

Reliable Design of Ammonia and Urea Plants

Authors

Pasquale Talarico
CASALE GROUP – Switzerland

Andrea Scotto
CASALE GROUP – Switzerland

Summary

During the design of ammonia and urea plants many aspects have to be taken into account besides process performances. The plant reliability is a factor as important as process performances in determining the future plant profitability. To design a reliable plant it is necessary to take into account many aspects, such as the process mechanical design of all parts, instrumentation, process control, and the plant layout. It is also essential to have a good quality control in every phase of the project. This paper describes the design choices that are crucial in order to reach the highest standard of reliability in these plants.

Reliable Design of Ammonia and Urea Plants

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Introduction

As Reliability is a broad scope, understanding what it is, comes first. Exploring the literature, it is possible to find many definitions of reliability, like:

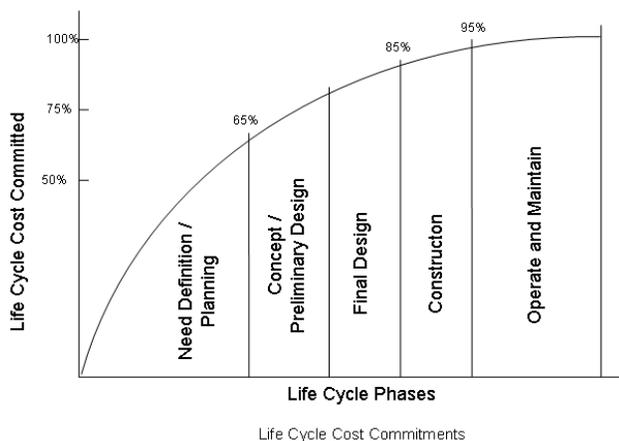
- The ability of a system or component to perform its required functions under stated conditions for a specified period of time.
- The idea that something is fit for a purpose with respect to time;
- The capacity of a device or system to perform as designed;
- The resistance to faults or failures of a device or system;
- The ability of a device or system to perform a required function under stated conditions for a specified period of time;

- The probability that a functional unit will perform its required function for a specified interval under stated conditions.
- The ability of something to "fail well" (to fail without catastrophic consequences and is restorable in a reasonable period of time).

In our opinion the more accurate statement is:

"The high reliability of plants is a choice and not an accident of fortune".

In fact, once a plant is designed and built there is very little that can be done to reduce operating costs and reliability is a significant part of them, because they are substantially established during the plant's design. If low operating costs is the target, Figure 1 makes it clear that they are designed into the plant and equipment during feasibility, design and construction phases.



Source: Blanchard, B.S., Design and Management to Life Cycle Cost
Forest Grove, OR, MA Press, 1978

Figure 1. Life Cycle Cost Commitments

A part from general statements and standard activities which are usually performed during a plant's design phase like HAZOP, SIL analysis etc., this paper has the objective to provide additional and unusual approach to plant's reliability as it may be seen from the eyes of a process licensor.

Therefore the paper describes the reliable design approach for Ammonia and Urea plants that should be undertaken by the various engineering disciplines through the illustration of some specific examples which are out of the well know and recognized critical area of these type of plants.

As an example, it is well known to the majority of the specialists of the fertilizer sector that corrosion phenomena are of paramount importance for the reliability high pressure Urea plants but in case a low-pressure carbonate pumps fails the overall urea plant may stop as well with the same result of losing the overall production.

The Ammonia plant is a sequence of different units. It is important for reliability that all of them, including the sections or equipment generally considered less critical like process condensate pumps, turbine condensate pumps, medium pressure low temperature exchangers, compressor seal gas system, operate according

to recognize state of the art because their failure will also result in an undesired plant shut-down.

Having this approach in mind, this paper will provide some specific examples related to the more significant disciplines which are typically involved in the design of Ammonia and Urea plants. In particular it will illustrate the process design as well as the mechanical, machinery, instrument and piping design.

1. Process Design

The process design has a fundamental role for the operating reliability of the plants: as an example the proper selection of operating conditions, the control system and the material of construction is a paramount step in the further development of the project.

Furthermore, the operating flexibility originated by the proper selection of a scheme that can allow to safely operate the unit within a sufficiently wide span of pressure, temperature and fluid composition ranges is an aspect that can boost the plants reliability. In fact this feature, under certain conditions, can prevent the plant to trip in case of human error or instrumentation failure.

Entering more in the specific approach highlighted above the following paragraphs provide some specific examples of how the process design can contribute to Ammonia and Urea plant reliability.

Ammonia Process Design

The ammonia plant is a quite complicated petrochemical gas plant that utilizes seven different chemical reactions and fourteen unit operations working on range of operative condition that spans from cryogenic (-33°C / -27°F) up to elevated temperature (1000°C / 1832°F) as well as from low pressure (1 bar / 15 psi) to high pressure (150 bar / 2175 psig).

The know-how to manage all the wide range of

operative condition and fluids to be handled is of critical importance.

