An innovative Safety Solution for Overpressure Protection in the Urea Synthesis Section

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Summary

Any stripping urea plant needs a protection system against overpressure to avoid operating pressures to rise higher than the design pressure of the High Pressure equipment and piping systems. Overpressure can for example occur in the situation that cooling capacity fails while the High Pressure stripper continues to produce strip gasses. All world standards require in such situations a safeguard by means of pressure safety valves.

Although these pressure safety valves are essential for protecting the High Pressure synthesis section against too high pressures, these also have some limitations and cause some troubles. In synthesis sections of a urea plant typically full lift safety valves are applied because of the large blow off volumes. In most situations the safety valves do not close properly anymore after opening. Furthermore SKW has experienced that sometimes a safety valve already fully opens before reaching the set pressure.

Excellent teamwork between SKW, its service partner Räcklebe & Totz, the safety valve manufacturer LESER and with the support of the licensor Stamicarbon, has resulted in an Innovative Safety Solution for Overpressure Protection in the Urea Synthesis section: Safety Valves with Supplementary Loading Systems (SLS) or also defined as Controlled Safety Pressure Relief Systems (CSPRS) according to ISO 4126-5. Pre-conditions are the use of the material SAFUREX® and special proprietary design and construction details.

The paper describes the step by step development and implementation of the Innovative Safety Solution for Overpressure Protection in the Urea Synthesis of SKW Piesteritz in Germany.

The following benefits have been achieved: Increased safety & reliability, operating pressure closer to the set pressure of the synthesis safety valve leading to higher conversion figures in the reactor; for the design of new urea plants, the design pressure of the High Pressure equipment items can be reduced leading to lower investment and longer inspection intervals.

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An innovative Safety Solution for Overpressure Protection in the Urea Synthesis Section

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INTRODUCTION

The Synthesis section is a very sensitive part of the UREA plant. In order to protect the equipment, spring loaded safety valves are commonly installed. The design has mandatory limitations because of physical properties of safety valve components. Unexpected behaviour with too early untightness and opening of safety valve was the main problem in the SKW Piesteritz UREA plant. SKW was the initiator of this innovation process.

SKW Piesteritz is the largest ammonia and urea producer in Germany and one of the most innovative fertilizer producers in Europe. Their plant is located in Lutherstadt Wittenberg, in a largely agricultural region of Saxony-Anhalt in eastern Germany. The roots of the fertilizer production located there can be traced back to the year 1915. Today SKW Piesteritz is part of the Czech Agrofert Holding, a.s. Around 770 employees at sites in Piesteritz and Cunnersdorf produce a broad range of agrochemical and industrial chemical products. Around three million tons are produced every year.

Räcklebe & Totz Industrieservice GmbH (R&T) is a service company for High Pressure Valves and Rotating Equipment.

R&T’s main business is the supply, installation and maintenance (both workshop and field) of these components. R&T is working for companies in various industries; one of their main customers is SKW Stickstoffwerke Piesteritz (ammonia, urea, nitric acid, coating resins).

R&T was responsible for the installation of the high pressure equipment in the SKW plant.

With more than 700 employees, LESER is the largest manufacturer of safety valves in Europe and a leader in its market worldwide. LESER safety valves are developed and tested for the international market in our certified test lab at LESER headquarters in Hamburg, Germany. Valve production, with a capacity of over 130,000 valves per year, takes place at our modern factory in Hohenwestedt, Germany.

For the urea industry, LESER has developed state of the art safety valves especially for carbamate services, which leads to a higher safety and reliability standard. These safety valves are available in 316L Urea Grade, 25-22-2, duplex and Safurex® material.

LESER developed the advanced safety valve and supplementary loading system.

Stamicarbon was founded in 1947 and is the world leader in urea licensing. In the 1990s new breakthrough innovations in the urea synthesis section were made with the development of the Urea 2000Plus™ PoolCondenser and PoolReactor technology, simplifying the design and construction and consequently lowering the investment cost. During last decade the Safurex® material and Stamicarbon fluid-bed Granulation technology were also developed.
DEVELOPMENT OF A SOLUTION

Any stripping urea plant needs a protection system against overpressure to prevent operating pressures from rising higher than the design pressure of the equipment and piping systems. For instance, overpressure can occur, if the cooling capacity fails while the high pressure stripper continues to produce strip gasses. All world standards require a safeguard by means of pressure safety valves in such situations.

