ThyssenKrupp Industrial Solutions

In Arzew, Algeria, we built the Sorfert complex comprising 2 x 2,200 t/day ammonia plants and a 3,450 t/day urea plant based on our proven Uhde ammonia process, UFT urea granulation technology and the Stamicarbon urea melt process.

4,400 t/day of ammonia

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Leading fertilizer technologies – Ammonia

In order to secure global food supplies, our engineers at ThyssenKrupp Industrial Solutions have been developing large-scale plants for the fertilizer industry for over 80 years now. As a leading general contractor we offer our customers throughout the world a wide range of cutting-edge Uhde technologies.

Engineering Excellence

ThyssenKrupp Industrial Solutions
Contents

04  ThyssenKrupp Industrial Solutions’ ammonia experience
07  The Uhde ammonia process
08  - Steam reforming
10  - CO₂ removal
11  - Ammonia synthesis
12  - Steam system
13  - Concept variants
14  - The Uhde Dual-Pressure Process
16  Proprietary Uhde equipment designs
17  - The Uhde primary reformer with a cold outlet manifold system
20  - The Uhde secondary reformer
21  - Process gas cooling train downstream of the Uhde secondary reformer
22  - Uhde ammonia converter and waste heat recovery
25  - Production and consumption figures
26  Services for our customers
27  Recent references
Having erected several thousand plants, ThyssenKrupp Industrial Solutions is one of the world’s leading engineering companies. Our Business Unit Process Technologies supplies chemical plants, refineries and coking plants on the basis of tried-and-tested technologies made by Uhde, while the portfolio of the Business Unit Resource Technologies comprises complete cement plants and grinding systems of the Polysius brand, as well as machines, plants and systems for mining, extraction, preparation, processing or transhipment of commodities.

With many years of experience in the EPC business, we offer our customers concepts, market studies, plant layouts, design engineering, supplies, manufacturing services, erection and commissioning – all from a single source. Our employees on all continents use their knowledge and engineering competence to create innovative solutions and to look for ways to conserve natural resources.

Over 40 locations in 25 countries – divided into six regions – form a close-meshed network that allows us to align our services to local conditions consistently. Thanks to this on-site expertise and global networking, we are able to set standards that offer our customers a true competitive edge.

Our comprehensive service concepts take the entire life cycle of a plant into account. We offer OEM spare parts service and complete maintenance management, as well as servicing, modernisation projects and conversions.
ThyssenKrupp Industrial Solutions’ ammonia experience

The first ammonia plant to use an Uhde proprietary process went on-stream at the site of the Mont-Cenis coal mine at Herne-Sodingen, Germany, as far back as 1928. The plant had an output of 100 t/day of ammonia and comprised four reactors with a capacity of 25 t/day each, the loop operating at a pressure of 100 bar.

The fact that the first Uhde-engineered ammonia reactors were equipped with an internal heat exchanger and a synthesis loop with an integrated two-stage refrigeration unit deserves a special mention. Unfortunately, this efficient system was soon considered outdated, and it was not until the seventies that these design principles were taken up again.

Rising energy prices have posed an increasing challenge for ammonia plant designers since this period. As early as 1968, Uhde took up the challenge and engineered a plant with an energy consumption of only 7.8 Gcal per tonne of ammonia.

This natural gas-based plant with a capacity of 880 t/day incorporated the following essential elements for reducing energy consumption:

- Maximum heat recovery from the primary reformer flue gas by cooling it to 135°C at the stack inlet.
- Preheating of the combustion air for the primary reformer.
- Generation of 125 bar steam from process waste heat downstream of the secondary reformer and in the ammonia synthesis unit.
- High-pressure steam superheating with waste process heat downstream of the secondary reformer.
- Three-bed ammonia reactor with heat exchangers between catalyst beds.

All subsequent ammonia plants designed by ThyssenKrupp Industrial Solutions have incorporated most of these low-energy features.

In recent years, ammonia plant technology has undergone radical developments in terms of both design and equipment. In order to improve plant efficiency, efforts have had to be focused on reducing power consumption, improving process heat recovery, minimising stack losses and cutting energy consumption for CO₂ removal.

The company’s objective of making a substantial improvement in energy efficiency has relied heavily on experience and involved a broad spectrum of technical expertise including a technical review of process design, engineering design, research and development and the evaluation of operating data. Equally important has been the enhancement of plant operability and reliability. Hence, much attention has been paid to past successful experience and proven energy-saving features.

