

# The Various Corrosion phenomena in High Pressure Piping of Urea Plants

NTT Consultancy  
Giel Notten  
Senior Corrosion Engineer

## **Content:**

1. Introduction
2. Process side

Our next paper will describe

3. Atmospheric corrosion / Corrosion Under Insulation
4. Measures to increase the reliability and integrity of High Pressure Pipe Line systems
5. Conclusions

## **Summary**

High Pressure piping is often an area which receives less attention during the lifetime of a urea plant; there is no logical reason for this. Paying not enough attention or wrong inspection/repair procedures can lead to catastrophic incidents. This paper will provide an overview of the various corrosion phenomena occurring in High Pressure Piping systems in urea plants. It will elaborate the corrosion phenomena from the inside (process side) as well as the outside (atmospheric corrosion / corrosion under insulation). Many incidents have illustrated the risks involved and have shown the importance to pay sufficient attention to this part of the urea plant.

## 1. Introduction

Corrosion phenomena of High Pressure Piping can be both from the process side as well as from the outside. Both are important and can be risk to assure the integrity of High Pressure Pipe Line system in urea plants.

## 2. Process side

Urea is formed in a modern urea plants according to the following two-step reaction scheme:

Formation of ammonium carbamate:



Dehydration of ammonium carbamate to urea:



It is ammonium carbamate which is the corrosive component in the urea plants especially at higher pressures and higher temperatures.

In urea plants typically austenitic stainless steels such as 316L Urea Grade or 25-22-2 are applied as the material of construction for High Pressure Piping systems; these materials can experience corrosion in the presence of ammonium carbamate. Two principle types of corrosion need to be distinguished: 1) passive corrosion and 2) active corrosion.

Passive corrosion is taking place always and anywhere when carbamate is in contact with stainless steels in the presence of oxygen; it is in fact the formation of a passive chromium oxide layer on the surface which protects the stainless steel. As the oxide layer dissolved in the solution, continuously new oxygen need to be added to rebuild the passive layer and thus continuously a certain overall corrosion rate is taking place, typically between 0.02 and 0.1 mm/year depending on the temperatures, carbamate concentration, oxygen content etc. This passive corrosion does not form a threat to the integrity of the equipment and materials as this kind of corrosion is incorporated in the design. Maybe only in older urea plants (>20 years) regular inspections need to confirm sufficient margins are available to assure the integrity of the applied materials.

More dramatic is the situation when for example the oxygen is not present anymore or when temperatures are too high. In that case the oxygen layer cannot be assured anymore and active corrosion starts with significant higher rates such as 30 to 60 mm/year. No design margins are available for active corrosion phenomena and specific attention need to be paid during the design, construction and operation of any urea plants to avoid active corrosion.

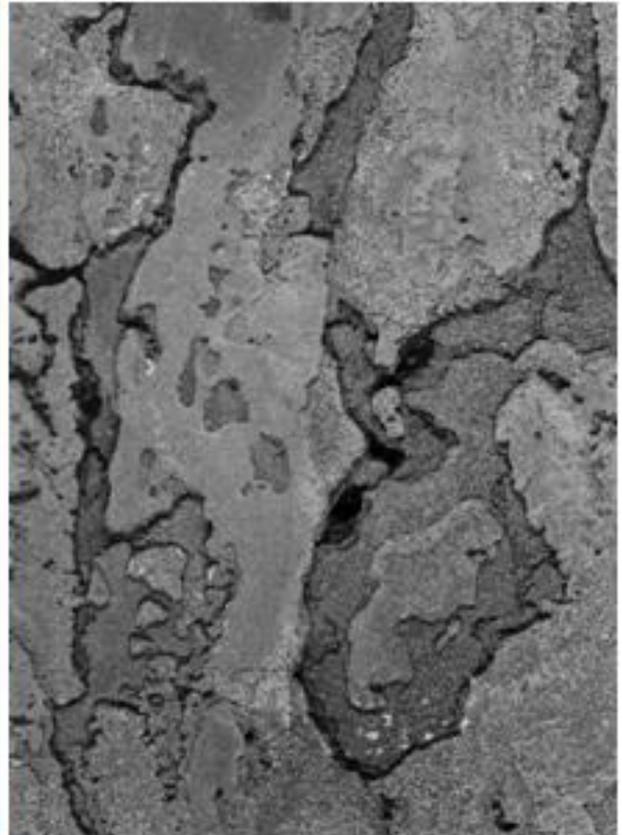


The pictures above show examples of passive and active corrosion in a urea plant. Passive corrosion (left) one can recognise by blue/reddish/brown colours indicating the oxygen layer. Active corrosion (right) however gives a shiny surface which is many times locally present, sometimes even with locally a significant reduction of the wall thickness.

