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KNOWLEDGE • OPTIMIZATION • INNOVATION

Explosion risks in high-pressure scrubbers of CO2 stripping plants

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1. ABSTRACT

During the Stamicarbon symposium in the year 2000 the paper titled "Explosion risks in urea plants: The Stamicarbon Y2K update" was presented. With respect to explosion risks it was concluded that hydrogen is the dominant component contributing to an explosion in a urea plant. Concentrations of hydrogen higher than 5% (by mol), in the presence of oxygen, should be avoided in process equipment and pipelines.

The paper also pointed out that customers and regulators continuously raise their expectations with respect to the safety performance of petrochemical plants. To achieve this, operators, manufacturers and licensers are required to periodically actualize their safety standards and design specifications.

Among other sources of information, experimental research and incident case history will provide them with new insights regarding the development of risk scenario's and subsequently the way to design their process (equipment).

Based on the year 2000 design philosophy, a standard Stamicarbon grass roots urea plant incorporates a high pressure (design pressure ~160Barg) scrubber sphere design in conjunction with a catalytic combustion of hydrogen in the CO_2 feed stream to the urea plant.

In this configuration the hydrogen converter reduces the probability of the presence of an explosive atmosphere within the HP scrubber whilst the sphere explosion dome volume mitigates the consequences for the plant environment in case of an internal deflagration reaction in the scrubber.

Recently several operators of so called cigar type high pressure scrubbers have asked Stamicarbon to supply new (identical) cigar type high pressure scrubbers in Safurex® infinity duplex stainless steel.

Most of the early generation cigar type high pressure scrubber are however characterized by a very limited explosion dome volume and as such do not comply with the latest Stamicarbon design standards, as they have developed over time.

Incorporation of the safest option, the sphere high pressure scrubber with an adequate explosion dome volume, is not always technically feasible or requires disproportional investments to adapt existing structural work (load limitations) and/or piping arrangements.

This paper elaborates on the exploration of design solution alternatives in the background of a risk based approach.

2. PROCESS SAFETY PERSPECTIVE

2.1. PHYSICAL PROPERTIES OF GAS MIXTURES

For an explosion to occur the presence of a gas mixture, with a composition within the flammability limits, and simultaneously a source of ignition should be present. In urea plants, the combustible components of concern are ammonia and hydrogen and any present combustible components such as methane.

The flammability limits of mixtures containing ammonia, hydrogen and methane at elevated temperature and pressure are known already quite some time. Knowledge on these flammability limits of course is an important pre-requisite in safety studies. Moreover, the flammability limits, as reported, don't account for the considerable difference in mixture reactivity, with respect to combustion, that exists between e.g. ammonia-air mixtures on one hand, and hydrogen-air mixtures on the other. It is also well known that the minimum ignition energy for hydrogen/air mixtures is much lower as compared to ammonia/air mixtures.

To obtain a more in depth understanding of the behavior of NH_3/H2/Air mixtures a project was executed by Stamicarbon in the late nineties to conduct practical experiments.

The project aimed at oxygen containing process gases mixture reactivities with respect to deflagration to detonation transitions in pipelines under conditions (composition, pressure and temperature), that are typical for a urea and melamine plants. The experimental set up consisted of a 20-m long pipeline with an internal diameter of 59 mm. In this pipeline NH_3/H2/air gas mixtures were introduced and the likelihood of detonation of these gas mixtures, as a function of their composition, was tested at (initial) 150 °C and (initial) pressures up to 150 bar.

The most important parameter measured was the flame speed.

The main results of the project can be summarized as follows:

- For ammonia/air mixtures over the entire concentration range, flame speeds were sufficiently low to prevent detonation: The maximum flame speed measured (near the stoichiometric NH3/air ratio) was 1.8 m/s. (Transition of flames to detonation develops once a flame accelerates to 800-1000 m/s!).
- The experiments showed that up to 5% (by mol) of hydrogen could be added to these ammonia/air mixtures, with flame speeds that remain far from detonation.
- At higher hydrogen concentrations, especially in the presence of small amount of ammonia, distinct flame acceleration was observed. It cannot be ruled out that in actual process piping turbulence producing internals fittings could accelerate the flame propagation sufficiently for detonation to occur.

The test rig was also used for explosion tests on gas mixtures containing NH3/H2 as combustibles mixed with oxygen enriched air. These experiments resulted in an unpleasant surprise: at an experiment with oxygen enriched air (40 mol% O2 / 60 mol-% N2) a detonation occurred that was so violent, that the test rig (test pressure 3700 bar!) was severely damaged.

The mixture tested now of the incident contained 28% of ammonia and only 3% of hydrogen. Considering the findings at 'normal air', this violent detonation was rather unexpected. Because of this incident, Stamicarbon decided to stop further safety research with oxygen enriched air systems.
The present Stamicarbon Y2K guideline does not allow for use of oxygen enriched air systems in a urea plant.

2.2. EFFECT OF AN EXPLOSION

In a urea plant we can distinguish two different effects of an explosion:

- The direct effects such as rupture and fragmentation of equipment. These direct effects form a threat to people in the direct vicinity of the equipment concerned.
- Rupture of equipment results in a release of the hazardous chemicals contained by the equipment. This second effect often results in a much larger risk as the urea synthesis section contains large amounts of ammonia at elevated temperature and pressure.
  Ammonia is a toxic substance, it is corrosive to the eyes, skin and respiratory tract.
  Inhalation of vapor/fumes can cause severe breathing difficulties (lung edema). In cases of high exposure there is the risk of death. These effects justify a differentiation in the safety approach, depending on the amount of ammonia that would be released in case of loss of containment.

