How to Manage Leaks in Urea Plants

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Content

1. Introduction

Leaks in the high-pressure synthesis section of a urea plant may lead to catastrophic consequences. UreaKnowHow.com started to collect incidents in an incident database and in 2017 AmmoniaKnowHow.com and UreaKnowHow.com introduced FIORDA, the Fertilizer Industry Operational Risk Database, a global open source risk register for ammonia and urea plants.
A surprising conclusion from this database is that most safety risks in a urea plant lead to a sudden release of a cloud of toxic ammonia. An early detection of a leak is important as a minor and small leak can easily be contained.
But what to do after a leak has been detected? Can one retighten a flange connection, can a temporarily clamp solve the problem or does one need to shut down the plant ?
This paper discusses why leaks in the high-pressure synthesis section of a urea plant are dangerous, what happens when there is a leak, what can be the consequences, are all leaks critical and what can be the prevention and mitigation measures ?

2. Why are leaks in the high-pressure synthesis section so critical ?

Figure 1 shows several examples of leaks in urea plants.

Figure 1: Several examples of leaks in a urea plant

In urea plants leaks easily can occur; this is due to two factors:

1) Corrosion challenges
In a urea plant one must continuously take into account the risk of corrosion due to presence of ammonium carbamate. At the relatively high temperatures, ammonium carbamates behaves like a strong Brönsted acid. A proper material selection of the equipment and materials is important but also the presence of a sufficient amount of oxygen is very critical to keep the corrosion rates within certain limits (passive corrosion). Even in case sufficient oxygen is present, always a certain passive corrosion rate will occur, which is in the order of 0.01-0.02 mm per year (0.0004–0.0008 inch/year). This means that slowly wall thicknesses reduce and finally leaks can occur. When oxygen is not sufficiently present, for example in crevices or dead ends or in condensing liquid in a gas phase, passive corrosion will turn into active corrosion with much higher corrosion rates occur, some 30-50 mm per year (1–2 inches per year).

2) Sealing challenges
Due to the corrosive medium only a limited number of special urea grade materials can be applied in a urea plant. This means that required hardness difference between for example flanges and the lens ring is not easy to realize, because for a proper sealing the difference in hardness should be minimum some 20 hV. Also one is limited in the selection of the type of seals; a design with gaps or crevices cannot be used. The consequences is that more attention is required to obtain a proper sealing.

Let's have a closer look at a very often used sealing type in a urea plant, the lens ring joint.
Most of the times, one uses threaded flanges from carbon steel with carbon steel bolts and nuts, as indicated in Figure 2 below.

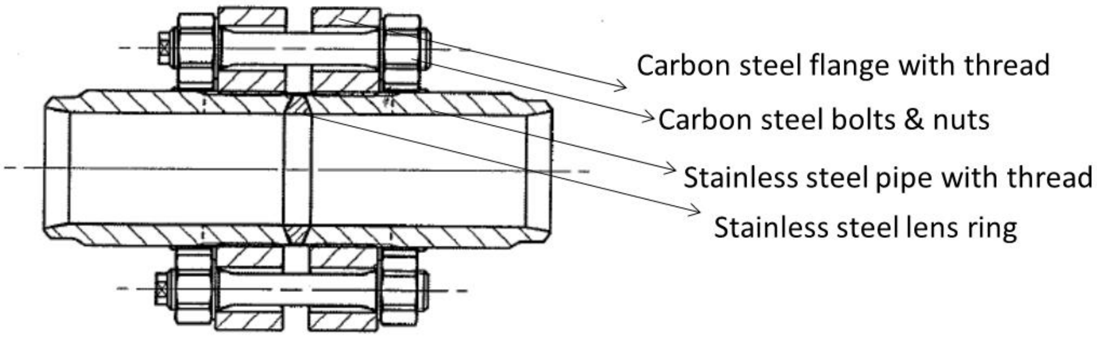

Figure 2: A typical lens ring flange connection

The shape of the lens ring is such that a line-shape sealing ring is created as indicated in Figures 3 and 4 below.