Such know-how covers all the engineering disciplines who must do the following starting from the process design:

- Define the most appropriate flow scheme and operative parameters of each equipment/unit according to the "state of the art" of the available proven technology.
- Define the most appropriate design condition and material selection for all equipment/units of the whole plant.
- Define the sparing philosophy for all machines.
- Define the required instrumentation for monitoring and control the plant operation within the defined operative parameters along the plant.
- Define the required instrumentation and emergency shut-down system for preventing operation outside the defined operative parameters that may offset the reliability and safety operation of any equipment, units or plant sections.
- Define the safety relief system able to manage any possible overpressure that may be caused by plant mal-operations, utility failure or failure of process control and emergency interlock system.

As an example the design of a suitable steam network system and in particular the control system for the let-down station and associated valves is important for minimizing the network steam pressure fluctuation in case of partial unit/section shut-down avoiding to triggering undesired total plant shut-down.

Urea Process Design

As it is well known the modern urea processes are the recycle type of process, therefore a temporary or sudden inefficiency of the synthesis loop, or more in detail of the urea

reactor, would have a significant impact on the overall urea plant performances and under certain conditions may even lead to a plant shut-down.

Typically the best way to overcome this problem is to provide a stable recycle flow of carbamate to the high pressure section thus preventing the further increase of water in the synthesis loop that typically ends up in further lowering the reactor efficiency.

This kind of problem can be safely and environmentally addressed providing a pressurized carbamate tank with a sufficient hold up to manage the described transient situation. In fact the excess of carbamate generated by the synthesis loop can be stored under pressure, thus preventing unnecessary ammonia venting to atmosphere, maintaining or even reducing the carbamate flow to the reactor.

Once the conditions of the reactor are recovered the excess carbamate can be slowly recycle to the synthesis without affecting the plants operation and production.

2. Pressure Equipment Design

The pressure equipment in petrochemical process plants is designed to last from 10 to more than 25 years, according to the operating conditions, without maintenance and it is usually not spared. Therefore their reliability is one of the key factors for the entire plant reliability since their failure usually imply a plant shut-down and quite often personnel and plant safety is concerned.

Reliability concerns in the design and construction of equipment have been incorporated in the requirements of various codes or practice of design, which are based upon the wide experience and knowledge of professional experts and specialists in the industry, backed up by the experience of local plant managers, engineers and operators who

have direct experience in the relevant plant operation.

But equipment reliability has to be taken into special consideration from the beginning of the whole project and should be developed in each step of the project as an integrated aspect of design, not considered as a separate issue referring only to the mechanical features.

This is particularly true for Ammonia and Urea plants that involve high pressure, elevated temperature and corrosive conditions, often mixed together, which requires reliability considerations for equipment to be already incorporated in the process concept.

The most important factors affecting equipment reliability are the metallurgical and mechanical features and the aspects to be considered are:

- Definition of the best design solutions for the defined conditions and material selection.
- Full development of the defined design solutions according to the best available technologies.
- Selection of the most appropriate supplier of equipment, with particular care for the critical items, which can assure not only the best performance but also the most proven design from a reliability and safety point of view.
- Perform all the required test at the equipment supplier to guarantee a correct manufacturing quality.
- Proper installation and commissioning.
- Compliance with the monitoring and maintenance procedures to preserve equipment characteristics and prevent failures and early deterioration.

In all these steps reliability aspects shall be one of the leading targets.

It should be noted that metallurgical and mechanical aspects cannot be treated separately,

since any material choice involves specific mechanical features and vice versa.

Whereas the fundamentals are common, Ammonia and Urea equipment shall face different conditions which impose significant differences in their design to reach the desired reliability.

Equipment for Ammonia Plants

The Ammonia process is characterized mainly by gaseous fluids, mixtures of hydrogen, methane, steam, air, carbon mono and dioxides and ammonia. Gaseous mixtures are generally not corrosive, therefore carbon and low alloy steels are extensively used in ammonia plants, but if they are at high temperature and/or high pressure, they can become highly aggressive and require special design and material selection to assure reliable operations. The most challenging sections are the reforming and the synthesis sections.

In the reforming section the high temperatures, in some part above 900°C (1650°F), are a challenge in itself, but the presence of hydrogen, carbon mono and dioxide and steam in the gas can lead to phenomena such as metal dusting, which can have catastrophic consequences.

The design of equipment in this section involves very different solution and materials, from the use of special metals for high temperature, to the extensive use of refractory, to water jacketing, from the selection of high alloys resisting to metal dusting, to design features that avoid the temperature range in which metal dusting is possible.

The most critical items are the primary reformer, the secondary reformer, the connecting transfer line and the downstream boiler system. For those items in addition to the needed precautions during design, construction, testing and installation, a very specific experience along the supply chain from the

designer to the Manufactures is required to achieve the expected reliability.

In the synthesis section the material selection is mainly governed by two phenomena related to the particular conditions of gas that contains hydrogen and ammonia at high temperature and pressure. These conditions require a specific material selection and equipment design, to avoid problems related to the two concurring phenomena: hydrogen attack and nitriding.

Hydrogen Attack

The term hydrogen attack is used to indicate several phenomena linked to the damages caused by hydrogen. The most considerable ones for ammonia plants are:

- High Temperature Hydrogen Attack, which in an Ammonia plant typically occurs in areas such as secondary reformers, waste heat boilers/exchangers, high temperature shift converters, methanator and synthesis loop equipment (Figure 2).