Stamicarbon supported with process technology competence and gave assistance for the material definition.

Although these pressure safety valves are a must for protecting the high pressure synthesis section against overpressures, they also have certain limitations. In the synthesis sections of a urea plant, full lift safety valves are typically applied because of their large discharge capacities. Often several safety valves are installed in parallel and each has a slightly different set pressure to prevent all valves from discharging at the same time. At SKW, three full lift safety valves were installed with a discharge capacity of 52,000 kg/hr each.

According to ISO 4126-9 First Edition 2008 Annex A (refer to Attachment 1) and in similar regulations equal to API STD 520 8th Edition 2008 Part I, the typical pressure levels of the protected system and the safety valve device are shown as an overview. Common terms and definitions for the protected system are: maximum allowable working pressure (MAWP) and maximum allowable accumulated pressure (MAAP). In the industry it is common to set the safety valve at the same pressure as the defined MAWP.

Common terms and definitions for safety valves are: overpressure and blow-down, which indicate the pressure level of full opening and reclosing of safety valve when subjected to an overpressure situation.

The typical operating range of the system is below the reseating pressure plus additional margin of safe operation.

SKW EXPERIENCES UNTIL 2008

The pressure safety valves at SKW are designed to start to open at the set pressure ($P_s$), to fully open at a pressure of $1.05 \times P_s$ and to discharge the required flows at the maximum defined relieving pressure of $1.1 \times P_s$.

After opening, the safety valves should close again at a reclosing pressure of $0.9 \times P_s$. Therefore, safety valve manufacturers advise that the recommended operation is below $0.85 \times P_s$.

At SKW the three synthesis pressure safety valves start to open at $P_s = 157$ barg and at a pressure of max. 165 barg (5% over $P_s$) they are fully open and close again at a pressure of $\geq 141.3$ barg (-10%). Between opening and closing, large amounts of carbamate gas ($\text{NH}_3$ and $\text{CO}_2$) are emitted to the atmosphere. This is an inappropriate behaviour and an environmental problem.

In several situations the safety valves do not open or close as intended. As a consequence of crevice corrosion at the seat, SKW has experienced that a safety valve sometimes opens before reaching the initial adjusted set pressure.
A) Crevice corrosion

![Fig. 1 carbamate crystallization at safety valve outlet](image)

Traditional safety valves suffer from crevice corrosion problems causing small leakages which often go undetected. These small leakages can lead to the risk of crystallization of carbamate in the outlet line of the safety valve even when heat tracing is applied.

Furthermore, due to the increase of effective seat area the safety valve can open before reaching set pressure.

B) Erosion corrosion

Once the safety valve opens, the carbamate gas will flash from synthesis pressure to nearly atmospheric pressure leading to the formation of carbamate crystals, which can cause damage of the seat and disc. This leads to the risk of the safety valve no longer closing properly.

C) Operating in the sensitive operating pressure area

LESER states that spring loaded safety valves, which operate at an operating pressure for gas application between 0.85 – 1.0 x $P_s$ are operating in a sensitive pressure area. This is because of reduced closing forces which are a result of downward spring forces ($F_s$) and upward medium pressure forces ($F_p$).
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In this area a pressure peak can cause unintentional lift of the safety valve before it reaches set pressure.

**WORK ORDER OF SKW TO LESER**

The following requirements were targeted for the new overpressure protection system:

1. Safety valve should start to discharge as close as possible to and not before the set pressure to generate maximum tightness up to the set pressure
2. Safety valve should close as soon as possible after blowing-off to minimize medium loss to the environment
3. Safety valve should close without need for refurbishing to minimize plant downtimes
4. Availability and reliability should be maximum to generate maximum operation period

It was clear that a team of experts was needed to realize these challenging targets. SKW and R&T found a successful co-operation with the well-known safety valve manufacturer LESER in Germany and received support from Stamicarbon in the Netherlands.

**THE SOLUTION**

**Development of the LESER Flushing System**

LESER and Räcklebe & Totz investigated, if a standard LESER full-lift safety valve could be modified by introducing a steam injection which heats and flushes the seat. Substantial advantage was created by the construction material, Safurex®, which cannot suffer from crevice corrosion. This is caused by the metallurgical design of Safurex®.