In 1998, Uhde joined forces with Synetix, now Johnson Matthey Catalysts (JMCatalysts), to further improve the Uhde ammonia process. This partnership builds on the traditional strengths of the two companies and takes advantage of JM Catalysts’ know-how in catalysis, ammonia plant operation and support services together with the experience in design, engineering and project execution that ThyssenKrupp Industrial Solutions can offer. The partnership allows strong collaboration between JM Catalysts and ThyssenKrupp Industrial Solutions’ engineers so that the Uhde ammonia process can be further optimised to take best advantage of the latest high-performance catalysts from JM Catalysts, thus improving efficiency and lowering cost.

The most recent successful implementations of the Uhde ammonia process include a plant in Turkmenistan with a capacity of 600 t/day, a 2,000 t/day plant for Qatar Fertiliser Co. (QAFCO) in Mesaieed, Qatar, seven 1,200 t/day plants in Egypt, a 2,000 t/day plant in the UAE (FERTIL 2) and a 2,200 t/day plant in Iowa, US, which is under construction.

A new milestone in ammonia technology was achieved with the plant built for Saudi Arabian Fertilizer Company (SAFCO) in Al Jubail, Saudi Arabia. It was the first plant to be based on the "Uhde Dual-Pressure Process" and, with a single-train capacity of 3,300 t/day, it was and still is one of the world’s largest ammonia plant. Built in 2006, it has since been marginally topped by an Uhde Dual-Pressure plant built in Saudi Arabia (MAADEN I). Two other plants of this type and capacity are currently under construction, one in Saudi Arabia (MAADEN II) and the other in Louisiana, US.
Ammonia plant in fertiliser complex in Tecen, Turkmenistan.
Capacities:
- 600 t/day of ammonia
- 1,050 t/day of urea synthesis
- 1,050 t/day granulation unit

Process flow sheet of Uhde’s first ammonia plant in Herne, Germany, completed in 1928.
1,500 t/day ammonia plant and fertiliser complex, Saskferco, Canada
The Uhde ammonia process

The block diagram of an Uhde ammonia plant found below shows the conventional sequence of process steps that form the basis of most present-day ammonia processes. However, ammonia processes cannot be judged solely on the basis of a block diagram. A more detailed scrutiny of the facts and figures shows that what appears to be a conventional set-up is in fact a state-of-the-art ammonia plant concept.

The total consumption figure (feed + fuel + electric power) per metric ton of ammonia produced is in the range of 6.4 to 7.2 Gcal (26.8 - 30.1 GJ), depending on local conditions (e.g. cooling water temperature) and project-specific requirements (such as the natural gas price, etc.).

The following process areas have undergone major modifications in order to achieve these figures:

- Steam reforming section including its waste heat recovery system.
- Steam system.
- Optional gas turbine drive for the process air compressor.
- CO₂ removal unit.
- Ammonia synthesis unit.

Assuming the reader to be familiar with the basics of ammonia technology, attention in the following sections has been restricted to those aspects specific to the Uhde low-energy concept.
The following modifications to conventional plant designs have contributed to improvements in overall efficiency:

- Shift of part of the reforming reaction from the primary to the secondary reformer as a result of the following measure:

  Installation of a purge gas recovery unit, by means of which hydrogen is recycled to the suction side of the syngas compressor, thereby allowing operation of the secondary reformer with excess air while the hydrogen-to-nitrogen ratio of the make-up gas is kept close to 3:1.

- Preheating of the process air for the secondary reformer to a higher temperature of up to 600°C. Shifting part of the reaction to the secondary reformer leads to lower operating temperatures in the primary reformer and therefore to fuel savings.

- Optimum use of the reduced primary reformer load is achieved by increasing the reformer pressure to about 44 bar whilst maintaining the estimated lifetime of the reformer tubes at 100,000 hours. This step entails a reduction in overall energy consumption as the aggregate power required for the synthesis gas compressor is reduced.

- Increase in the feed/steam mixture preheat temperature. This reduces the firing requirements in the primary reformer by shifting the heat transfer duty from the radiant section to the convection section.

- Decrease in the steam-to-carbon ratio to 3.0. This includes an adequate safety margin against the formation of carbon deposits on the primary reformer catalyst. Reducing the admixture of steam to the feed results in less heat being absorbed in the primary reformer radiant section and therefore lower fuel consumption. Nevertheless, the steam-to-gas ratio is high enough to minimise by-product formation in the HT shift through the use of commercially proven catalysts.