The conditions under which hydrogen attack can occur are defined by a set of empirical curves, namely the Nelson Curves, reported on API 941, which set permissible operating limits as a function of steel type, hydrogen partial pressure and temperature.

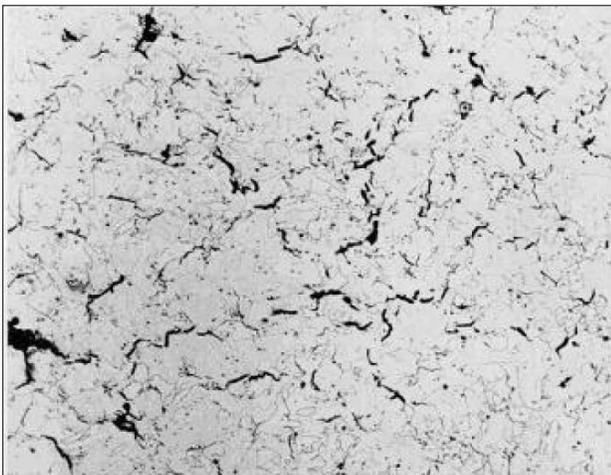


Figure 2. High temperature hydrogen attack

- Hydrogen assisted cracking, which has also been detected in Ammonia plants vessels, in particular where the component had not been adequately post weld stress relieved during fabrication. For this reason Hydrogen assisted cracking can occur at service temperatures well below the relevant Nelson curve. Generally it occurs in low alloy with a chrome level above 2%, typically utilized in the hottest part of the synthesis section.
- Hydrogen disbonding could affect components where an overlay of stainless steel or Inconel 600 has been applied on a carbon or low alloy pressure resistant body, usually to provide protection against high temperature hydrogen attack, nitriding and hot corrosion from sulphides (H₂S) typical of Ammonia plants.

There have been numerous instances where equipment incorporating this design has suffered from cracking at the interface between the austenitic layer and the base metal after being in service for a period of time.

It could be connected to entrapped at the overlay-base metal interface during a cooling down cycle or to a phenomenon called 'carbon migration' with carbon migrating from the alloy steel and concentrating at the austenite-alloy steel interface to produce a high hardness, crack susceptible martensitic zone.

This degradation mechanism is not uncommon in Ammonia Plants with an Inconel 600 overlay on low alloy with a chrome level above 2%.

Nitriding

In the presence of a hot ammonia atmosphere, above a certain temperature depending on the type of steel, ammonia reacts with iron to form a hard and brittle Fe-N inter-metallic layer. This phenomenon is called Nitriding. Nitriding develops on low alloy steels and on stainless

steels, however, on the latter at a much reduced rate and higher temperatures compared with low alloy steels.

On pressure equipment this layer does not cause any problem until it remains compact and does not crack, but since a brittle material will reach more easily its rupture limit, in areas of stress concentration cracks can occur, exposing further surface to the nitriding atmosphere. This propagation, cycle after cycle, can lead to the component failure (Figure 3).

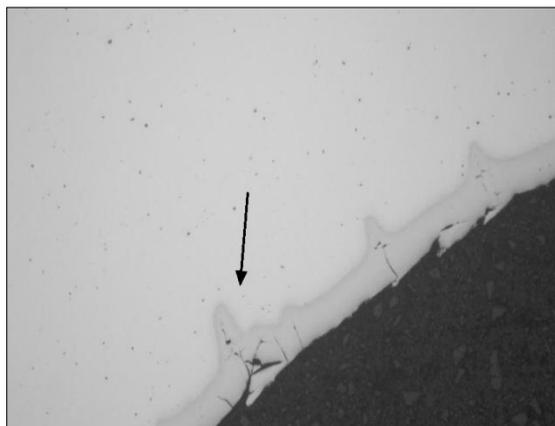


Figure 3. Section - Nitriding progress through cracks

For this reason in ammonia atmosphere, usually above 370-380°C, (700-715°F) carbon steel and low alloy steel are not used in contact with fluid and replaced with austenitic stainless steel or even non-ferrous alloy.

Nitriding occurs also on stainless steel usually above 400°C (750°F), but considering the high ductility of stainless steel and their low nitriding rate, their use guarantees an acceptable reliability in this situation. Only the thinnest components at the higher temperature usually require the selection of material such as Inconel 600 which is fully resistant to nitriding.

Synthesis Sections

All the equipment is critical in the synthesis section, but the most critical ones are the

ammonia converter and downstream exchangers, because they see the combined highest temperatures and the highest ammonia content.

In particular reliability is essential for the ammonia synthesis converter, which is the reactor with the longest run between catalyst changes, since it must run for 10-15 years. Ammonia catalyst, once reduced, should not come into contact with oxygen, since it is highly pyrophoric. Therefore converters should operate between catalyst changes without repair or inspection.

In general, since the use of stainless steel or higher alloy steels would be too expensive, these items are made from low alloy steel, selected according to the Nelson curves to resist hydrogen attack.

To avoid nitriding usually either the temperature of the pressure components is kept below 370°C or a lining with a nitriding resistant material is applied, this second solution being less reliable due to the possible occurrence of hydrogen disbonding.

The first solution usually calls for specific internal design, direct connections between equipment, which imply specific knowledge and design solutions, but guarantees a higher reliability. Since the detrimental effect of the process environment on the materials increases in direct proportion to the temperature, the latter needs to be kept as low as possible on high-pressure parts of the process. Reliability is increased keeping materials at a lower temperature by means of suitable thermal insulation and/or gas flushing.