LESER developed a steam injection which realizes in one step an indirect heating of the seat on the process side and a direct heating / flushing of the safety valve body and discharge piping. Furthermore, the steam injection flushes the seat when in open position, which reduces any risk of erosion/corrosion of the seat. Also in the case of a small leakage, such a flush system could prevent crystallization and erosion/corrosion of carbamate at the seat area.

The output of the design phase was a complex blockbody design which was produced with the LESER manufacturing technology from a Safurex® bar material.
Fig. 3  Closed position of LESER Flushing system safety valve

Fig. 4  Open position of LESER Flushing system safety valve

SKW installed these innovative safety valves in their three urea plants in 2008 and 2009. During the shutdown in 2011 these safety valves exhibited no corrosion or fouling on the inlet or outlet or main valve body, as shown in the picture below.
Although this innovation brings significant advantages, it does not realize all the set targets. These new safety valves (LESER-TYPE 526 DN50/80) still have the identical set pressure and closing pressure response as the old safety valves. For spring loaded safety valve the physical limitations are still that they close at a pressure up to 10% below the set-pressure. Also, vibrations and temperature fluctuations have a negative impact on their opening behaviour and can cause the spring loaded safety valve to pop up too early. This leads to the common practice of operators operating at a significantly lower synthesis operating pressure than the set pressure.

**Application of the Supplementary Loading System (SLS)**

To close as soon as possible after discharging and to minimize medium loss is a remaining target although the new design of LESER Flushing System for spring loaded safety valves was installed.

To supply the needed technology, these basic designs had to be compared regarding the applicability. Three basic types of safety valves - direct acting, pilot operated and supplementary loading system are known.

The oldest and most common type is the direct acting. Process pressure acts directly on a seat which is held closed by a spring. At a pressure close to the set pressure, some slight leakage (“simmer”) may occur between the valve seat and disc. This is due to the progressively decreasing net closing force acting on the disc (spring force minus force of inlet pressure).

As the operating pressure rises, the resulting force on the valve disc increases, opposing the spring force, until at the set pressure (normally adjusted to equal the vessel design pressure) the forces on the disc are balanced and the disc starts to lift.
As the vessel pressure continues to rise above set pressure, the spring is further compressed until the disc is at full lift. The valve is designed to pass its rated capacity at the maximum allowable accumulation. Following a reduction of vessel pressure, the disc returns under the action of the spring and reseats at a pressure lower than set pressure by an amount termed the blow-down.

Direct acting safety valves are subject to restrictions in respect to functional differences and the relevant attainable tightness on account of their physical features. Mandatory allowances applicable to directly acting safety valves can be substantially reduced by pilot operated safety valves or controlled (supplementary loaded) safety valves.

Pilot operated safety valves are controlled by process medium. To achieve this, the system pressure is applied to the pilot valve (= control component for the main valve) via the pressure pickup. The pilot valve then uses the dome above the main valve piston to control the opening and closing of the main valve.

With the supplementary loaded safety valve, the spring loaded reseating action is subjected to a supplementary force applied by a pneumatic actuator. A control system ensures that pneumatic pressure is supplied to the actuator through control lines. Impulses are transmitted to the control unit proper through redundantly arranged medium-carrying pressure tapping lines.

The individual control system automatically discharges the pneumatic loading pressure through relief valves when the specified set pressure is attained in the system section to be safeguarded. Then the
safety valve can open as intended. The opening action is assisted and the opening pressure differential is reduced when the controlled but oppositely acting pneumatic lifting pressure is applied in the actuator. When the pneumatic lifting pressure is active, the valve will open absolutely independent of the back pressure. The pneumatic loading pressure is applied again, if the opening sensing pressure drops below the specified level. The valve reseats faster than in common spring loaded safety valves. That is at a blow-down, which is lower than otherwise customary.

The top quality of pressure switches allows for accurate adjustment of the set pressure. Conform to ISO 4126-5 and VdTÜV type test approval No. 768, the LESER supplementary loading system works according the open circuit principle.