The process data of the reforming section are summarised below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam/carbon ratio</td>
<td>3.0</td>
</tr>
<tr>
<td>Feed/steam, primary reformer inlet °C</td>
<td>530 - 580</td>
</tr>
<tr>
<td>Pressure, primary reformer exit bar</td>
<td>39 - 43</td>
</tr>
<tr>
<td>Methane, primary reformer exit vol.%</td>
<td>10 - 13</td>
</tr>
<tr>
<td>Methane, secondary reformer exit vol.%</td>
<td>0.3 - 0.6</td>
</tr>
<tr>
<td>Process air temperature °C</td>
<td>520 - 600</td>
</tr>
<tr>
<td>Combustion air temperature °C</td>
<td>250 - 440</td>
</tr>
<tr>
<td>125 bar steam, superheated °C</td>
<td>530 - 540</td>
</tr>
<tr>
<td>Stack temperature °C</td>
<td>120 - 180</td>
</tr>
</tbody>
</table>
Special mention should be made of an essential item of equipment in the steam reforming section: the steam superheater, located in the process train downstream of the secondary reformer.

In a low-energy plant, the objective is to recover as much heat as possible from the convection section for direct process use, thereby reducing the fuel requirement. This reduces the heat available in the convection section for superheating HP steam. The balance of the energy required for this purpose is therefore recovered in the superheater downstream of the secondary reformer. The duty of this superheater is in the range of 15 to 40% of the heat available between the secondary reformer exit and HT shift inlet, depending on the process parameters selected.

The lower the fuel consumption figure, the more process gas heat is utilised to superheat the HP steam, whereas the total HP steam generated is reduced. In other words: fuel savings also reduce the net energy export.

A superheater of this type was installed by what was then Uhde for the first time in the Gewerkschaft Victor plant, which went on stream in 1970. This same design configuration was also used for the CIL plant in Canada (on-stream since 1985) and is now the superheater of choice in all of the ammonia plants recently built by ThyssenKrupp Industrial Solutions. Firstly this arrangement provides the necessary flexibility to adapt the plant to any given set of process requirements, and secondly, it enables the steam system to operate safely under any normal, or abnormal, operating conditions.

An internal bypass in the evaporation section permits the shifting of heat transfer duty between the evaporator and the steam superheater. In normal operation, the internal bypass remains partially open. By closing it, the gas temperature at the superheater inlet can be reduced, thus increasing steam generation. This is important in overcoming partial plant failures, e.g. in the case of a loss of steam production in the ammonia synthesis section.
The Uhde ammonia process
CO₂ removal

Various chemical and physical absorption systems are available for the removal of CO₂, e.g. aMDEA®, Benfield, Amine Guard and Selexol. ThyssenKrupp Industrial Solutions has used all these processes in the past and has the experience of many years of commercial operation. The lowest energy consumption is achieved using the OASE WHITE® process licensed by BASF. The key to these energy savings is that the solution is primarily regenerated by flashing rather than steam stripping.

The activated OASE WHITE® process uses a solution of N-methyldiethanolamine and water with a special activator as the solvent. As the activated MDEA solution isotherms for CO₂ are between those of a typical chemical solvent and a physical solvent, this process combines the benefits of both chemical and physical CO₂ removal processes.

The design selected incorporates a two-stage absorber. Most of the CO₂ is removed in the lower part using a semi-lean solution that has been regenerated in a two-stage flash loop without any need for stripping energy. Final purification to the ppm range then takes place in the upper part of the absorber with a relatively small portion of the total circulating solvent. It is only this portion that has to be thermally regenerated by a stripping process in a reboiling column. This process scheme permits a reduction in the specific energy consumption of the CO₂ recovery system to 1,340 kJ / Nm³ of CO₂ (13,000 BTU / lb mole of CO₂).

In addition, the process offers the following advantages:

- High CO₂ recovery rate (> 96%) and CO₂ purity (> 99% by volume).
- No need for corrosion inhibitors as the solution is not corrosive to carbon steel.
- Minimisation of solution losses because activated MDEA has a low vapour pressure and does not degrade during operation. No reclaiming of the solution is required.
- No toxic solvents.
- No crystallisation problems.
The Uhde ammonia process
Ammonia synthesis

The most fundamental improvements to earlier designs have been effected in the ammonia synthesis unit.

The main feature of this unit is its high conversion rate which is achieved by a large catalyst volume. In order to minimise reactor size and cost while keeping the pressure drop low, the large catalyst volume requires:

- Use of small grain-size catalyst.
- Application of the radial-flow concept in the ammonia reactor.