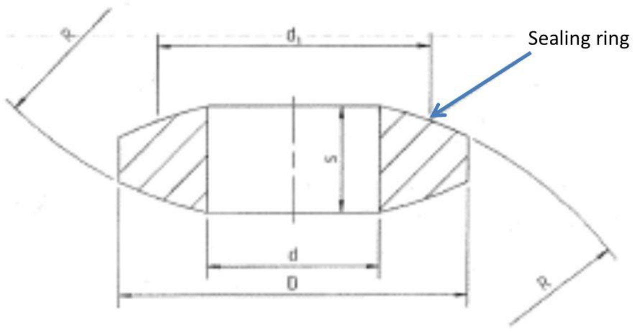

Figure 3 and 4: Line sealing principle of a lens ring (left) and a real life example showing normal passive corrosion on the process side of the lens ring (right)

The big advantage of a line-shape sealing ring is that less force is required to create the sealing. The sealing effect is achieved by elastic deformation of the surfaces and that implies that applying the right bolt load is very important. Lens ring gaskets are in principle reusable, but in a urea plant we do not recommend to use a lens ring gasket twice. Lens ring gaskets are also sensitive to high bolt forces. With increasing loads, the lens ring gasket deforms and the shape changes, the radius becomes flatter and that means that no longer a line-shape surface exists and the contact surface between the lens ring gasket and flange increases (flat surface sealing). So that the risk for crevice corrosion becomes reality.

3. What happens when it leaks ?

It is common knowledge that crevices should be avoided in the high-pressure synthesis sections of urea plants. In a crevice ammonium carbamate liquid enters, oxygen will be depleted and corrosion rates (active corrosion) increase leading to crevice corrosion and the flange connection will start to leak. The picture below shows the result of crevice corrosion on a stainless steel flange face.

Figure 5: Signs of crevice corrosion of a stainless steel flange face

However a crevice and/or a leak can occur in a lens ring flange connection due to several causes such as no proper alignment, insufficient torque on the bolts, too thin lens ring gaskets, lateral defects in the face of the lens ring or flange face, pipeline vibrations (reciprocating pumps, high pressure drops) or excessive stresses due to not proper piping design / installation. The picture below shows a typical leak of a lens ring flange connection.

Figure 6: A typical leak of a lens ring flange connection

Typically a leak cannot be stopped anymore because solids, which are formed during the flashing from high pressure to atmospheric pressure, will erode the leak path.
Furthermore the leaking ammonium carbamate is extremely corrosive for carbon steel parts like the threaded flanges, bolts and nuts as shown in the picture below.

Figure 7: Corroded carbon steel bolts due to a leaking lens ring flange connection

Please realise also the mechanical integrity of stainless steel parts can be at risk due to the leak. In a crevice active corrosion will occur due to the lack of sufficient oxygen present resulting in high corrosion rates (active corrosion).

4. Causes and consequences of leaks

Leaks can be caused by several factors:

- Wrong materials of construction
- Inferior design
- Inferior quality assurance during fabrication / installation
- Wrong and inferior torqueing practices
- Various corrosion phenomena from process side and from utility / atmosphere
- End of lifetime conditions

In case of a leak, best practice is to shut down the plant and solve the leak. But in case one decides otherwise always perform a proper risk assessment first. And assure you know all the possible failure modes and similar previous cases in the industry.
Further take into account the following possible consequences:

- Retightening to stop a leak (hot bolting) during operations is risky and very difficult, if not impossible; it easily introduces risks of overtightening the bolts since the mechanical properties at elevated temperature differ.
- A leak leads to the formation of solids, which easily can cause clogging.
- It is important to assure that erosion and corrosion properties of the leaking ammonium carbamate do not threaten the mechanical integrity of carbon and stainless steel parts. Proper flushing and a close monitoring are very important. In case of flushing one should avoid that water with ammonium carbamate can drip on carbon steel pressure bearing walls of high-pressure equipment as this can cause stress corrosion cracks in the carbon steel wall.
- Clamping of ammonium carbamate and ammonia pipelines, valves or accessories is extremely dangerous and should never be done.

5. What are critical leaks ?

Leak detection systems for loose liners

Loose liners in high-pressure equipment require leak detection holes in the carbon steel pressure bearing wall. Relatively long leak detection tubing typically connect these leak detection holes to an ammonia detector; this tubing is sensitive to clog due to the formation of solids.
Without this tubing, operators would need to inspect each and every hole during their daily plant tours. As these plant tours are done with a limited frequency only, in our opinion a too large period exists between a leak occurs and when it will be noticed. In this period the leak detection circuit gets clogged and nobody is aware of a leak being present. A sudden rupture of the leaking high-pressure equipment is not unthinkable; multiple serious incidents have been reported in our industry.[ref. 1]
Connecting leak detection holes with an ammonia detector and wait until the leaks shows up at the monitor (so called passive systems as shown in Figure 8) have proven not be reliable also as several serious incidents with these systems have been reported in the industry.[ref. 2]

Figure 8: A typical passive leak detection system

In our opinion an active state-of-the-art leak detection system with a very accurate and reliable ammonia detector is the best solution to detect leaks in loose liners. In that case one is able to confirm the leak, locate the leak area, calculate the leak size and prepare for a repair. And the time required to stop the plant, locate, repair the leak and restart operations will be minimum.