3. GRASSROOTS DESIGN PHILOSOPHY

In the late seventies of the last century hydrogen related fires and explosions occurred in China. These incidents led to an increased awareness of the safety aspects in this respect and triggered a revised safety philosophy. It initiated the following design changes for the licensed CO2 stripping plants:

- Adding a hydrogen combustion to combust the hydrogen in the carbon dioxide feed.
- Changing the <u>total</u> condensation of inert vapor in the urea synthesis in a <u>partial</u> condensation including the required sufficiently large pressure relief volume

In the eighties it appeared that total condensation in a urea CO2 stripping synthesis had process wise advantages and again the safety philosophy was updated to result in an acceptably low residual risk for a scrubber total condensation concept in urea synthesis sections. Subsequently this resulted in the sphere type of high pressure scrubber which still today represents Stamicarbon's latest standard design. The sphere is dimensioned such that it incorporates a sufficiently large explosion pressure relief volume (dome) compared to the volume in which a deflagration explosive mixture can be present. Next to this dome volume the hydraulic pressure of that dome is prescribed as a design figure for the dome. (typically, 1.5 times the maximum operating pressure in the synthesis).

When in a high pressure scrubber, the vapors from the synthesis are fully condensed the passivation air in combination with hydrogen and other flammables can form a gas mixture that may lead to deflagration. This total condensation is very well possible in diverse operational conditions of the plant since the inert vapor is contacted with a solvent (carbamate or water) in the scrubbing part of the high-pressure scrubber. The maximum effect of a deflagration is a fast pressure increase inside the scrubber and ultimately the rupture and fragmentation of the packed bed in the scrubber leading to an immediate threat to operators and release of significant large volumes of toxic ammonia. This event is classified as an event of the highest consequence category.

Given the low ignition energy of the flammable mixture at urea synthesis conditions, an ignition source is assumed to be present anytime. The probability of such an event can be reduced by introducing a hydrogen removal unit, in which the combustible component hydrogen is catalytically removed from the CO_2 feedstock. However, the likelihood of the event is not always reduced enough to meet today's Stamicarbon safety design standards. For this reason, measures to reduce the consequence of an internal deflagration are to be considered.

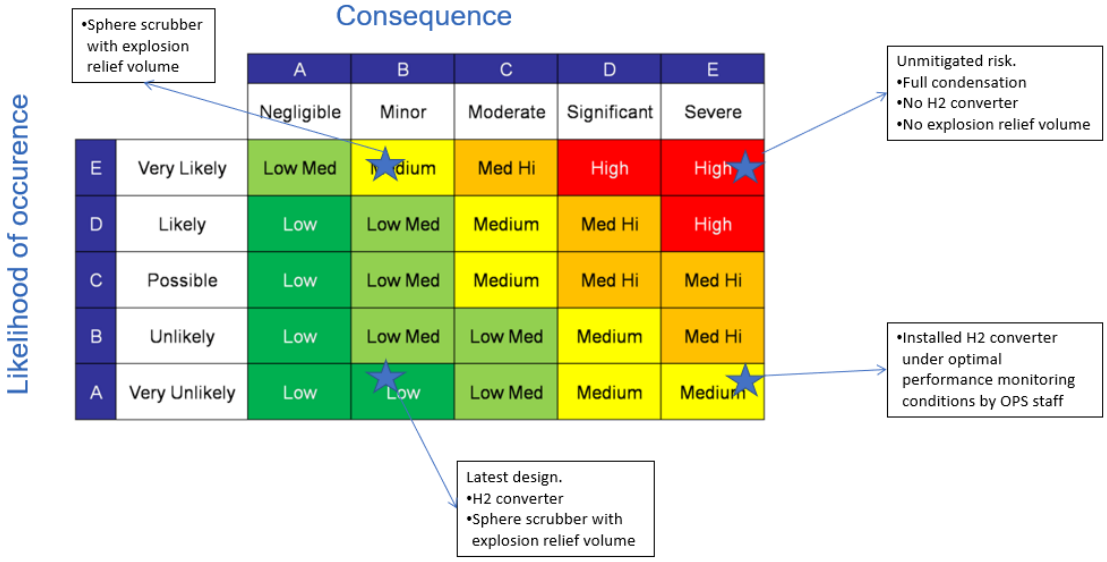


Fig.1 Combination of both the sphere type HP scrubber and a H2 converter results in the highest possible safety performance, a low risk category plotted in the risk matrix above.

Note: The pressure relief volume protects the process only against deflagration explosion events. The pressure relief volume is not adequate to protect the process against detonation explosion events and thus enriched oxygen containing combustible hydrogen mixtures are prohibited to be present.

In Stamicarbon plants equipped with a hydrogen combustion unit and feeding air (not oxygen enriched) there are no cases known of scrubber fragmentation caused by an internal deflagration.