Uhde has always advocated three-bed reactors with high ammonia conversion rates per pass. Therefore, the Uhde ammonia synthesis unit is based on a three-bed reactor system, each bed with a radial flow. A high-conversion synthesis loop offers considerable advantages since the recycle gas quantity is considerably reduced and, consequently, power requirements for the circulator are lower and heat exchanger surfaces smaller. Refrigeration requirements also decrease overproportionately because most of the ammonia produced is condensed upstream of the loop chiller.

Studies on innovative high-activity precious metal-based catalysts have revealed that no economic advantage can be gained through their use in view of the uncertainty of future prices for the precious metals required. Furthermore, due to the different physical properties operational problems can be expected. For maximum reliability and cost-effectiveness ThyssenKrupp Industrial Solutions therefore uses only well-proven magnetite-based catalysts in all three beds. The first of the three beds will typically be filled with prereduced catalyst to accelerate the initial start-up.

Depending on the site-specific and project-specific conditions, the three catalyst beds are arranged in either one or two ammonia reactors.

Designs with one ammonia reactor and one waste heat boiler cannot optimally exploit the reaction heat for the generation of high-pressure steam. However, optimum heat recovery can be achieved if an additional waste heat boiler is introduced between the second and third bed.

This arrangement improves the gas-side temperature of the boilers and provides an additional advantage in that it permits a higher boiler feed water temperature at the boiler inlet, which means that the preheating of the boiler feed water can be enhanced by using the low-level heat available in other plant sections, for example downstream of the LT shift.

The effect of a two-boiler system on high-pressure steam generation is significant: it is increased from 1.1 to 1.5 t/t of ammonia. The process parameters of the synthesis loop design are shown below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{H_2}{N_2}$ ratio, methanation exit</td>
<td>2.95</td>
</tr>
<tr>
<td>Synthesis loop pressure</td>
<td>bar</td>
</tr>
<tr>
<td>$NH_3$ reactor inlet</td>
<td>vol.%</td>
</tr>
<tr>
<td>$NH_3$ reactor outlet</td>
<td>vol.%</td>
</tr>
<tr>
<td>HP steam generation</td>
<td>t/t $NH_3$</td>
</tr>
<tr>
<td>Number of reactors</td>
<td>1 or 2</td>
</tr>
</tbody>
</table>

Ammonia synthesis
The Uhde ammonia process
Steam system

The diagram shows the heat management system underlying the Uhde low-energy ammonia plant concept, the essence of which is the optimum utilisation of process waste heat for the generation of superheated high-pressure steam.

High-pressure boiler feed water is heated in a first step downstream of the LT shift; the stream is then split into two, one part-stream going to the ammonia synthesis unit and the other to the HT shift for further preheating.

High-pressure steam is only generated from process waste heat at two locations:

- Downstream of the secondary reformer.
- In the ammonia synthesis unit.

Superheating of high-pressure steam takes place downstream of the secondary reformer and in the primary reformer convection bank.

The superheated steam is expanded in the high-pressure part of the syngas compressor turbine and fed to the medium-pressure system.

Medium-pressure steam at 49 bar, 415 °C, is used as process steam or for the following equipment:

- Condensing turbine that drives the syngas compressor.
- Condensing turbine that drives the process air compressor / alternator.
- Back-pressure turbine driving the boiler feed water pump.

Depending on the plant requirements, the process air compressor turbine or the refrigeration compressor turbine can be fed with HP steam. All other machines are driven by electric motors.

Further reduction of the overall energy consumption is achieved by application of a gas turbine drive combined with a heat recovery system.
The plant concept presented here constitutes the basis of the Uhde low-energy ammonia technology. The design can easily be adapted to suit the specific conditions of any project. Variations may range from minor process modifications (e.g. in the steam system) to the replacement of entire units (e.g. substitution of the aMDEA® CO₂ removal system for an Amine Guard, Benfield or Selexol unit).
The Uhde ammonia process
The Uhde Dual-Pressure Process

Chemical plant capacities have for a long time been taking on ever greater dimensions. The reason for this is the reduction of the specific production costs through economies of scale. More than ever before, the plant construction sector is facing the challenge of exploiting this advantage while at the same time continuing to employ proven technologies and equipment.

ThyssenKrupp Industrial Solutions and Johnson Matthey Catalysts have risen to this challenge and developed a process based on existing technology which now enables ammonia plants to produce very large capacities. This new process (see flowsheet) delivers a capacity of 3,300 t/day using well-tried and tested equipment. It also provides the basis for even larger plants (e.g. 4,000 - 5,000 t/day).