Leak detection systems for tubes and tube-tubesheet connections

High-pressure heat exchangers in urea plants typically consist of carbon steel tube sheets at the process side cladded with a corrosion resistant layer. The carbon steel is sensitive for carbamate corrosion and critical for the integrity of these heat exchangers. In the steam or condensate side typically a conductivity analyzer is present to detect any leak in a tube or tube to tubesheet connection. In case a leak is confirmed one must shut down the plant as the carbon steel tubesheet will suffer from high corrosion rates as show in Figure 9.

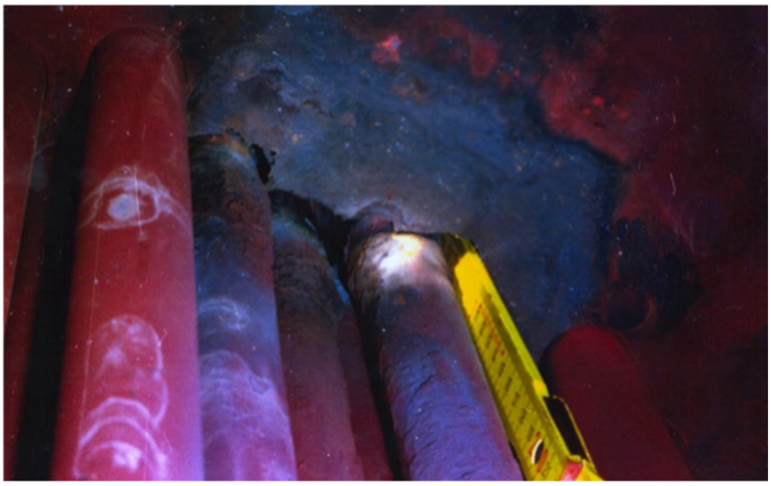

Figure 9: Severe corrosion of the carbon steel tubesheet due to a leak in a tube.

Leaks along threaded connections

Leaks along threaded connections causing corrosion of the threads are very dangerous. The mechanical integrity of the threaded connection will weaken and a rupture and serious incident can occur. In case of a leak along a treaded connection, one must shut down the plant.

Threaded connections one can find in for example high-pressure valves (Figure 10) and high-pressure reciprocating pumps.

Figure 10: Leaks along a threaded bonnet connection of a high-pressure drain valve.

Cracks

Cracks are initiating leaks and a rupture will follow. Cracks can be caused by amongst others vibration issues, strain induced intergranular corrosion of high pressure synthesis gas lines caused by a combination of stresses, large grain sizes of austenitic stainless steels and condensation of ammonium carbamate gases. Leaks due to cracks are critical as the leak size can grow suddenly leading to loss of integrity. It is recommended to shut down the plant in case one finds a leak caused by a crack.

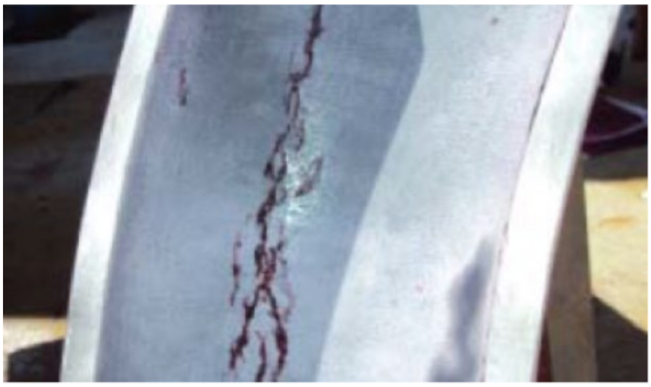

Figure 11: Cracks in a high pressure carbamate gas line.

Accessories in high-pressure piping systems

Accessories in high-pressure piping systems like weld-o-lets are critical parts, the more in case these consist of several parts welded together. Especially in case 316L Urea Grade is applied as material of construction, higher corrosion rates can occur in the heat affected zones. Also in case the design of such a weld-o-let is such that a dead zone exist, higher corrosion rates can result from lack of sufficient refreshment of oxygen in the liquid phase or condensation of carbamate gases.