This concept inherently increases the safety of high-pressure parts.

Even with the improved construction technology, some recent cases involving an additional hot wall ammonia converter suffered

from weld cracking on the girth weld between shell and head, showing that the philosophy of keeping cold the pressure components is still the one guaranteeing the highest reliability.

Also the synthesis loop heat exchangers located downstream the ammonia converter are subject to the same concerns as the ammonia converter, especially the first exchanger after the converter outlet.

Whatever exchanger is selected either a steam super-heater, or a boiler, or boiler feed water pre-heater, or a gas-gas exchanger, the design philosophy should be the same: keep temperature low. Of course the design solutions to achieve this target are specific to each type of exchanger.

The possibility to directly connect the exchanger to the converter, avoids the need for high-pressure, high-temperature piping, which is a usual source of trouble and leakage, and saves, at the same time, material and pressure drop.

The arrangement of the exchanger itself (for example, whether the gas is on the shell side or the tube side) depends on the plant configuration, but the use of U-tube type greatly increase the exchanger reliability over the fixed tube-sheet type. All design possibilities to reduce stresses shall be considered, such as using fountain-type U-tubes, in which the tubes are arranged radially instead of parallel to each other, as in a conventional U-tube exchanger, permitting a symmetrical thermal stress distribution, while no part of the pressure-retaining wall of the gas channel is exposed to the hottest gases.

For kettle type boilers (Figure 4), the horizontal disposition usually is more reliable than the vertical ones, where boiling water contaminants deposit on the tubesheet causing corrosion.

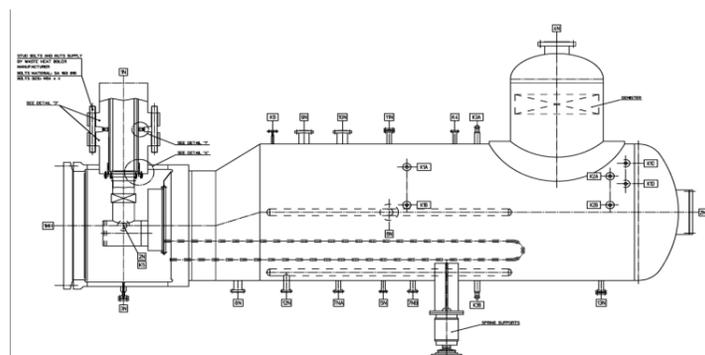


Figure 4. Horizontal type synthesis boiler directly connected to ammonia converter

When super-heaters are considered, since tube material is subject to nitriding temperatures, high alloy material specifically developed for stress corrosion resistance should be preferred over stainless steel, because of the high risk of stress corrosion inherent in this material.

Other Sections

The same principles for design and materials selection should be used to guarantee the reliability of the equipment in all other sections of the plant, although temperature and pressures are lower.

However it should be considered that each plant has its own specificities, different ambient conditions, local rules, types of feed gas and therefore the approach one design fit all is not appropriate to ensure the best design and reliability.

Special consideration should be given in these aspects to the CO₂ removal section, where the possibility to choose different solution and the different corrosiveness involved in each choice is a key aspect of the plant reliability.

Equipment for Urea Plants

The urea process is characterized by the presence of quite aggressive process fluids like ammonium carbamate, ammonium carbonate and urea solution, which require the use of special stainless steels, especially under synthesis conditions (high pressure and high temperature). In principle, all urea processes utilize stainless steel, but while the low-pressure, evaporation, vacuum and wastewater treatment sections use standard commercial stainless steels (AISI-304L or AISI-316L), the synthesis loop is manufactured with special steels properly studied for urea application.

It has to be kept in mind that different process choices greatly affect the material selection of the equipment; therefore, the same equipment in a different process scheme may require a completely different approach.

The most common type of special material for the Urea synthesis is 316L 'urea grade' (UG) steel.

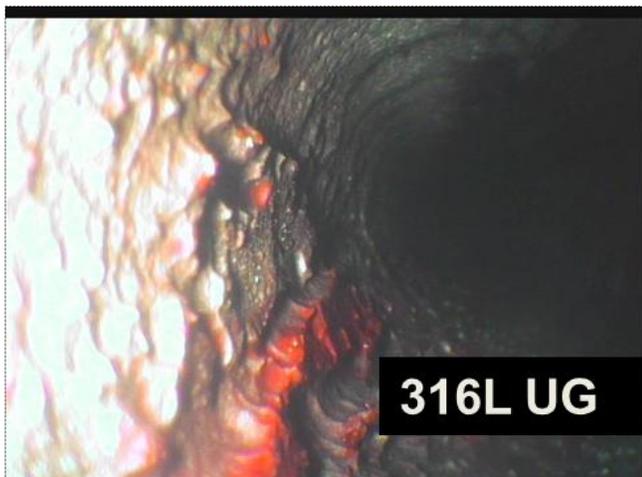


Figure 5. Active corrosion in 316L Urea grade material

This material is widely used in urea plants, mainly because of its excellent weldability, fair corrosion-resistance and relatively low cost. However, the large amount of passivation air

required and limited corrosion-resistance in harsher conditions prevents its application for the most critical components (Figure 5).