Since 2015 Stamicarbon offers the adiabatic flash melt plant design. In this design the high-pressure scrubber becomes obsolete. In between the high-pressure stripper and the low-pressure recirculation section a flash tank is placed in which the urea solution leaving the high-pressure stripper is flashed at a pressure of about 20 bar (medium-pressure) before it is released into the existing recirculation section.

The released vapor by this flash together with the vapor leaving the high-pressure reactor in the synthesis are condensed in a newly installed shell and tube heat exchanger which is the pre-evaporator. In this pre-evaporator heat is recovered from these vapors by condensing them against a urea solution from the LP recovery. The released condensation heat is used to pre-concentrate the urea solution leaving the recirculation section before it is collected in the urea solution tank. The principle of the proposed Evolve Melt Flash Design is illustrated in the next flow sheet.

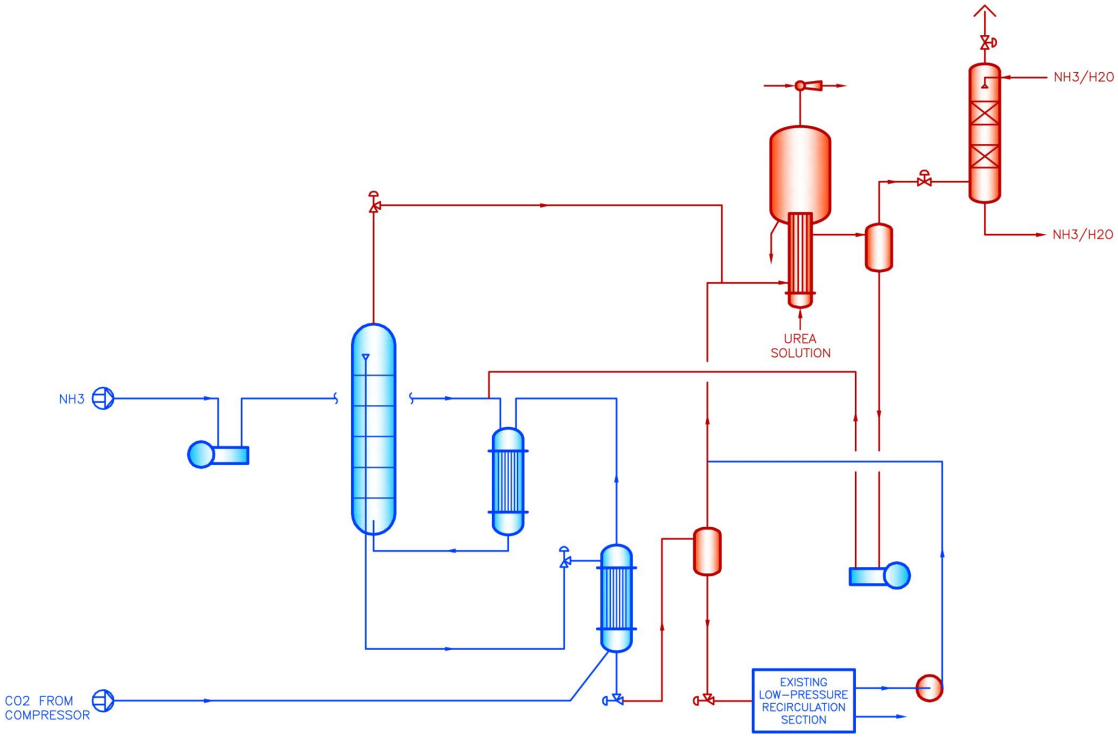


Fig.2 Flowsheet adiabatic flash melt plant design

The total condensation of the ammonia and the carbon dioxide in the inert vapor takes place in the absorber downstream the pre-evaporator at a much lower pressure (about 4 bar) before the inert is released into the atmosphere.

The absorber is designed to be deflagration proof, so in case of an undesired event, there is no loss of containment to be expected. Thus, the Flash Design is an excellent opportunity for safeguarding your existing urea plant at limited costs.

Moreover, the Flash Design gives the opportunity to decrease the stripping efficiency and thus the steam supply on the existing stripper. Consequently, the OPEX of the plant is decreased significantly by the application of this retrofit proposal in comparison to the original plant design.

More details and experiences with the Flash Design is explained in the symposium paper 'Experiences with the Launch Melt Flash Design'.

4. DESIGN PHILOSOPHY EXISTING FACILITIES

Recently several operators of so-called cigar type high pressure scrubbers, of the total condensation type, have requested Stamicarbon to supply new (identical) cigar type high pressure scrubbers in Safurex® as a replacement.
Incorporation of the safest option, the sphere high pressure scrubber with explosion dome volume, is not always technically feasible or results in disproportional investments due to the restrictions in weight or available space.

4.1. MITIGATING THE CONSEQUENCE OF AN INTERNAL DEFLAGRATION BY DESIGN

Several design options are known, and have been applied, in order to minimize the effects of an explosion:

4.1.1. "Dome area" constructions.