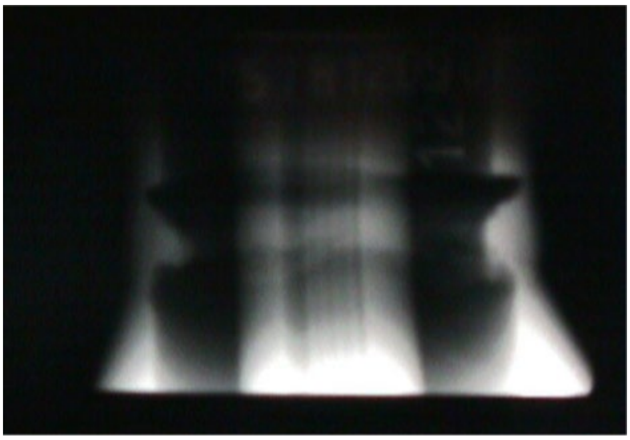

Figure 12: Severe corrosion in the heat affected zones of a weld-o-let.

End of lifetime conditions

Passive corrosion is a normal and accepted phenomenon in any urea plant, which means that the wall thickness of tubes, liners, overlay welding and piping systems will decrease continuously during the life time of the plant. Leaks can occur when one reaches end of lifetime conditions, which is typically between 15 and 25 years for the standard materials of construction like 316L Urea Grade and 25-22-2 in strippers.

6. Prevention Measures

As explained in Chapter 3 it is very difficult to stop a carbamate leak. Best practice is to prevent a leak. This can be done by the following measures:

Minimize the number of flange connections

It is good practice to minimize the number of flange connections in a urea plant due to the challenges one faces to avoid leaks as explained in Chapter 2.

Choose higher alloy materials of construction

A relatively high number of safety incidents occur with high-pressure 316L UG carbamate lines and NH_3 and CO_2 carbon steel feed lines. This is caused by the following facts:

- Many failure modes exist when using standard materials like 316L UG and carbon steel
- Many welds of piping systems are made in the field instead of shop
- Welds in low pressure parts of feed lines are typically considered a lower risk level
- Piping systems are typically difficult to inspect and to reach

By choosing higher alloy materials one is able to avoid most failure modes in high-pressure piping systems in the synthesis section of urea plants as indicated in Figures 13 and 14.

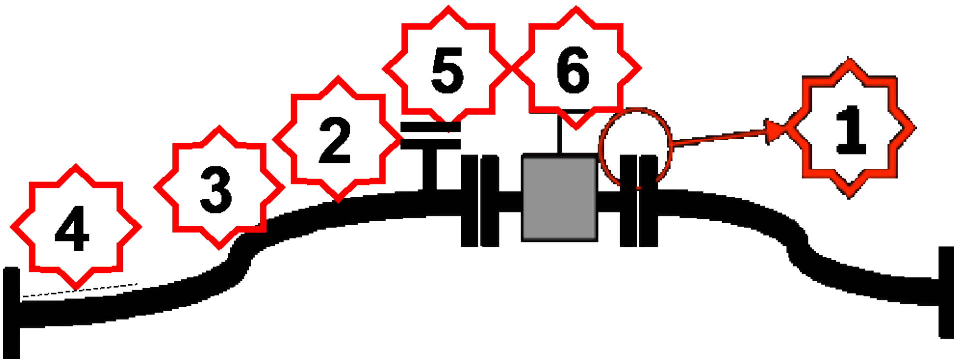

Figure 13: Failure modes in 316L Urea Grade high pressure piping systems.

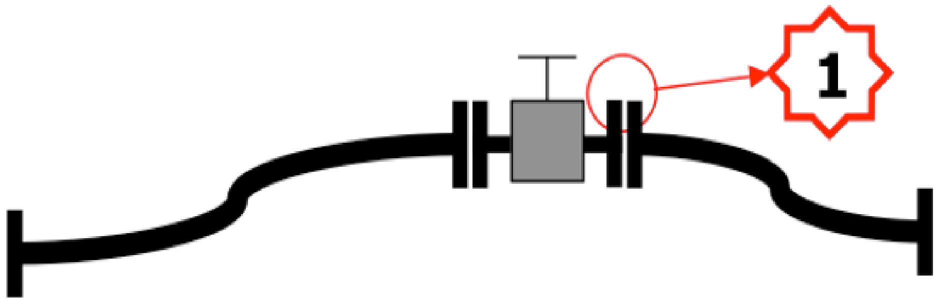

Figure 14: Failure modes in super-duplex high pressure piping systems.