The super-austenitic stainless steel type 25Cr-22Ni-2Mo is an upgrade of 316L-UG. It has better corrosion-resistance, higher passivation and re-passivation capacity and excellent weldability.

This material is generally the basic selection when the presence of passivation air allows stainless steels to be used.

This type of material has been used for many years in urea plants and has proven to be reliable within its operating limits. The performance of this material has always been satisfactory, even in the most critical items such as the HP stripper.

As for 316L-UG, since the introduction of 25-22-2 CASALE has developed the relevant specifications aimed to define the technical requirements, acceptability criteria and qualification tests for base material to be used in CASALE equipment as well as all the requirements for welding 25-22-2. These specifications are the result of CASALE experience in the field of urea and are continuously updated on the basis of the improved experience and the technical progress.

While austenitic stainless steels are susceptible to stress corrosion cracking (SCC) by chlorides which may be present in the utility fluid, especially in carbamate condensers, duplex stainless steels have high resistance to SCC.

They have been used in some plants for urea synthesis components such as mixers, valves and piping for more than 30 years.

But experience shows that common duplex stainless steels are not suitable for the harsher conditions, such as stripper or reactor components.

Specific duplex steels have been developed for the urea process conditions, to extend their use to more critical components. These types of duplex usually have high levels of chromium, which is favorable to passivation of steel. As a consequence, duplex stainless steel is easier to passivate than austenitic steels, which means duplex stainless steel requires less dissolved oxygen compared to austenitic stainless steel.

However, it has to be remembered that the dissolved oxygen content in the liquid phase varies, even if the oxygen feed is constant. The excessively low dissolved oxygen content, not oxygen feed, could cause active corrosion even in high-chromium duplex stainless steel. Therefore the quantity of oxygen feed must be determined on the basis of an analysis of the complete system.

The passive corrosion rate of duplex stainless steel developed for urea application is generally comparable to that of 25Cr-22Ni-2Mo.

Special duplex materials developed to increase their already high resistance to erosion are selected for valves plugs, ejector nozzles, mixers and similar application.

Titanium and Zirconium are reactive metals which owe their corrosion-resistance to its ability to passivate. The addition of oxygen to the process is not required to passivate these metals. Moreover, they are neither subject to intergranular corrosion in urea synthesis conditions nor to stress corrosion cracking. Therefore they are ideal candidates for the most critical components in the urea synthesis. Titanium has been widely utilized in the past.

Equipment made of this material is suitable for the highest temperature, even in absence of oxygen, but it is expensive and its life is limited due to erosion, especially in the case of strippers. In addition, reliability is lower compared with stainless steel equipment because of the construction difficulties; therefore, maintenance costs are higher.

Zirconium is even more expensive than titanium and the construction requirements are also higher, as both welding and forming have more stringent purity requirements.

This aspect lays many doubts over the reliability of a large welded construction made of this material, which has rarely been attempted.

In any case the correct material selection by itself does not guarantee a reliable performance in the harsh environment of the urea synthesis.

Careful material screening and specific construction procedures are keys requirements to achieve the requested corrosion resistance.

Usually, detailed standards are developed by the licensor specific for each type of material, to guarantee the quality of the actual materials used in construction and assure that its characteristics do not deteriorate during the manufacturing process.

Material selection is never separate from design, because other parameters like mechanical properties, workability and weldability as well as economic considerations like prices, availability and delivery have to be taken into considerations. Even an accurate material selection cannot by itself guarantee the reliability of equipment, without correct design, quality construction, and proper operation and maintenance. In fact corrosion, even if under control, is always present.

The special materials required for corrosion resistance are not generally suitable for the heavy-gauge construction needed to withstand the high operating pressures for the dimensions typical of modern plants. In general, such equipment would be too expensive, and for some materials the procedures involved in fabrication would impair the corrosion-resistance properties, such as stainless steel and, especially, duplex steels.

For these reasons in nearly all applications the corrosion-resistant materials are applied as a lining to a pressure-resistant shell made of steel. Different choices are available, related both to the materials selected and to the design philosophy.

The easiest way is to apply the corrosion resistant layer directly to the pressure bearing steel. That can be done by weld overlaying, or cladding.

The main problem with this type of design is that any damage to the protective lining cannot be detected until also the pressure envelope is corroded, with a high possibility of catastrophic failure.

This solution has been used in the past, but it is not generally considered nowadays for the synthesis equipment. The common solution is to apply the corrosion-resistant material as a loose lining to the pressure casing. The loose lining seals the corrosive fluid, while the external casing has only a structural function. A leak detection system is provided between the internal layer and the pressure casing to inform of any damage to the corrosion-resistant lining, before the fluid can corrode the pressure components.

This feature is essential for the reliability of the equipment, since early detection of any failure of the corrosion-resistant layer could prevent damage to the pressure shell that could result in the equipment collapsing or, at least, to damage that is difficult to repair.

Automatic leak detection systems greatly improves the safety and reliability of equipment, permitting an early intervention, which usually prevent extended damages difficult to repair.

Urea Reactor

The reactor is a simple vessel with adequate volume to let the reaction progress, but the

pressure, the large dimensions and the huge surface to be lined make it a critical construction, where each detail must be designed according to specific features to guarantee the expected reliability.