These are provisions that allow a deflagration in a section possibly containing an explosive mixture (marked yellow below) to expand in a much bigger volume which is available by design to accommodate this event. After expansion the resulting total pressure will still be well below the rated design pressure of the enclosure. This construction has already been applied in several variations within high pressure urea scrubbers:

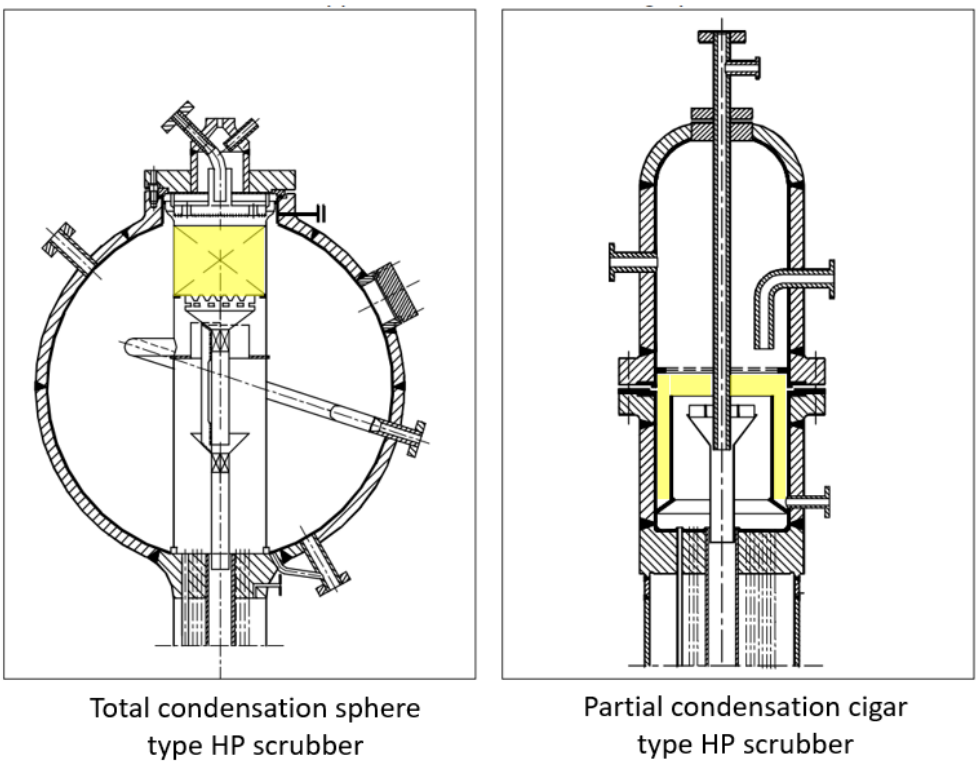


Fig.3 Explosion relief volume options (in yellow the area where a combustible mixture can exist)

In case of an explosion in the protected part of the equipment, the internals will be damaged, and the production process must be stopped for repair. However, the mechanical integrity of the high pressure scrubber sphere will not be jeopardized, and a loss of containment scenario can be avoided.

4.1.2. Rupture discs

This provision can theoretically protect the equipment against a too high pressure in case of a deflagration by venting the contents to the environment. It is obvious that the rupture disc discharge should be vented to a safe location to avoid the same consequences as a failure of the enclosure. As the rupture disk must be largely dimensioned to handle a deflagration, the release will be significant and instantaneous. As no secondary containment is foreseen a single rupture disc scrubber design without a pressure relief volume construction is not allowable.

4.1.3. Deflagration proof equipment.

In case an enclosure would be designed for the pressure developed by an internal deflagration the enclosure would mechanically be able to withstand the internal deflagration. This mitigation by design is practically feasible in case of low pressure equipment. Designing medium or high pressure vessels to be deflagration proof would result in very high design pressures resulting in high investments and is for that reason not practical.

Deflagration proof design is recommended for low-pressure equipment in which there can be explosive gas-mixtures with high hydrogen concentrations (>5% by mol at total condensation). In a plant with low hydrogen concentrations (<5% by mol at total condensation) and equipment with an insignificant ammonia content volume a deflagration proof design is therefore not deemed necessary. As threshold value max. 5% (by mol) of hydrogen in the fully condensed gas is recommended to distinguish between 'high' and 'low' concentration in this respect.
It should be noted that in pipelines, at higher hydrogen concentrations, flames could accelerate into detonations. Detonation proof design of pipeline systems is not possible.

4.1.4. Adiabatic flash revamp concept

In certain occasions, clients request to replace the existing cigar type scrubber of the type total condensation because the existing scrubber is at the end of life and where the location of the newly installed scrubber is limited by either the restriction in weight and/or space.

In the first place the scrubber can be replaced by a scrubber of the partial condensation type. However, this has the consequence that the inert vapor leaving the scrubber contains more ammonia and carbon dioxide as per original design and consequently this inert vapor needs a further purification before it is released into the atmosphere. Usually as a consequence this purification of the inert vapor needs some retrofitting of the plant and will result in a slight increase of the steam consumption and thus OPEX of the plant.

For some clients it is recommended to transform the plant into an Evolve Melt Flash Design (Refer to Chapter 4). The HP scrubber will become obsolete and the LP absorber can be designed deflagration proof.