The first plant to apply this process was the SAFCO IV ammonia plant in Al-Jubail, Saudi Arabia. With a capacity of 3,300 t/day it was by far the largest ammonia plant worldwide. The plant has been in operation since 2006. A second plant based on the Dual-Pressure Process came on stream with a similar capacity in 2011 and the next two plants are under construction.

The key innovation of the Uhde Dual-Pressure Ammonia Process is an additional medium-pressure once-through ammonia synthesis connected in series with the conventional high-pressure ammonia synthesis loop as follows:

1. The once-through ammonia synthesis involves compression of the make-up gas in a two-stage intercooled compressor. This is the low-pressure (LP) casing of the syngas compressor. The pressure at the discharge of the compressor is about 110 bar. At this pressure the three-bed, intercooled, once-through converter produces approximately one third of the total ammonia output. The syngas-ammonia mixture leaving this converter is cooled and 85% of the ammonia produced is separated from the gas as liquid.

2. The remaining syngas is then compressed in the high-pressure (HP) casing of the syngas compressor to the operating pressure of the ammonia synthesis loop (up to 210 bar). Since the syngas has been cooled down the HP casing can operate at a much lower temperature than in the conventional ammonia process. The high synthesis loop pressure is achieved through a combination of the chilled second casing of the syngas compressor and a slightly elevated front-end pressure. In this conventional ammonia synthesis loop the remaining two thirds of the total ammonia is produced.

Technology highlights

- Well-proven magnetite-based catalysts can be used in all stages of the new process.
- Energy efficiency is improved by 4% compared to the conventional Uhde process.
- A high conversion rate in the high-pressure synthesis loop combined with the reduced production requirement results in reduced piping sizes in the high-pressure loop. Standard piping can be used for capacities of 4,000 t/day and more.
- The syngas compressor of a 3,300 t/day dual-pressure plant is the same size as that in current 2,000 t/day ammonia plants; several reference compressors are in operation.
- Only 2/3 of the hydrogen recovered from the purge gas has to be recompressed to the loop; 1/3 is converted to ammonia in the once-through synthesis.
- The process design is extremely flexible with a large number of process parameters available to optimise the use of catalyst and machinery.
- It is now possible to achieve a synthesis capacity of about 3,300 t/day of ammonia using conventional equipment and catalysts that have proved to be reliable and efficient in existing plants.
- There are no major deviations from proven process conditions.
- The front-end of the plant is very similar to the conventional Uhde design except that it operates at a pressure of about 3 bar higher, a process condition which is well within our proven long-term design and operating experience.
The Uhde Dual-Pressure Ammonia Process

Second ammonia converter

Once-through ammonia converters

Off-gas

Purge gas recovery

NH₃ chiller

NH₃ from once-through conversion

Make-up gas from front-end

NH₃ chiller

H₂O

CW

Note: Molecular sieves (dryers) not shown

First ammonia converter

LP casing

- 110 bar

- 210 bar

HP casing

NH₃ chiller

CW

NH₃ chiller

Ammonia from front-end

~ 210 bar

NH₃

Low pressure section

High pressure section

HP steam

HP steam

PGR unit

NH₃ from HP loop

HP steam

NH₃ chiller

CW

CW
A good process alone is not sufficient. It is at least as important to have proven and reliable designs for critical items of equipment. Only the two combined will make a good plant.

ThyssenKrupp Industrial Solutions has pioneered the development of essential items of equipment for ammonia plants and is one of the leading contractors in this field. These developments include:

- Primary reformer with a cold outlet manifold system.
- Secondary reformer.
- Process gas cooling train downstream of the secondary reformer for generating high-pressure steam and superheating high-pressure steam.
- High-efficiency ammonia converter system with three beds, indirect heat exchange and radial flow.
- Ammonia synthesis waste heat boiler.

ThyssenKrupp Industrial Solutions holds, or has pending, a number of patents for such equipment and has granted numerous manufacturing and marketing licences to equipment manufacturers and chemical engineering contractors.
The Uhde primary reformer is a furnace in which a multiplicity of tubes filled with catalyst are heated by burning fuel. The process gas temperature required at the outlet of the catalyst-filled tubes is about 800°C at a pressure of approximately 45 bar. Inevitably, the service life of components such as the reformer tubes is limited. Material deterioration occurs through the combined effects of creep, alternating thermal and mechanical stresses, external and internal oxidation and carburisation.

Consequently, the furnace designer is faced with two main tasks:

- Firstly, to minimise the number of components subject to wear and tear due to the combined effects of high temperatures and pressures.
- Secondly, to allow as smooth and safe an operation as possible.