The reactor has been layered with titanium, zirconium, austenitic stainless steels (316L-UG and 25Cr-22Ni-2Mo) and duplex stainless steel. The choice depends on the type of process and the specific experience of the licensor. 25Cr-22Ni-2Mo has been the typical choice for modern plant, giving excellent results in terms of reliability and endurance.

Stripper

The stripper is possibly the most critical equipment in the urea process.

Different process designs have different requirements; that is why so many materials have been used in the past.

The equipment itself is generally a falling-film evaporator, and different details in design are generally related to the different material requirements.

Tube material is the most important choice. Reliability is mainly connected to the specific choice that each basic material selection involves.

Notwithstanding the general similarity, each basic material selection, from stainless steel to duplex to titanium imply a specific detailed design, where specific knowledge and experience is the key for a trouble free life of the equipment.

Carbamate Condenser

The design of this equipment can vary substantially according to the technology selected.

Horizontal or vertical installation with process fluid tube side or shell side are commonly used. Since the reaction heat is usually utilized to generate steam stress corrosion can be a problem. In this case the use of a duplex material for tubes may be advantageous.

Other Sections

The same principles for design and materials selection should be used to guarantee the reliability of the equipment in all other sections of the plant, although fluids are less corrosive and pressures lower.

In general, but not always, common stainless steel and standard components can be used. Only with experience and deep process knowledge is it possible to know when this is not true, making the difference between success and failure. Sometimes more troubles arise in this area than in the synthesis loop because less diligence has been exercised in materials selection.

Although common stainless steels can be used, the appropriate limits on chemical composition must be observed and quality checks carried out in many components to avoid corrosion which, when starts, can be fast.

A typical example is the use of welded stainless steel tubes for exchangers. Whereas the base material can be suitable for the operating conditions, often the autogenous weld impairs the corrosion resistance, leading to localized corrosion (Figure 6). In general welded tubes should not be used in most of the Urea plant equipment.

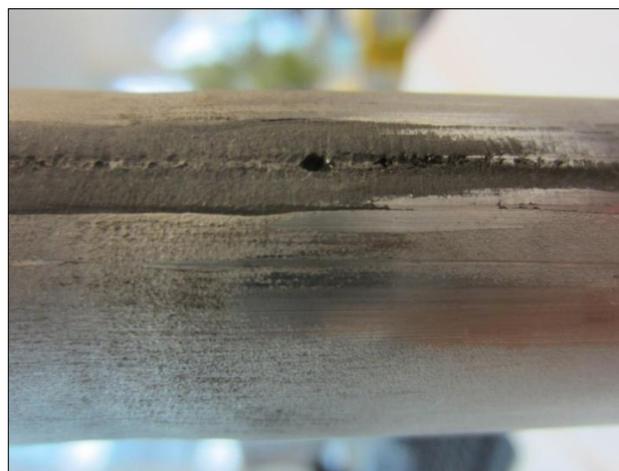


Figure 6. Typical localized corrosion of a welded tube

The same is valid for all component selection: in general, standard components can be selected but not all standard components are suitable.

A typical case is the hydrolyser in the waste water treatment, where the stripping action of steam is used to remove the NH_3 and CO_2 from the treated urea plant waste water condensate so as to maximize the hydrolysis of the urea content.

That actually increases the corrosiveness of the fluid.

Special test and chemical composition limits should be prescribed for the stainless steel employed. Further tests should be provided on the welds to assure the reliability of this equipment.

3. Rotating Equipment Design

Several crucial choices must be made for the selection of the proper equipment. Hereafter some key points are discussed considering two groups of machines: centrifugal compressors and centrifugal pumps.

Centrifugal Compressors

The required process performances are always the starting point for the compressor selection. Other points that need to be considered during the selection process are the following:

- *Operating range, turndown capacity and anti-surge*

A sufficient turndown capacity (Figure 7) is required to permit an easy plant operation in all cases (i.e. start-up, shut-down, SOR, EOR, etc.) and to avoid as far as possible the undesired opening of the anti-surge valves. Anti-surge control system shall be carefully designed and a sufficient number of control loops for each compressor train shall be considered.

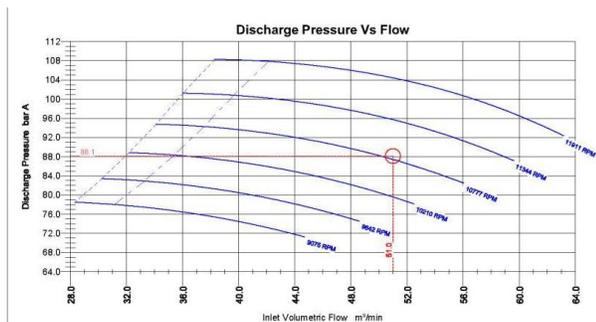


Figure 7. Compressor performance curves

- *Material selection*

Starting from the minimum process requirements the compressor material selection shall be properly checked considering problems of corrosion (i.e. wet CO₂), but also allowable stresses. For this last point special consideration shall be given to impellers' material. The tip speed shall remain well inside the limits of the applied material, of the references of the selected vendor and of the applied technology for the construction of the impellers (i.e. welded, brazed or milled from solid forgings).