4.2. MITIGATING THE PROBABILITY OF AN INTERNAL DEFLAGRATION BY DESIGN

Most urea plants operating under a Stamicarbon license are of the total recycle concept, CO_2 stripping. For those plants the following safe operating conditions are defined to mitigate the probability of an internal deflagration:

- Dose oxygen in the form of air. Oxygen enrichment systems are prohibited in urea plants With air dosing in the range of 0.6 vol% oxygen in the carbon dioxide feed for austenitic synthesis construction materials or 0.3 vol % of oxygen in case of Safurex® application as construction material in the synthesis,, limit the hydrogen concentration in the feedstocks to the urea plant to safe values obtained by calculation. In most cases, in order to meet these concentration limits, it will be required to operate a catalytic hydrogen removal system in the CO_2 feed; in exceptional cases a hydrogen reducing system (e.g. pre-flash) in the ammonia feed will be required.

- Monitor these hydrogen concentrations on a regular basis; in case these hydrogen concentrations are exceeded, ultimately corrective actions must be taken (the plant must be stopped).
- To minimize the possible ignition sources, all equipment (high pressure as well as low pressure, including piping) in which there is a flammable component (e.g. hydrogen, methane or ammonia), that might contain oxygen or air, should be grounded and protected against direct hit by lightning. During operation, no 'hot work' (welding, cutting) activities at or near such equipment is allowed. Such hot work activities may only be done when the absence of flammable components (including ammonia) in the equipment or piping has been ascertained.
- Continuous monitoring of the performance of the hydrogen converter is of crucial importance in the mitigation of the probability of an internal deflagration. It however does not mitigate the effect of a deflagration!

4.3. RISK PERSPECTIVE OF EXISTING PLANT CONFIGURATIONS

Before the introduction of the sphere type high pressure scrubber, Stamicarbon used to design cigar type high pressure scrubbers. Different types of cigar type scrubbers can be distinguished as the design has evolved over time. All types do not meet the criteria that form the basis for the design of the sphere type high pressure scrubber and do not meet the current safety standard of Stamicarbon.

As several customers who operate cigar type have requested to supply new (identical) cigar type high pressure scrubbers in Safurex® all types of cigar type scrubbers were assessed for possibilities to meet the current design criteria.

The conclusions can be summarized as following:

1. High pressure (strict identical) scrubber replacement in kind is not possible. With such replacement, either modification of the design (scrubber and/or process), additional safeguarding or operational constraints are always required.
2. Cigar type scrubbers on the principle of total condensation may have met Stamicarbon past design criteria but do not meet current safety design criteria.
3. Cigar type scrubbers on the principle partial condensation may need relatively little (mechanical) design changes to meet the current standard design criteria.

4.4. RISK BASED DECISION MAKING

At the moment a customer decides that replacement of a high pressure scrubber is due (end of lifetime) the customer might have a strong preference to plan for a "replacement in kind". An end of lifetime replacement is most of the time funded from a maintenance budget and requires no- or minimal modifications to the existing plant structure and piping arrangements. In case of a cigar type scrubber of partial condensation with a sufficiently large pressure relief volume this approach is perfectly acceptable. In all other cases it is preferred to transform the plant into an Evolve Melt Flash Design.

In case the customer persists in a replacement in kind, the unmitigated risk of such a configuration needs to be carefully evaluated. As the actual risk exposure is determined by many parameters, both in design as customer specific operating conditions, a comprehensive risk assessment of the present configuration is a pre-requisite. This initial assessment is to be prepared in close cooperation with the operator/customer as Stamicarbon will most likely not be aware of all operational conditions nor availability and effectiveness of existing safeguarding provisions.

In this respect a full understanding of operating conditions and safety measures is required to ensure that the replacement scrubber can be operated within (inter)nationally accepted risk acceptance criteria. Risk Acceptance Criteria (RAC) are frequently used worldwide in many industries.

These criteria allow the authorities or whoever adopts them to detect activities with high level of risk for the society or an individual. Their goal is to ensure that the level of risk is acceptable with respect to safety, cost and the environment and to balance and compare risk against the benefits. criteria that are used to express a risk level that is considered as the upper limit for the activity in question to be tolerable.

Within the EU the implementation of the Seveso III-directive 2012/18/EU is the basis for the legislator to define the criteria in relation to societal risks. As directives and standards do not contain RCA figures, authorities most of the time use F-N curves (Fig.4) which represent the function between the number of fatalities and their probability and can provide a good indicator for evaluating societal risks.

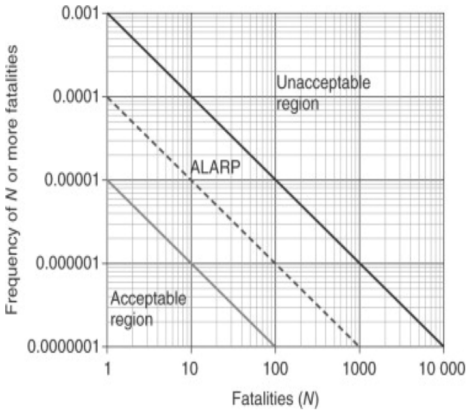


Fig.4 F-N curve example

In the implementation of the Seveso Directive the Dutch legislator has considered the individual risk of fatal injury of somebody in the public outside of the plant perimeter to be acceptable at an individual risk probability of 10^{-6} per year.
In general, the individual risk of plant population is considered acceptable at an order of magnitude higher than the public: 10^{-5} per year. Worldwide, RAC's in this order of magnitude are commonly applied.