Legend

1. Crevice corrosion (flange connections, some accessories like for example thermowells)
2. Condensation corrosion (gas phase piping systems)
3. Strain induced intergranular corrosion
4. Chloride stress corrosion cracking (carbon steel tracing)
5. Active corrosion (e.g. dead ends, weld-o-lets)
6. Erosion corrosion (e.g. 2-phase lines, valves)

Figure 13 shows that besides the unavoidable failure modes passive corrosion and possible design, fabrication and installation failures, 316L Urea Grade high-pressure piping systems suffer from crevice corrosion at flanges and some accessories, condensation corrosion of gas lines, strain induced intergranular corrosion, chloride stress corrosion cracking due to carbon steel tracing touching the stainless steel main pipeline in chloride containing ambient conditions, active corrosion due to loss of sufficient oxygen in the liquid phase and erosion corrosion due to high velocities.
Figure 14 shows that most of these failure modes can simply be avoided by choosing a super-duplex as material of construction. Besides a higher safety and reliability level one is able to save weight as due to the higher strength figures a lower wall thickness can be accepted.

Similar one is able to avoid the numerous failure modes in carbon steel ammonia feed lines like atmospheric corrosion, corrosion from inside due to carbon dioxide, erosion issues, vibration issues and weld failures simply by choosing stainless steel as material of construction.

Choose a better design

Another way to prevent and/or reduce failure modes and consequential leaks is to choose a better design. Figure 15 shows two possible designs for a thermowell.

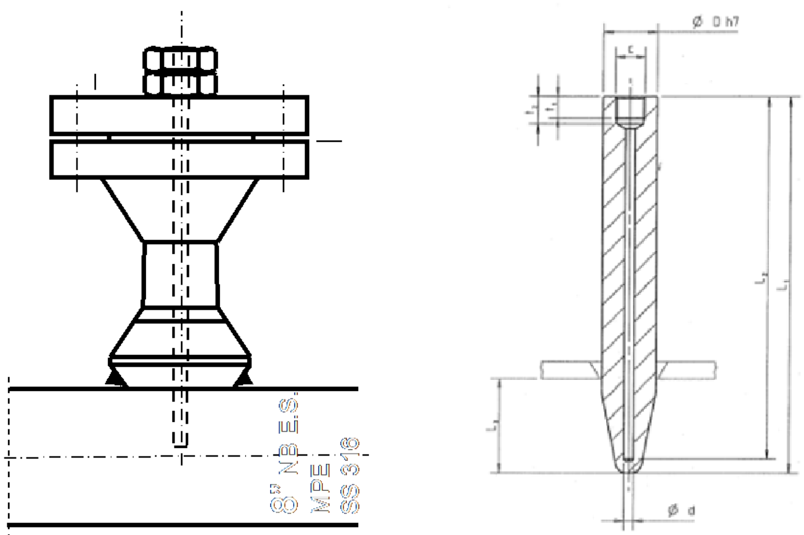

Figure 15: Two possible designs for a thermowell.

The design on the left side of Figure 15 a weld-o-let is applied to install the thermowell. This weld-o-let has some disadvantages like: 1) It consist of several parts welded together, whereas each weld introduces risks to reduce corrosion resistance due to overheating; 2) It forms a dead zone in liquid phase pipelines leading to higher corrosion rates as a result of lower oxygen levels and 3) It potentially forms a heat sink in gas phase pipelines leading to condensation corrosion.
The BHDT design on the right side avoids all abovementioned risks and leads to higher safety and reliability levels.

Assure a proper quality and experience during fabrication / installation / maintenance

Processing urea grade materials require special know how and experience. It is therefore recommended to involve qualified and experienced fabricators during the fabrication, installation and maintenance of these equipment items and materials.
Regarding high pressure flange connections it is recommended to minimize the number of flange connections, in case of flanges use of flange passports and train your mechanics how to handle these flanges. A flange passport leads to the following benefits:
1) By means of a number of basic questions the awareness for good workmanship increases;
2) The mechanic is triggered by a number of questions and
3) It gives the possibility to unambiguously record deviations and to follow up.

Perform risk based inspection programs

As equipment and materials experience continuous corrosion and several failure modes, it is recommended to perform a risk based inspection when the plant becomes 10-15 years old. The program of a risk based inspection should be tailor made and inspections should be performed by qualified and experienced inspectors taking into account all possible failure modes both from process side as well as utility and atmospheric side.

