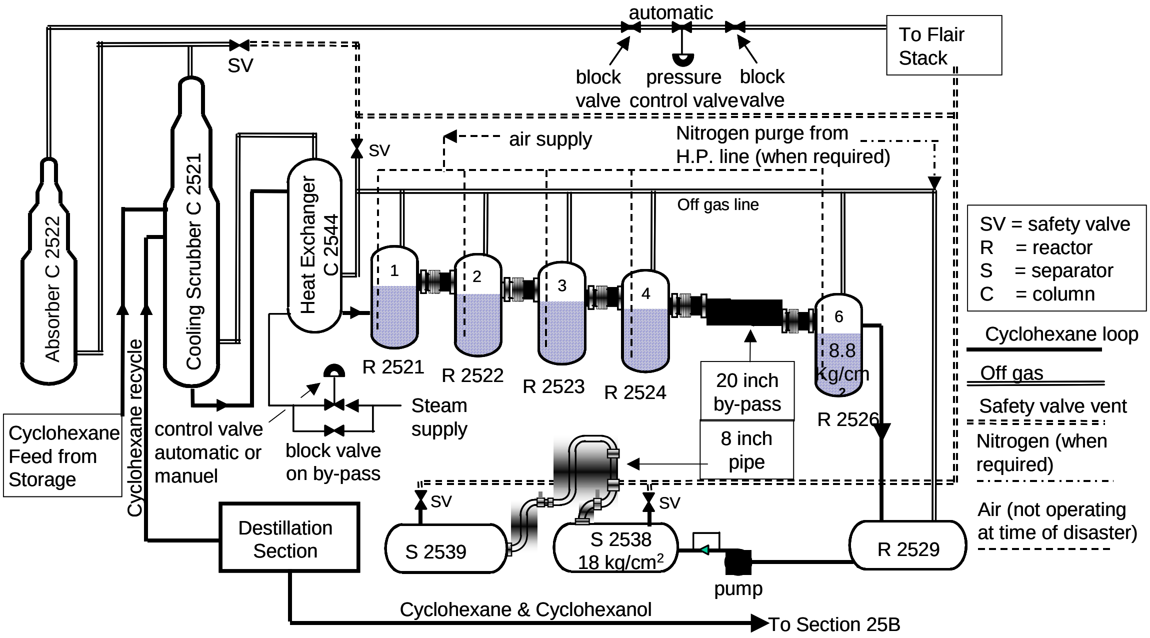


Figure 1: Simplified flow diagram of cyclohexane oxidation section

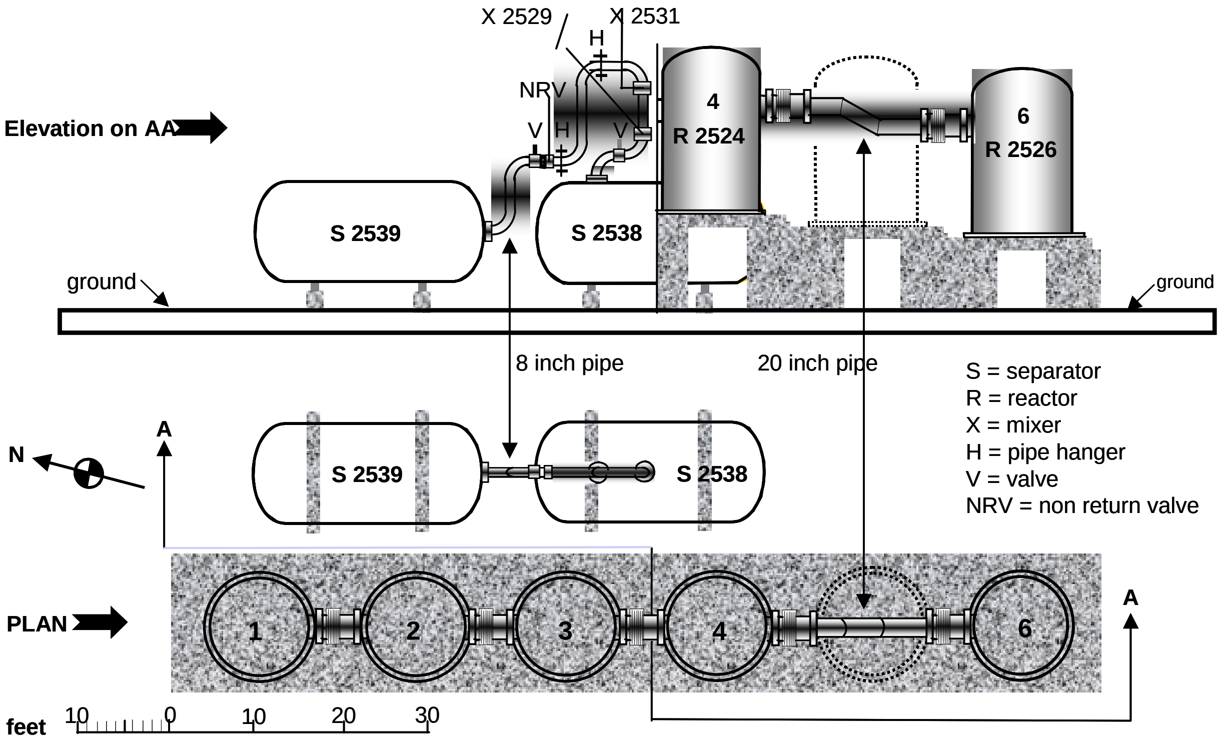


Figure 2: Simplified plan & elevation of the oxidation section

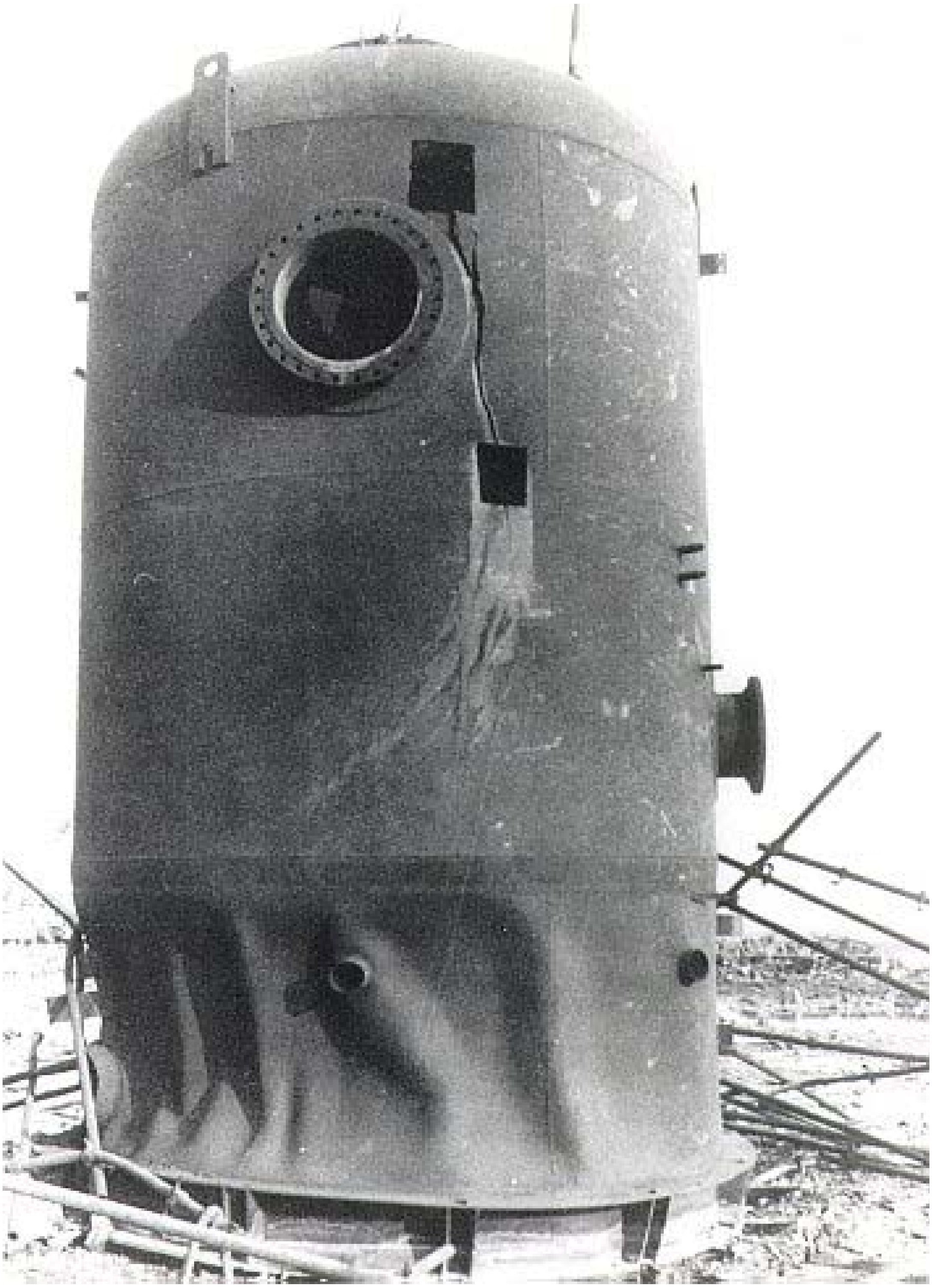
Indirect cause of the disaster

The indirect cause of the disaster is the leakage of the no. 5 reactor. After removal of the no 5 reactor the 20 inch bypass line was installed.
The investigation to the cause of the leakage in the no. 5 reactor is described in the next chapter.

Failure of Reactor No. 5

The reactor is constructed out of $^1/_2$ inch carbon steel internally clad with a $^1/_8$ inch Stainless Steel AISI 316L layer.
Due to a small cyclohexane leakage via the transition of the Mitchel agitator on top of the reactor there was a risk of explosion. To eliminate the risk of explosion it was decided to install a spray nozzle above the reactor. The water used for spraying was cooling water which was treated with nitric acid to maintain the pH level at the desired level.
About six months after installing the spray nozzle on the No. 5 reactor a leakage was observed due to cracking as shown in photo 1.

Photo 1: Nitrate SCC in carbon steel reactor due to ingress of cooling water used for sprinkling.



For investigation to the cause of cracking some samples were cut out of the reactor wall. These samples with branched cracking are shown in photos 2 and 3.

Microscopic examination indicated that the cracking in the carbon steel was caused by nitrate stress corrosion cracking.

Photo 2: External nitrate SCC in carbon steel reactor.