- *Mechanical behavior*

During the selection process the rotor dynamic issues shall be carefully evaluated.

It is recommended to use always machines referenced for the same application with similar speeds and performances. At least a preliminary evaluation of the critical speeds and of the rotor stability shall be performed during the evaluation process. Final reports for lateral analysis, torsional analysis and stability analysis shall be reviewed after purchase order award to the selected Vendor.

- *Quality control*

The requirements for inspections and tests shall be carefully defined during the design phase.

Not only the final tests (i.e. mechanical running test, performance test etc.) shall be considered. Inspections and tests on the raw materials (i.e. castings, forgings etc.) and during the manufacturing process (i.e. hydrostatic test, spin test, balancing test etc.) shall be also taken into account.

- *Installation and commissioning*

A proper installation and commissioning is essential in order to achieve the best possible mechanical behavior and reliability. The required work hours for site supervision shall be considered starting from the design and tender phase.

Centrifugal Pumps

At least the last two of the above points (i.e. Quality Control and Installation and Commissioning) are fully applicable also to the centrifugal pumps.

Other key points for the pump selection are the following:

- *Operating point*

A pump is properly selected when the operating point will fall into the Preferred Operating Region, in other words when it is close to Best Efficiency Point (BEP).

This is important not only for the efficiency but also for the mechanical behavior (i.e. lower vibration levels, longer life for bearings and mechanical seals etc.).

- **NPSHa and NPSHr**

Pumps shall be selected with a proper margin between Net Positive Suction Head available (NPSHa) and Net Positive Suction Head required (NPSHr).

Pump selection can be affected by an extremely low value of NPSHa. Some service in ammonia and urea plants are really sensitive to this matter and for them pump selection shall be carefully evaluated (i.e. Semi-lean Solution Pumps, HP Carbamate Pumps).

- **Mechanical Seal Selection**

The seal selection shall be done during the design phase considering the properties of the process fluid. The previous experience for each specific service shall be also taken into account.

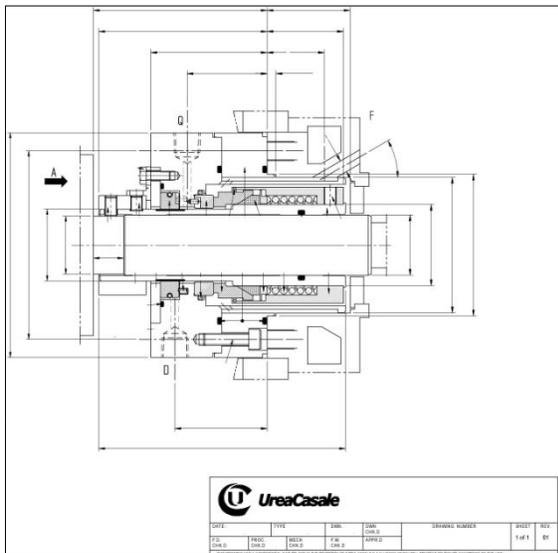


Figure 8. Mechanical seal

For some services the installation of double pressurized seals with flushing from an external source is required (i.e. HP Ammonia Pump for urea plants). This type of seal arrangement is the one that

guarantee the maximum level of reliability, safety and environmental protection.

For those services having fluids that can crystallize but, where single mechanical seals (Figure 8) can be applied (i.e. melt urea, urea solution, etc.), a proper selection of flushing plan is necessary. For these service Urea CASALE requirement is to apply an internal recirculation (API Plan 01) in conjunction with steam (or hot water) quench (API Plan 62) to the atmospheric side of the seal (Figure 9).

For melt urea, a steam jacket is also required.

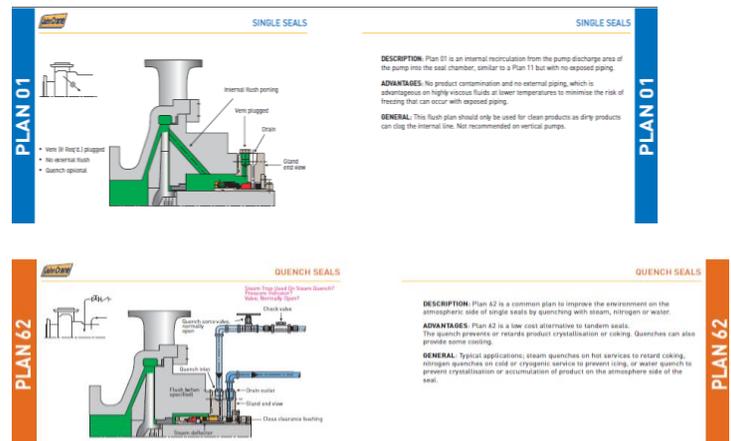


Figure 9. Flushing plans (Source: John Crane)

4. Instrumentation Design

The reliability of ammonia and urea plants is a critical goal to meet during the development of the engineering. A good and operator friendly control philosophy is the first issue to address.

The operator interface is a very important issue to take in consideration. It shall be easy to read and simple to operate in order to minimize the intervention in case of problems.

The redundancy of the control and safety systems such as DCS or ESD in various aspects is the way to balance the availability and the safety of the plants.