In the High Pressure Pipe lines of a urea plant active corrosion is in most of the cases caused because not enough oxygen is present to assure a passive layer.



For example between a flange connection a crevice can exist when the two flanges are not connected in a correct way as shown in the figures above. In this crevice the carbamate solution is stagnant. Oxygen in the carbamate solution is slowly consumed because of the passive corrosion, after a certain period active corrosion will start leading to a leak and damage of the flange face.

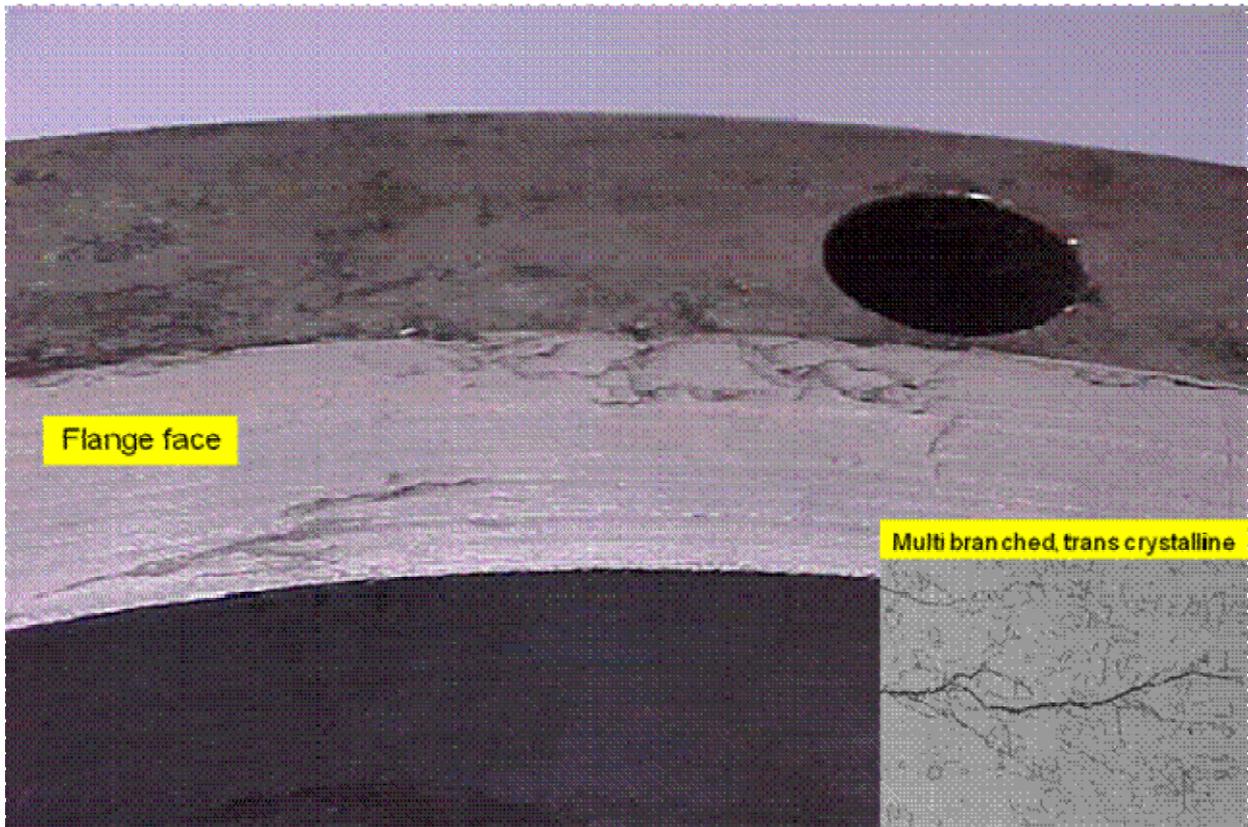


The pictures above show another corrosion phenomena, which occurs easily in gas phase High Pressure pipelines of urea plants is condensation corrosion. Carbamate containing gas condenses against cold spots and the liquid carbamate does not contain any oxygen so active corrosion readily starts.

It is good practice to trace and carefully insulate gas phase High Pressure lines to maintain a temperature higher than 153 °C, which is the maximum condensation temperature of carbamate. However damaged insulation or wrong design details can cause cold spots leading to condensation corrosion as is shown in the pictures below.