7. Mitigation Measures

Once a carbamate leak occurs most of the times one cannot do a lot except shutting down the plant. Ammonium carbamate will dissociate into ammonia and carbon dioxide and thus a carbamate leaks forms a health threat due to the presence of ammonia. Key is to act quick and keep the ammonia cloud small.

Install a proper ammonia leak detection system

Installing a proper ammonia leak detection system at critical locations is a good way to detect leaks at an early stage and be able to act quickly. Professionals from the Ammonia Safety & Training Institute (www.ammonia-safety.com) confirm an early detection and quick action of an ammonia leak is vital to avoid catastrophes. Critical locations are the high pressure synthesis especially at locations which are difficult to reach like for example the top floors. Also the carbon steel ammonia feed lines and the ammonia and carbamate high pressure pumps are critical with respect to potential ammonia leaks.

Shut down the plant

In case of a leak, the best option is after the leak has been confirmed and the leak has been located to shut down the plant. We realize in real situations this is not always an easy choice to make, but in case one faces a critical leak a described in Chapter 5 we only can recommend to shut down the plant.

Flush with steam and/or condensate

In case of a small leak one could consider to flush away the solids and dilute / absorb the ammonia from the leak by means of a continuous flush with steam and/or condensate. Monitor continuously the leak and integrity of the leaking equipment by means of a camera as even flashing ammonium carbamate can corrode carbon steel bolts and nuts. Refer to Figure 7.
When a flush is applied be careful that water with ammonia and ammonium carbamate does not drip on high pressure vessels located under the leak. This mixture can cause stress corrosion cracks

in the carbon steel pressure bearing wall of these vessels. This risk increases when one uses fine grain carbon steel materials.[ref. 3]

Do not let the solids reduce / stop the leak

Do not allow solids to form even if these reduce / stop the leak. One does not know what happens under these solids and corrosion ammonium carbamate still can corrode carbon steel parts and even stainless steel parts due to active corrosion as a result of lack of oxygen. Refer to Figure 16.

Figure 16: Solids have stopped the leak but created a critical unsafe situation.

Do not install a clamp on ammonium carbamate and ammonia lines

Installing a clamp on a ammonium carbamate line is not allowed because of the following reasons:
1) One does not know what happens to the materials underneath these solids and ammonium carbamate corrosion will weaken the carbon steel parts and even stainless steel will corrode as a result of lack of oxygen;
2) During the installation of the clamp additional forces will be applied and these extra forces might lead to a rupture due to the corrosion that might have occurred due to the leak.

Also installing a clamp on ammonia lines can be very risky and did lead to catastrophic events. [ref. 5]

8. Conclusions

We like to draw following conclusions when discussing how to manage leaks in urea plants:

- Leaks in the high-pressure synthesis section of a urea plant are always risky and the longer they last the more dangerous a leak will become. An early detection by means of a proper ammonia leak detection system is important.
- The most safe option is to shut down the plant and solve the leak.
- Perform always first a proper Risk Assessment and assure you know all the possible failure modes. Search for similar cases in the industry (AICHE, Incident Database UreaKnowHow.com, FIORDA), Perform all possible Non Destructive Testing inspections.
- Never install a clamp on an ammonium carbamate or ammonia pipeline. Realize that the installation of clamps may create crevice corrosion risks and other risks due to the injection pressure and possible other forces on the leak area. Clamps when installed should always be considered a temporary solution and develop a procedure to check its integrity during installation.

- Consider flushing instead of clamping. Monitor the leak and integrity of the leaking equipment continuously. Avoid that flushing liquid can drip of the carbon steel wall of a high-pressure equipment.
- In case of a crack, shut down the plant.
- In case of leak along a threaded connection, shut down the plant.
- Take all possible preventive measures to avoid leaks.
- **Apply zero tolerance for any kind of leaks in urea plants.**

References:

1. UreaKnowHow.com Incident Database: https://www.ureaknowhow.com/ukh2/round-table-1/33.html
2. UreaKnowHow.com Incident 18-005: https://www.ureaknowhow.com/ukh2/round-table-1/33/1867.html
3. AICHE Ammonia Safety Manual: 1994, Failure of Urea Strippers and Repair Experience, Pota HP, e.o.
4. UreaKnowHow.com Incident 00-001: https://www.ureaknowhow.com/ukh2/round-table-1/33/292.html
5. AICHE Ammonia Safety Manual: 2011, Failure of Urea Strippers and Repair Experience, S G Gedigeri