In the petrochemical industry it is impossible to retro-actively bring existing facilities up to the latest design standards. Resources (manpower/budget) are scarce and will be allocated there where they create the highest benefits regarding risk mitigation, quality improvement or capacity gains. A risk based approach can help to evaluate the tradeoff between investment and obtained risk mitigation.

RAC's can be applied with regard to replacement projects in existing facilities. The initial risk assessment is the reference to determine what additional safety measures should be put in place to arrive at an acceptably low residual risk.

In the industry ALARP* (refer to Fig. 5) demonstration is commonly practiced to document that the safest alternative requires disproportional investment or is not technically feasible.

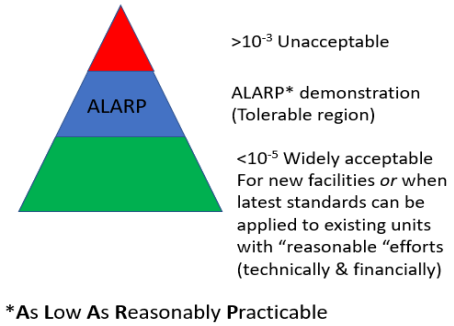


Fig.5 Example plant risk acceptance criteria

Although the licensor can advise in design solutions and facilitate the initial risk assessment, risk acceptance criteria are to be defined by the plant owner in conjunction with local and federal authorities (permitting).

4.5. VISUALIZING RISK AND MITIGATION OPPORTUNITIES

Stamicarbon can facilitate a risk assessment template by proposing a suitable methodology and drafting the parameters determining the actual risk level.
Populating this risk assessment template with actual process conditions and details around already implemented safeguarding remains however the responsibility of the plant operator.

4.5.1. Initial risk

A widely used risk assessment methodology is Fault Tree Analysis (FTA).
FTA is a graphical method that starts with a hazardous event and works backwards to identify the causes and enablers of the undesired event. Intermediate events related to the top event are combined by using logical operators such as AND and OR. This analysis method is mainly used in the fields of safety engineering and reliability engineering to understand how systems can fail, to identify the best ways to reduce risk or to determine event rates of a safety accident.
Failure modes of components being part of safety instrumented systems can be derived from industry databases or actual test records available at the operator of the facility.
An example of an FTA applied in a scrubber replacement project can be found in attachment 1.

4.5.2. Risk validation

Based on the current risk it should be evaluated whether this level of risk is in line with internationally accepted standards and federal/local legislative obligations.
If this is not the case, additional risk mitigation measures should be put in place.

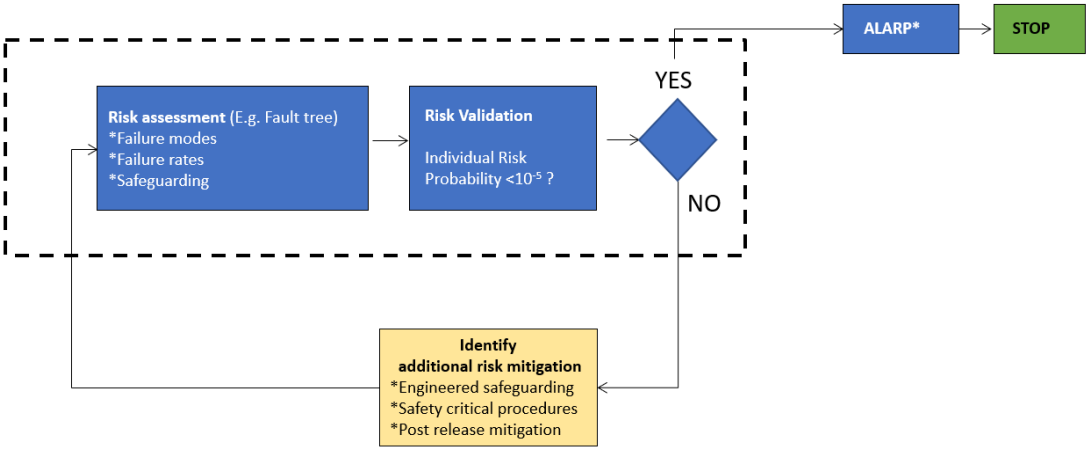


Fig.6 Sequence for risk validation

The effect of the implementation of additional mitigation measures should again be fed to the risk assessment tool to conclude whether the target individual risk probability is achieved.
If this can be confirmed the risk assessment should be documented by the customer in an ALARP document stating that the risk has been reduced to a level "As Low as Reasonably Practicable". This document may be required by the (local) regulator and should include the rationale why not the safest solution was chosen (Sphere type scrubber or Adiabatic flash revamp concept).

In the case of cigar type scrubber replacement projects, the most obvious arguments will be:

- Exceedance of the civil structure's max. load (sphere type scrubber adds weight).
- Disproportional costs to adapt piping isometrics (to fit in larger sphere type scrubber)
- Additional equipment and piping in the Adiabatic flash concept revamp.

As the "disproportional cost" criterium is arbitrarily, ALARP demonstration in relation to the replacement of existing HP scrubbers may be difficult to defend towards legislators as affordable technical alternatives are readily available.

4.5.3. Risk mitigation opportunities

In chapter 4.3 is concluded that high pressure (strict identical) scrubber replacement in kind is not possible. This statement will be supported by the outcome of the initial risk assessment which in most cases will call for additional risk mitigation measures to achieve the target risk probability.