The principle is characterized by the fact that on failure of the external control energy the control unit does not change the loading or relief of the main valve. This means that the safety valve works like a spring loaded safety valve. Also other safety valve models can be equipped with the LESER supplementary loading unit provided that their design is suitable for the controlling force. The important specification requirements include:

- Automatic release of the additional controlling force if the set pressure is exceeded.
- At least three separate pressure tapping lines and sensing lines of the control unit.
- Release of controlling force by manual operation.
- Lifting of the safety valve by manual operation.
- Monitoring of sensing lines during operation.
- Multiple controls of several safety valves by one control unit.
- Normal operation of the direct acting safety valve in the event of a failure of the control energy (air).

**Pneumatic Actuator Units**

The size of the actuator unit (1, 2 or 3) depends on the required closing force of the safety valve at the defined set pressure.

LESER supplies the complete actuator fully assembled with the LESER safety valves. All spring loaded, flanged valves are available with actuators.

Flexible transfer hoses with non-interchangeable screwed connections for the control lines and a locking device are included in the supply.
Fig. 9  Pneumatic Actuator in loaded position

Fig. 10  Pneumatic Actuator in lifted position (with lifting air present)

1. Top piston
2. Loading air
3. Bottom piston
4. Lifting air
5. Reset spring
6. Pressure pins
7. Valve spindle
The pilot operated safety valves utilize the process pressure instead of a spring to keep the valve seat closed. When the set pressure of the pilot control is reached, it opens and depressurizes the volume above the piston, either to the atmosphere or into the discharge header, thus reducing the load on the top of the piston to the point where the upward force on the seat can overcome the downward loading. This causes lifting of the piston to its full open position.

With a supplementary loading system and pilot operated safety valves, one is able to operate the synthesis pressure much closer to the set pressure than with the direct acting safety valves.

The supplementary loading system is more suitable for Urea synthesis section protection because a process media controlled pilot operated safety valve may tend to have problems with crystallization of process medium (carbamate) in the relevant functions of the pilot.

It was discussed with LESER, if a conversion of existing safety valve to pneumatic controlled supplementary loading system safety pressure relief system according to AD2000 Merkblatt A2 and ISO 4126-5 would be feasible. This would lead to the benefits of opening and closing pressure of the safety valve being closer to the set pressure and the time period of opening being significantly shorter. This again would allow operators to run the synthesis pressure closer to the set pressure leading to higher plant capacity and/or lower steam consumption on the HP stripper. Furthermore emissions would be reduced.

However, the major concern was how to realize a safe and reliable pressure measurement as near as possible to the safety valves in the high pressure carbamate gas line from reactor to scrubber. Because of the corrosion and crystallization risks of the medium carbamate, the pressure cannot be measured directly. LESER proposes to measure pressure via a pressure transmitter.

Development of a pressure measurement system

In order to apply a SLS Safety Valve, it is important to assure that the pressure measurement system indicates the same pressure which is present at the safety valve. The allowable length of the capillaries is limited and it is critical that the distance between the control unit and actuator on the safety valve is limited to assure quick reaction of the safety valve.

As a result the pressure should be measured in the high pressure carbamate gas line where the safety valves are installed. A special pressure measurement system with a tantalum diaphragm is suitable for the high pressure carbamate gas and has been developed for accurate and reliable monitoring of the synthesis pressure. Crystallization and corrosion risks at the diaphragm are avoided by special (no dead pockets) design and construction details.

Three parallel pressure measurements are installed in order to have two spare positions for a sufficiently reliable (1 of 3) operation according to ISO 4126-5.
Testing and operational experience

The described three developments were combined into a complete full SLS safety valve system. This new SLS safety valve system uses pressure transmitters located at the protected system instead of a direct process medium transmitted system located in the control unit as it is applied for example in steam boilers. This pressure transmitted system has been approved by TUEV Nord Authorities in Germany according to European Pressure Equipment Directive and ISO 4126-5.

In August 2011, the SLS was successfully retrofitted to the safety valves in Plant #1 of SKW. During start-up of the plant the system was tested by introducing CO₂ to the synthesis in the presence of TUEV authorities.