The minimum requirements of redundancy on DCS are concentrated in the common parts plus those parts related to critical controls. ESD is typically redundant but final safety strategy needs are defined with dedicated SIL study.

For field instrumentation attention shall be paid to critical High Pressure Control Valves for Urea service where type of material, particular design of the trim and body, jackets, heating and experiences of specialized vendors are the basis to guarantee a good result. Those valves are the result of years of operation and modification to meet good a reliability required on those types of plants.

Other critical devices are the Safety Relief Valves on urea service where heating and flushing is a must to obtain a high reliability and safety of the plant.

A steam injection is necessary for preventing crystallization in the seat of the valve and discharge piping (Figure 10).

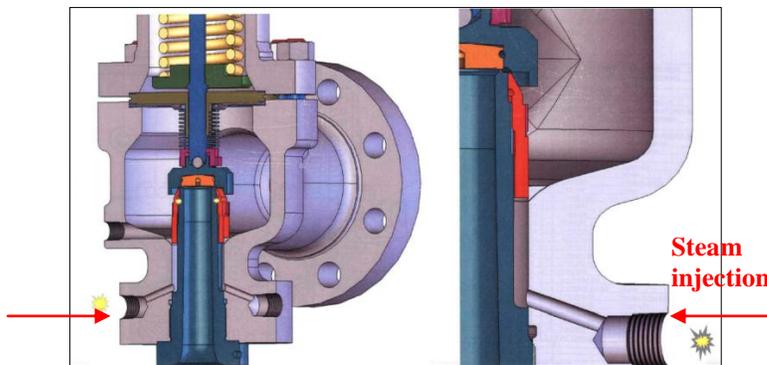


Figure 10. Relief valve for urea application

In general, for transmitters, the attention shall be given to instruments with diaphragms and capillary, as they are not simple to bypass in case of malfunctioning. Special care is required during construction and tests are necessary to verify the real conformity with the requirements.

Critical instruments are in the area of urea reactor, stripper, compressor and pumps discharge.

Engineering experience on these types of plants is a must to develop a good detail and a choice of the dedicated valves and instruments.

5. Electrical Design

Ammonia and Urea plants operation and reliability depend on safe and efficient operation on their electrical supply equipment.

One of most important issues of the electrical system in ammonia and urea plants is related to the necessity of installing very large motors which may require direct-on-line starting. In particular, when compressors are not driven by steam turbine, for example the CO₂ compressor in Urea plant and Natural Gas and Syngas compressors in Ammonia plant, they are normally driven by very large induction or synchronous electrical motors.

In that case, the network study is the best solution to analyse all the aspects related to the behaviour of the electrical distribution system. The results of load flow study, short circuit calculation, power system dynamic calculation, harmonic analysis, protection coordination and discrimination studies shall be carefully examined during engineering stage and appropriate solutions shall be adopted to anticipate any motor starting complications or undesired disturbing of external network which can be revealed during commissioning phase or when the plant is in operation.

The arrangement of the power distribution and control system shall be defined matching the process and operating requirements with the most modern electrical equipment and control philosophy.

For the power distribution, redundant feeding line is the typical supply concept adopted for the Urea and Ammonia plants.

In case of power failure of both incoming feeders, an emergency feeding line (coming

from external source or from a dedicated Emergency Diesel Generator) shall automatically feed the critical loads necessary to shut-down the plant and keep it in safe conditions. Automatic restarting of essential motors is usually applied to make operators task easier.

On the other hand, high performance automatic transfer systems with suitable interlock/inter-trip and Power Distribution Control System (PDCS), based upon one programmable logic controller, represent the basis of the control system.

6. Piping Design

Regarding plot plan development, engineers have today all the necessary instructions from dedicated and complete procedures and specifications. Moreover using modern technologies like 3D software and internet, all the aspects of safety, ergonomic, constructability, cost saving can be analyzed and solved by dedicated teams of engineers.

Then we can say that almost everything is already written in the literature, we have just to apply it.

We highlight just one of the aspects that most of the times is not sufficiently considered. We are speaking of developing and handling over a plant where the maintenance can be done using the staff normally dedicated to this activity in the modern plants.

Since technologies have not been substantially modified in the years and Companies have developed similar plants, layouts for fertilizer plants have been consolidated, compacted and extremely rationalized during the years, using or cutting any available room in order to reduce construction costs. Most of the times, for Clients this means tight access to equipment, valves or instruments and additional manpower and devices are always required for the purpose,

increasing costs and time. Also equipment, that is known to be replaced after a limited number of years, is sometimes placed where their removal is critical.

Then in the ideal plant any heavy removable part, such as equipment or part of equipment, instruments, valves, devices, should be studied and places in such a way to be accessible and dismantled using a crane. This method allows a small team to easily and safely maintain their plants.

7. Conclusions

This paper has described all the aspects relevant to reliability that are always taken in consideration by CASALE during the design stages of ammonia and urea plants in addition to process performance.

The design of a new plant requires deep knowledge on all engineering disciplines, about possible problems as well as a specific experience in the relevant process. CASALE as engineering company has in-house specialist able to manage in an efficient and professional way all the issues related to plant reliability.

Moreover, CASALE, as a supplier of a wide range of proprietary equipment, has developed several reliable solutions that best suits the needs required both for plant retrofitting and for new plants.