Independent from the outcome of the initial risk assessment, the following design principles should at least be respected:

- For passivation of the synthesis materials, the application of air is mandatory. Application of enriched air or pure oxygen is prohibited for this application.
- Cigar type scrubbers based on partial condensation with a sufficiently large explosion dome volume are acceptable.
- Replacement of a cigar type high pressure scrubber on the principle of total condensation is only possible by a nowadays standard sphere type high-pressure scrubber. From safety point of view the frequency of occurrence of the presence of a flammable oxygen containing process gas is much higher as compared to the processes where a partial condensation is applied. That makes that the total condensation scrubber designs are more complicated and requires a much larger pressure relief volume caused by the presence of the volume required by the packed bed that is considered as a possible volume in which a flammable oxygen containing gas mixture can be present.

The high pressure cigar type scrubber with total condensation will not withstand an internal deflagration. The residual risk (Probability x Consequence) when operating these types of scrubbers can only be lowered by reducing the probability parameter; lowering the probability of the presence of an explosive atmosphere internally of the scrubber. This will however not mitigate the effect of a deflagration!

As already concluded in chapter 4.2; Continuous monitoring of the performance of the hydrogen converter is of crucial importance in the mitigation of the frequency of occurrence of the event of an internal deflagration. For this reason, all additional mitigation is focused on the reliability of the hydrogen converter.

In case a properly functioning hydrogen converter and a high quality ammonia feedstock (low hydrogen content) can be sustained, there are not enough combustible components to create a combustible mixture during normal operation and/or plant upset conditions.

Possible mitigating measures to lower the probability of an internal deflagration:

- Provide the hydrogen converter with a ΔT measurement to monitor its effective combustion process. Eliminate the human error probability (operator response to alarm) for the ΔT measurement by replacing it by a 2oo3 SIL2 temperature measurement and interlock.
- Provide the discharge of the hydrogen converter with a continuous analyzer with a safety critical alarm (dedicated annunciator) alarming at a too high hydrogen concentration. The units of the hydrogen analyzer should be indicated in ppm-vol to indicate a dangerous breakthrough of hydrogen.
- Lower Probability of Failure on Demand (PFD) of H_2 analyzer by more frequent calibration.
- Avoid instantaneous failure of the hydrogen converter (catalyst poisoning) by providing clean CO_2 (no lubrication oil from reciprocating compressors or ammonia plant catalyst contamination)
- NH_3 feedstock preferably to be supplied from a refrigerated storage tank or flash section
- Analyze NH_3 feedstock periodically to verify that H_2 content is sufficiently low.

As the scenario of rupture high pressure scrubber is categorized in the highest consequence, risk mitigation should be proportionate to the risk. To effectively mitigate a risk of this type, engineered protective layers should be in place. Only engineered layers of protection can be proof tested to ensure their availability during the full lifecycle of the plant.
Leaning on human intervention (operator response to an alarm), will not effectively reduce the risk to an acceptable value.

In adequate (engineering) measures as suggested above, are effectively implemented the probability of an explosive mixture in the HP scrubber will become very unlikely.

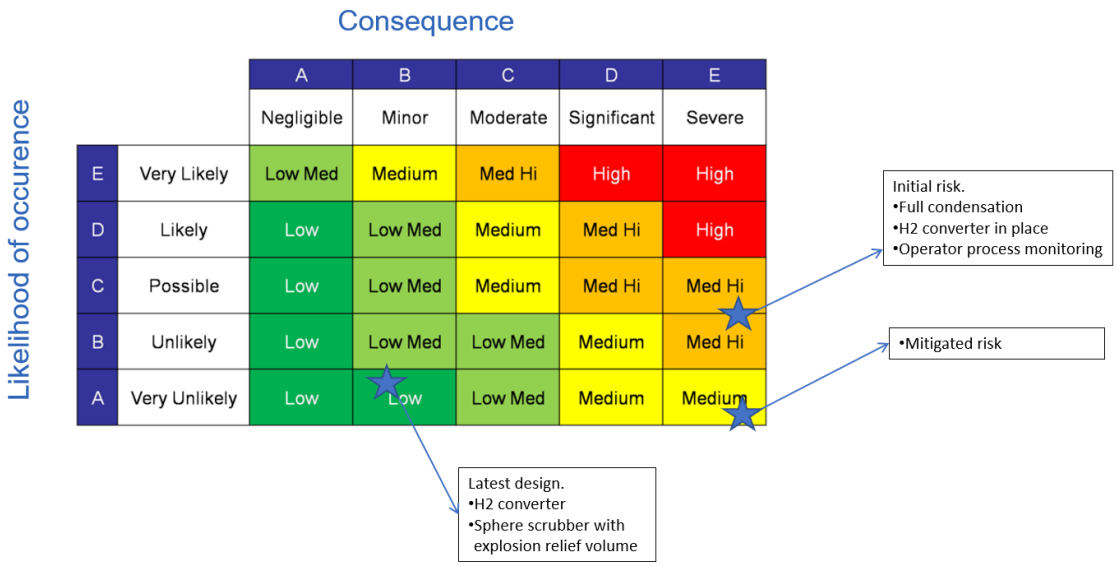


Fig.7 Plotted risk scenario after mitigation

Important note:
Engineering measures which are taken credit for need to be maintained during the lifetime of the facility. We must remember that the risk became acceptably low because of the presence and effectiveness of engineered risk mitigation. These scenarios should not be parked and forgotten but will require continuous attention; periodic loop testing of interlocks, testing records, control of defeat, training of personnel etc.