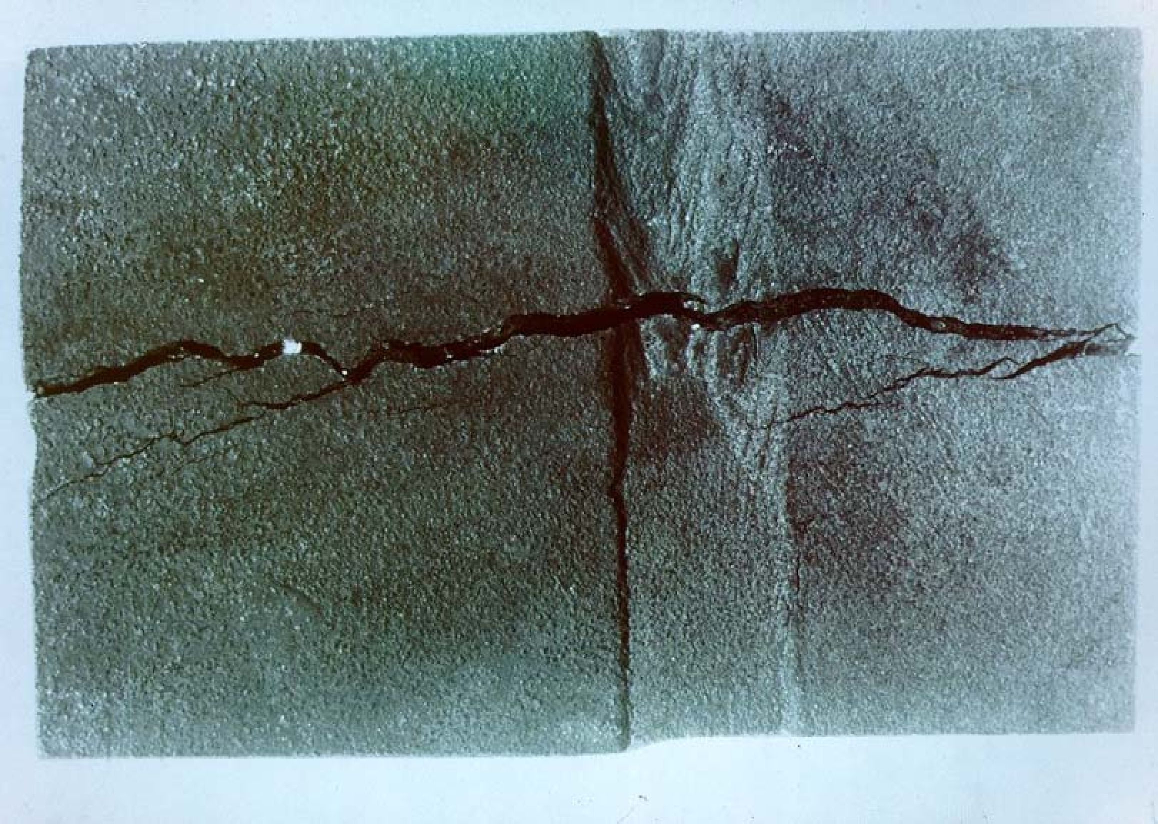
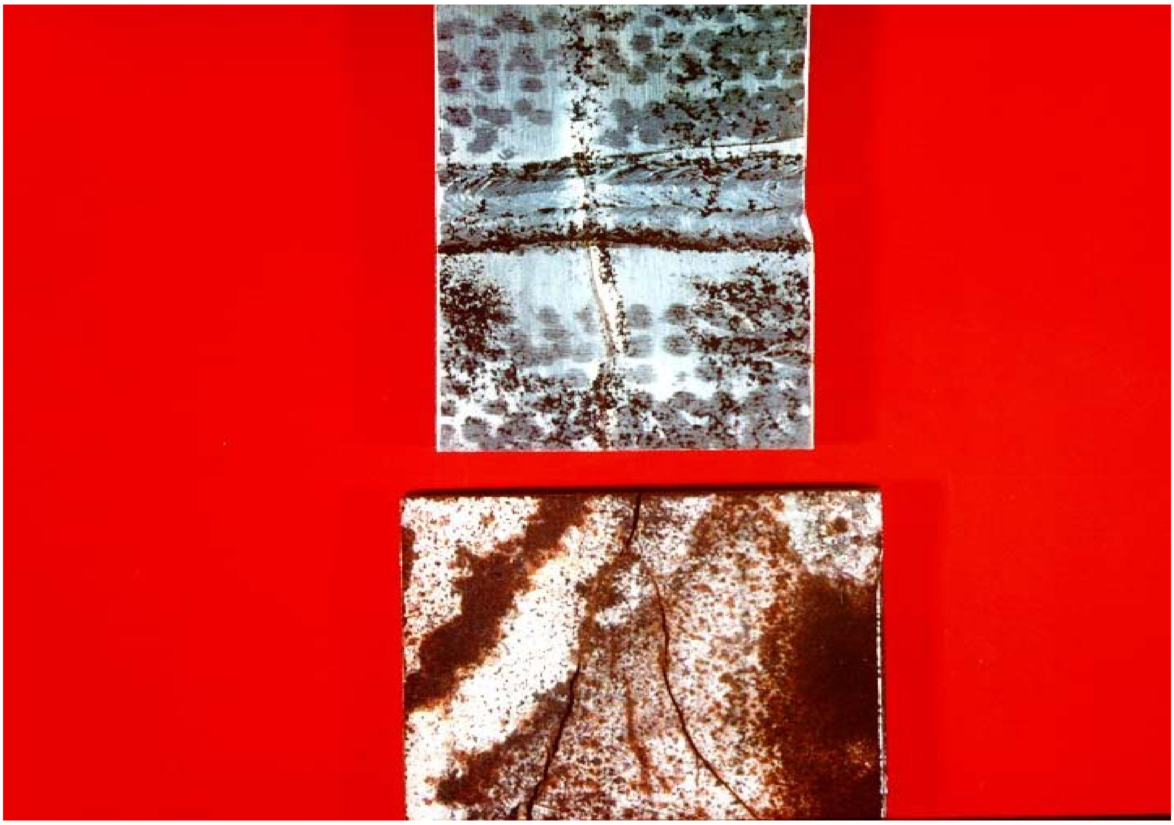


Photo 3: External SCC in carbon steel reactor; internally stainless steel clad.