The following main features show our approach to fulfilling the above requirements:

- Top-firing for an optimum uniformity of the tube skin temperature profile.
- Small number of burners (in comparison with a side-fired reformer).
- Internally insulated cold outlet manifold system made from carbon steel and located externally under the reformer bottom.
- Internally insulated reformer tube-to-manifold connection which operates at moderate temperatures.
- Each tube row is connected to a separate outlet manifold.

Advantages of the Uhde reformer:

- No high-alloy outlet pigtails and/or outlet manifolds or risers which work at creep conditions.
- Minimum number of components exposed to the severe process conditions.
- Uniform temperature profile over the entire length of the reformer tube with the lowest possible peak temperature, resulting in optimum utilisation of the reformer tube material.
- No thermal expansion problems with the outlet manifold system. The slight remaining thermal expansions do not have to be compensated by materials exposed to the severe process conditions. The design of very large single-box reformers is possible.
- The process gas outlet temperature is monitored for each tube row and is adjustable during operation for optimum reformer performance and temperature uniformity.
- Almost unlimited service life of the Uhde outlet manifold system with no maintenance required other than painting.
- Considerable operational allowance of the outlet manifold system with regard to process gas temperature and pressure.

More than 60 reformers of this type have so far been designed and constructed since 1966. All have performed excellently. The two largest units are equipped with 630 and 960 tubes, respectively.
Fertiliser complex no. 4 (SAFCO IV) for Saudi Arabian Fertilizer Company in Al Jubail, Saudi Arabia
Capacities: 3,300 t/day of ammonia
3,250 t/day of urea
3,600 t/day granulation unit
Proprietary Uhde equipment designs
The Uhde secondary reformer

Particularly challenging areas in secondary reformer design include:

- The transfer line from the primary reformer outlet to the secondary reformer.
- The refractory lining including the ceramic arch which bears the catalyst weight.
- The burners.

ThyssenKrupp Industrial Solutions’ answer to a safe and reliable secondary reformer comprises the following features:

- A refractory-lined transfer line between the primary and secondary reformer, which is only short as it is connected to the process gas inlet nozzle of the secondary reformer. Once in the secondary reformer, the gas passes through an internal riser into the combustion chamber. This design facilitates ducting and eliminates thermal stress between the transfer line and the secondary reformer.
- A multi-layer refractory lining with high-alumina bricks in the hot zones.
- A ring-shaped arch made of high-alumina bricks that provides a highly stable support for the catalyst. Due to the internal riser, the arch spans only half of the vessel diameter, resulting in improved stability compared to other designs.
- A multiple nozzle burner system comprised of nozzles equally distributed round the circumference of the combustion chamber at two levels.
- Discharge of the process gas from the central internal riser into the dome by reversing the flow direction. Air is added via a specific number of nozzles installed in the vessel wall at a defined angle, thus creating a vortex flow in the combustion chamber. The vortex flow ensures optimised mixing of air and process gas. The flames do not come into contact with the vessel refractory or the central riser pipe.
- A proprietary burner design, first applied in 1992, which avoids any metallic parts coming into contact with the hot reacting process gas.

Since its introduction in 1968, the Uhde secondary reformer has proved to be a reliable item of equipment with a long service life.
Proprietary Uhde equipment designs
Process gas cooling train downstream of the Uhde secondary reformer

The process gas from the secondary reformer has to be cooled from 1,000°C to a controlled temperature suitable for the downstream CO shift. The sensible heat can best be utilised in the generation and superheating of high-pressure steam.

The challenge in designing suitable cooling train equipment is to arrive at a concept which provides safe temperature limitation for all parts according to their particular load sensitivity and materials of construction. In addition, the equipment should be available at competitive prices.

Since 1966, ThyssenKrupp Industrial Solutions has both used and promoted use of the horizontal fire-tube boiler for this purpose. In 1969, the process gas cooling train was first modified to include a high-pressure steam superheater.

**Features of the Uhde process gas cooling train**

**Horizontal fire-tube boiler with:**
- Thin flexible tube-sheet design.
- Full-penetration tube to tube-sheets welds.
- Tube inlets protected by ferrules to limit the head flux at the tube inlet.
- Double layer refractory lining for the inlet and, if necessary for the outlet chamber with high-duty bricks on the hot surface.
- Internal gas bypass for temperature control with steam-cooled damper blades.
- Steam drum mounted on top of the boiler and supported by downcomers and risers.

**High-pressure steam superheater with:**
- Process gas inlet and outlet at the bottom.
- Preferably vertical arrangement of the superheating coil.
- Pressure shell in contact with the cooled process gas only.
- Internal bypass for temperature control.