5. CONCLUSION

With respect to explosion risks, hydrogen is the dominant component contributing to an explosion in a urea plant. When in a high pressure scrubber, the vapors from the synthesis are fully condensed the passivation air in combination with hydrogen and other flammables can form a gas mixture that may lead to a deflagration.

Recently clients have requested Stamicarbon to replace their existing cigar type scrubber with an identical design.

As a knowledgeable licensor Stamicarbon is expected to not 'blindly' copy past scrubber designs (which an equipment manufacturer may do) but to engage with the client to be able to offer the 'best possible design' (also from safety point of view) within the boundaries set by the client such as but not limited to: budget, lead time, dimensions, weight, improved operating conditions, safety provisions etc.

Within the context of offering high pressure scrubbers in replacement projects the following prioritization sequence will be followed by Stamicarbon:

- Cigar type scrubbers of the partial condensation type are to be modified to accommodate an explosion dome volume as per latest standard.
- Cigar type scrubbers of the total condensation type are to be replaced by a sphere type scrubber with an explosion dome volume as per latest standard.
- Modify plant to the Evolve Melt Flash Design (Refer to Chapter 4). The high pressure scrubber will become obsolete and the LP absorber is to be designed deflagration proof.

- In case the client persists to identically replace a high pressure cigar type scrubber of the total condensation type, Stamicarbon can facilitate the clients' risk evaluation to achieve an acceptable low residual risk. To effectively mitigate a risk of this type, engineered protective layers should be implemented.

In this context, when ordering a replacement of a scrubber the client should be guided to make an "informed decision", fully understanding its operating conditions and safety measures in order to be able to operate the replacement scrubber within international (and local) acceptable conditions.

It should be considered that the owner of the Plant is responsible for the safe operation of its plant and is responsible for meeting requirements on process safety and mechanical integrity. The owner of the plant deals with local authorities and regulators.

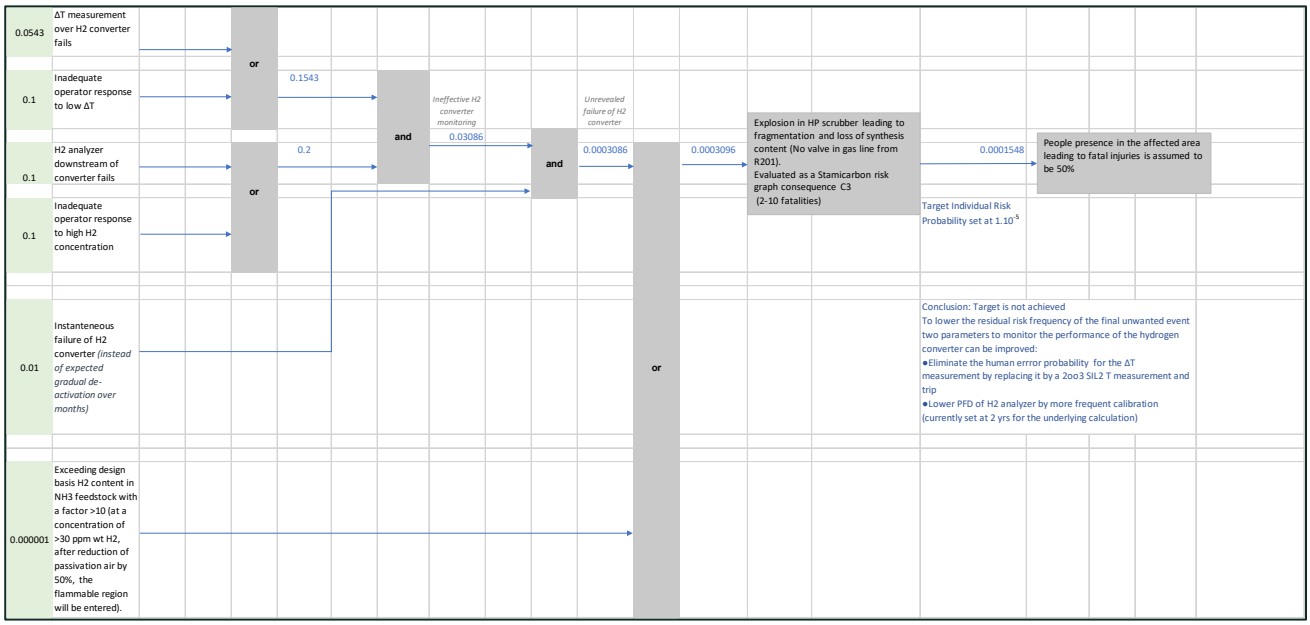
In terms of international codes, it is the responsibility of the 'user' of the equipment to identify scenarios that may lead to high pressure, to define pressure relief systems and eventually define the design pressure of the equipment.

For plants of other types (e.g. conventional plants or non-total recycle plants), Stamicarbon can be contacted in case of unclarity with the interpretation of the foregoing.

REFERENCES

- Y2K paper presented in the ammonia safety conference 2001.

Attachment 1



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