At SKW a leakage of the safety valves is identified by a lower temperature in the discharge line of the safety valve. During the tests it was proven that the safety valves kept tight until set pressure and no temperature decrease could be measured. Further, SKW did test the opening and closing behaviour of the new safety valves with the following results:
An innovative Safety Solution for Overpressure Protection in the Urea Synthesis Section

Asian Nitrogen + Syngas 2013 International Conference (Singapore 30 October - 1 November 2013)

Table 1
Comparison opening and closing behaviour

<table>
<thead>
<tr>
<th></th>
<th>Specified</th>
<th>Actual</th>
<th>Old situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening pressure (full lift)</td>
<td>157 – 158.6 (max. +1%)</td>
<td>157.3 (+0.2%)</td>
<td>165 (+5%) barg</td>
</tr>
<tr>
<td>Closing pressure</td>
<td>152.3 - 157 (max. -3%)</td>
<td>155.0 (-1.3%)</td>
<td>141.3 (-10%) bar-g</td>
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</tbody>
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The tests shown in table 1 were repeated conform to the German regulation in presence of Third Party inspectors three times with the same result.

This result is a major improvement compared to the old traditional direct acting safety valves. Operational staff immediately noticed that they were able to operate the synthesis pressure at a higher level or closer to the set pressure. The former average synthesis pressure of 142 barg was increased to a higher level of 152 barg. Due to the higher pressure the reactor conversion figure increases approximately 2% leading to a significant higher plant load and/or lower steam consumption on the HP stripper.

Due to the fact that the SLS safety valves close much earlier than the spring loaded safety valves the discharging amount and thus emissions to the atmosphere are reduced considerably. The picture below shows the results of a simulation calculation of the difference between spring loaded safety valve and supplementary loading system.
In the figure above it can be clearly seen that the new SLS inclusive the LESER flushing system spring loaded safety valve allow a higher operating pressure without any risks of leakages. The additional closing forces of the Supplementary Loading System lead to higher tightness.

Furthermore, the new SLS safety valves will have a shorter blow-off time between set pressure and reseating pressure (refer to blow-off ZB versus blow-off SV in the figure). Blow-off SV depends on the reseating pressure, which will be maximum 10% below the set pressure.

Actual blow off experiences at SKW shows that LESER Flushing Safety Valves close tightly after blowing off and the amount of emissions is reduced by about 75 % when applying the SLS safety valves in the urea synthesis section.

The following benefits have been achieved:

- Increase of safety & reliability
  - About 75% lower emissions due to a shorter opening time of the safety valve
  - Significant reduction of the risk of leakage before set pressure
  - Less sensitive to pressure pulsations
  - Less sensitive to piping vibrations
  - No need for plant shutdown to do services after blow-off
  - Reliable pressure measurement in carbamate gas
- Increase of the working pressure from 142 to 152 barg
  - 2% higher conversion figures in the reactor
  - Significant higher plant capacities
  - Significant lower energy consumption figures
- For the design of new urea plants, the design pressure of the high pressure equipment items can be reduced, leading to lower investment figures
- Longer inspection interval (SKW goes from one year to two years)

SKW implemented this SLS Safety Valve system also in their two other urea plants during the turnaround in summer 2012.

**CONCLUSION**

Excellent teamwork between SKW, its service partner Räcklebe & Totz, the company LESER and with the support of the licensor Stamicarbon has resulted in an Innovative Safety Solution for Overpressure Protection in the Urea Synthesis section.
Pre-conditions are the use of the material SAFUREX® and special proprietary design and construction details.

Safety aspects have been completely fulfilled with the sub-steps LESER Flushing System and Supplementary Loading system.

Economically the solution enables the operating company to produce more UREA per day.

This innovation can also be applied at the pressure safety valves of the recirculation section of a urea plant in order to realize more operational flexibility and lower emissions.

Additionally, it can offer significant benefits in the ammonia synthesis section.
ATTACHMENT 1: ISO 4126 EDITION 2008 ANNEX A

Annex A
(informative)

Safety device applications

% of maximum allowable pressure, \( P_s \)

- Maximum allowable short duration (momentary) pressure surge
- (or Accumulation)

Maximum allowable accumulated pressure: \( 100 + X \)

Relieving pressure

Overpressure \( \leq X \% \)

Set pressure

Reeating pressure

Marginal for safe operation

Operating range

Figure A.1 — Safety valve applications — Safety valve certified at \( X \% \) overpressure or less