Further with austenitic stainless steels one has to pay proper attention to chlorides as these can cause chloride stress corrosion cracking. Using glue or paint containing chlorides can cause already trans-crystalline cracks as in the flange face indicated in the picture below.



In the urea High Pressure synthesis section at several areas the pressure drops and velocities are high causing erosion corrosion as a passive layer cannot be maintained under these circumstances.



Sensitive areas are valve bodies, stems and bends when not designed in a proper manner (refer to the pictures above).

Finally dead points or other areas where stagnant flow can occur are points of attention as in these stagnant flow zones the refreshment of oxygen cannot be guaranteed leading again to a risk for active corrosion. The Pictures below show two examples of this type of corrosion.



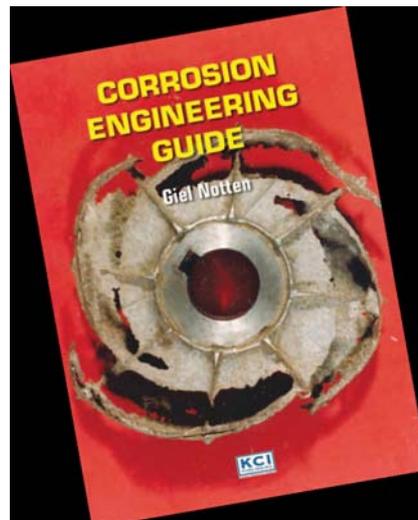
The reported case during the Ammonia Safety Conference 2009 of Yara Canada of corroded drain line is also an example of this type of corrosion. A similar incident occurred last year in a Chinese urea plant and likely many other cases did occur but have not been reported.

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 thirty-eight 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<sup>®</sup>, 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.



## Table of Contents

### Corrosion Engineering Guide

#### 1 Introduction

- 1.1 Importance of corrosion prevention and control
- 1.2 Improved equipment reliability by means of equipment condition monitoring

#### 2 Electrochemistry

- 2.1 Introduction
- 2.2 Thermodynamics
- 2.3 Electrode kinetics
- 2.4 Application of electrochemical corrosion theory on corrosion reactions

#### 3 Forms of Corrosion

- 3.1 Introduction
- 3.2 Electrochemical
  - 3.2.1 Uniform corrosion
  - 3.2.2 Galvanic corrosion
  - 3.2.3 Pitting
  - 3.2.4 Crevice corrosion
  - 3.2.5 Intergranular corrosion
  - 3.2.6 Selective corrosion/selective leaching
- 3.3 Electrochemical/Mechanical
  - 3.3.1 Stress corrosion cracking (SCC)
  - 3.3.2 Corrosion-fatigue
  - 3.3.3 Erosion-corrosion
- 3.4 Physical/metallurgical (mechanical)
  - 3.4.1 Hydrogen damage
  - 3.4.2 Liquid Metal Embrittlement (LME)
- 3.5 High temperature/chemical
  - 3.5.1 Oxidation and Sulphidation
  - 3.5.2 CO attack
  - 3.5.3 Metal dusting
  - 3.5.4 H<sub>2</sub> attack (Nelson)
  - 3.5.5 Nitriding
  - 3.5.6 Creep
  - 3.5.7 Carburisation
- 3.6 Atmospheric corrosion
  - 3.6.1 Introduction
  - 3.6.2 Forms of atmospheric corrosion
  - 3.6.3 Preventive measures
  - 3.6.4 Cases of atmospheric corrosion
- 3.7 Soil corrosion
- 3.8 Microbiologically induced corrosion (MIC)

#### 4 Corrosion Prevention and Protection

- 4.1 Introduction

- 4.2 Design and layout
- 4.3 Materials selection
  - 4.3.1 Introduction
  - 4.3.2 Carbon steel and cast iron
  - 4.3.3 Stainless steels (ferritic, martensitic and austenitic)
  - 4.3.4 Duplex stainless steels
  - 4.3.5 Nickel and nickel alloys
  - 4.3.6 Copper and copper alloys
  - 4.3.7 Aluminium and aluminium alloys
  - 4.3.8 Titanium, Zirconium and Tantalum
  - 4.3.9 Plastics
- 4.4 Protective layers
- 4.5 Changing corrosive environment
- 4.6 Changing electrode potential (Cathodic and Anodic protection)
- 4.7 Chemical industrial cleaning

## **5 Corrosion Examination, Inspection and Monitoring**

- 5.1 Corrosion examination
- 5.2 Quality Control of materials of construction
- 5.3 Inspection
- 5.4 On-line corrosion monitoring techniques