**Advantages of the horizontal fire-tube boiler:**
- Simple, fixed-tubesheet design.
- No crevice corrosion.
- Reliable natural water circulation.
- No heated dead ends on water side where debris can settle.
- Low metal temperatures at and near tubesheets due to efficient insulation and ferrules.
- Simple and reliable process gas temperature control.
- Easy access for inspection and maintenance.
- Low erection costs due to shop assembly of boiler and drum.

**Advantages of the high-pressure steam superheater:**
- Coil designed for high mechanical flexibility.
- Thermal expansions compensated for within the coil.
- Safe metal temperatures maintained by efficient bypass control.
- Temperature of the pressure-bearing shell governed by cooled outlet gas.
- Simple steam and process gas temperature control.
Proprietary Uhde equipment designs
Uhde ammonia converter and waste heat recovery

The demand for energy-efficient ammonia production dictates the following criteria for the design of the ammonia synthesis unit:

• High conversion rates and therefore large catalyst volume.
• Maximum utilisation of reaction heat for the generation of high-pressure steam.
• Low pressure drop in the loop.

Such criteria, in turn, call for the:

• Use of fine-particle catalyst.
• Application of the radial-flow principle.
• High-pressure steam generation wherever feasible.

The Uhde ammonia synthesis design therefore incorporates three radial-type catalyst beds arranged in either one or two ammonia converters.

**Features of the Uhde single-converter design:**

• Heat exchanger between catalyst beds for indirect cooling of synthesis gas; consequently, highly efficient temperature control.
• Radial flow from outside to inside through all catalyst beds.
• Design adaptable to full-bore or drawn-in top closure of converter, depending on project constraints.
• Heat exchangers extractable without removal of cartridge.
• An externally arranged BFW preheater/HP steam boiler downstream of the third bed.

**Features of the Uhde two-converter design:**

• Location of the first two catalyst beds in the first converter vessel and of the third bed in the second converter vessel.
• Radial flow from outside to inside through all catalyst beds.
• Simple U-tube heat exchanger between first and second catalyst beds for indirect cooling of the synthesis gas.
• Design adaptable to full-bore or drawn-in top closure of converter, depending on project constraints.
Easy withdrawal of internal heat exchanger without removing catalyst.

Smaller dimensions and lower weight of vessels to reduce transport and handling problems.

An external HP steam boiler downstream of the second catalyst bed.

An externally arranged BFW preheater / HP steam boiler downstream of the third bed.

Features of the Uhde HP steam boilers:

- Tubeshot cooling to prevent nitriding.
- Channels in contact solely with the cooled synthesis gas leaving the boiler.
- Freely movable U-tube design of the bundle.
- Internal bore welding, the heat exchanger tubes being joined to the tubesheet by means of full-penetration welds.
- Steam / boiler water separation in the upper part of the waste heat boiler.

Advantages of Uhde HP steam boilers:

- All components fabricated from hydrogen-resistant, easy-to-handle, low-alloy materials.
- Elimination of stress corrosion cracking and crevice corrosion.
- Low thermal stress.
- Integrated boiler feed water preheating.
- Tube-to-tubesheet welds all subjected to non-destructive tests.

The design of HP synthesis loop boilers is a long-standing tradition at ThyssenKrupp Industrial Solutions, dating back to 1969 when equipment of this type was pioneered.
SAFCO IV fertiliser complex.
Capacities: 3,300 t/day of ammonia
3,250 t/day of urea
3,600 t/day granulation unit.
Proprietary Uhde equipment designs
Production and consumption figures

Overall view of the QAFCO 4 ammonia/urea complex successfully commissioned by Uhde back in 2004.

Capacities:
- 2,000 t/day of ammonia
- 3,200 t/day of urea
- 3,500 t/day granulation unit

Feed and Energy Consumption

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas as feed and fuel (Gcal)</td>
<td>6.8 to 7.4</td>
</tr>
<tr>
<td>Electric power (kWh)</td>
<td>15 to 90</td>
</tr>
<tr>
<td>Overall feed and energy (Gcal)</td>
<td>6.4 to 7.4</td>
</tr>
</tbody>
</table>

Utilities

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Cooling water (T = 10 K) (mt)</td>
<td>120 to 260</td>
</tr>
<tr>
<td>Demineralised water (net cons.)</td>
<td>0.65 to 0.75</td>
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</table>

Effluents

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treated process condensate (mt)</td>
<td>0.85 to 1.15</td>
</tr>
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</table>