Liquid Metal Embrittlement

In a lot of stainless steel piping cracking was observed which was due to liquid zinc embrittlement. This cracking did occur during the fire after the explosion. The molten zinc from e.g. zinc coated floor grating caused immediate cracking of stainless steel at temperatures above 750 ^{o}C.

Learning points

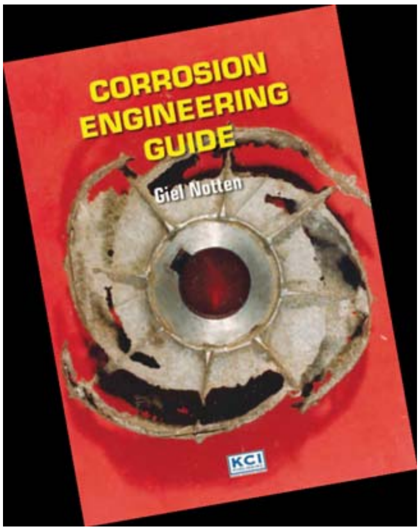
- A safety measure by installing a sprinkler installation to eliminate the risk of explosion can introduce another unsafe situation resulting in catastrophic explosion.
- Wetting of insulated carbon steel equipment by nitrate containing water may cause stress corrosion cracking.
- Liquid zinc can cause immediate cracking of stainless steel at elevated temperatures (e.g. during a fire).

Recommendations

- Avoid additional wetting of insulated equipment by water which is contaminated with nitrate
- Take care of a watertight insulation cover sheeting
- Apply a protective coating system if there is a risk of atmospheric corrosion
- Be aware of the risk of liquid zinc embrittlement at elevated temperatures (e.g. during a fire).

Literature

The Flixborough disaster, Report of the Court of Inquiry (Department of Employment)
ISBN 011 361075 0



Giel has written the Corrosion Engineering Guide, a valuable asset for any engineer working in a urea plant.

This guide is available via:
http://www.stainless-steel-world. com/
Please find the Table of Content of this Corrosion Engineering Guide herebelow.

About Giel Notten

Giel is a true materials and corrosion expert who, before his retirement in 2004, spent thirtyeight years working with DSM in The Netherlands. After gaining his Engineering degree at the Higher Technical School of Heerlen, The Netherlands, he joined DSM's central laboratory.
He was to remain with the company for the rest of his career and held several positions as a materials and corrosion expert there. For the last twenty years before he retired, Giel worked in the Corrosion Department as Managing Senior Corrosion Engineer. He has further participated in numerous conferences spreading the word about his broad experiences as a corrosion and materials specialist in chemical process plants.
For Stamicarbon, a subsidiary company of DSM, and licensing DSM's know-how, he set up programmes for lifetime extension studies in urea and ammonia plants and supervised them.
He was also involved in the development of Safurex®, the super-duplex stainless steel grade (developed by Sandvik in cooperation with Stamicarbon) for application in Stamicarbon urea plants.
Giel has always enjoyed teaching so, after only five years working in the field at DSM, he already began to develop a Corrosion Engineering course. Since then he has taught many young engineers from both inside and outside DSM about the ins and outs of corrosion control in chemical plants. He was also a board member of NACE Benelux and a member of the Contact Group Corrosion of the Dutch Chemical Process Industry and the Studiekern Corrosion of the Dutch Corrosion Society (NCC).
Since his retirement from DSM, Giel Notten has remained active as a corrosion engineering consultant. He has devoted much of his time to passing on his extensive knowledge and experience on the complicated topic of corrosion engineering to a new generation of engineers.
He has done this in the form of numerous corrosion courses and workshops.
Alongside his professional career, Giel has been very active in local societies and has been a Rabobank board member for about thirty-five years, twenty-five years of which as Chairman of the Board. Furthermore, he is an active cyclist. Together with his wife, Lianne, he has made trips up to 2500 km by bicycle to Santiago de Compostela, Spain and Rome, Italy.

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