Product Quality

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia content (% by wt.)</td>
<td>99.8 to 100.0</td>
</tr>
<tr>
<td>Water content (% by wt.)</td>
<td>0.0 to 0.2</td>
</tr>
<tr>
<td>Oil content (ppm by wt.)</td>
<td>Max. 5</td>
</tr>
</tbody>
</table>

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(1) expressed as lower heating value of natural gas per metric ton of ammonia
(2) electric power and steam export converted into fuel equivalents
(3) routed back to the demineralisation unit for re-use

All consumption figures are per metric ton of liquid ammonia and serve as general information only.
Local climatic conditions and gas composition may have a considerable influence on the performance figures.
ThyssenKrupp Industrial Solutions is dedicated to providing its customers with a wide range of services and to supporting them in their efforts to succeed in their line of business.

With our worldwide network of local organisations and experienced local representatives, as well as first-class backing from our head office, we have the ideal qualifications to achieve this goal.

We at ThyssenKrupp Industrial Solutions place particular importance on interacting with our customers at an early stage to combine their ambition and expertise with our experience.

Whenever we can, we give potential customers the opportunity to visit operating plants and to personally evaluate such matters as process operability, maintenance and on-stream time. We aim to build our future business on the confidence our customers place in us.

We provide the entire spectrum of services associated with an EPC contractor, from the initial feasibility study, through financing concepts and project management right up to the commissioning of units and grassroots plants.

Our impressive portfolio of services includes:

- Feasibility studies/technology selection.
- Project management.
- Arrangement of financing schemes.
- Financial guidance based on an intimate knowledge of local laws, regulations and tax procedures.
- Environmental studies.
- Licensing incl. basic/detail engineering.
- Utilities/offsites/infrastructure.
- Procurement/inspection/transportation services.
- Civil works and erection.
- Commissioning.
- Training of operating personnel using operator training simulator.
- Plant operation support/plant maintenance.
- Remote Performance Management (Teleservice).

We like to cultivate our business relationships and learn more about the future goals of our customers. Our after-sales services include regular consultancy visits which keep the owner informed about the latest developments or revamping options.

Our policy is to ensure utmost quality in the implementation of our projects. We work worldwide to the same quality standard, certified according to:

DIN/ISO 9001/EN29001.

We remain in contact with our customers even after project completion. Partnering is our byword.

By organising and supporting technical symposia, we promote active communication between customers, licensors, partners, operators and our specialists. This enables our customers to benefit from the development of new technologies and the exchange of experience as well as troubleshooting information.

ThyssenKrupp Industrial Solutions stands for tailor-made concepts and international competence.

For more information contact one of the ThyssenKrupp Industrial Solutions offices near you or visit our website:

www.thyssenkrupp-industrial-solutions.com
## Recent references

<table>
<thead>
<tr>
<th>Completion</th>
<th>Customer</th>
<th>Plant Site</th>
<th>Plant</th>
<th>Capacity</th>
<th>Contract</th>
<th>Project Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>Daelim for Saudi Arabian Mining Company, Ma’aden</td>
<td>Ras Al Khair, Saudi Arabia</td>
<td>Ammonia</td>
<td>3,300 t/day</td>
<td>E, P</td>
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<tr>
<td>2016</td>
<td>CF Industries</td>
<td>Port Neal, USA</td>
<td>Ammonia</td>
<td>2,200 t/day</td>
<td>E, P</td>
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<tr>
<td>2015</td>
<td>CF Industries</td>
<td>Donaldsonville, USA</td>
<td>Ammonia</td>
<td>3,300 t/day</td>
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<td>2013</td>
<td>Samsung for Ruwais Fertilizer Industries</td>
<td>Ruwais, Abu Dhabi, UAE</td>
<td>Ammonia</td>
<td>2,000 t/day</td>
<td>E, P</td>
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<td>2014</td>
<td>Egyptian Agrium Nitrogen Products Co. SAE (EAgrium)</td>
<td>Damietta, Egypt</td>
<td>Ammonia</td>
<td>2 x 1,200 t/day</td>
<td>Turnkey</td>
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<tr>
<td>2013</td>
<td>Orascom Construction Industries for Sonatrach Orascom Fertiliser Company (Sorfert)</td>
<td>Arzew, Algeria</td>
<td>Ammonia</td>
<td>2 x 2,200 t/day</td>
<td>E, P</td>
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<tr>
<td>2011</td>
<td>Samsung for Saudi Arabian Mining Company, Ma’aden</td>
<td>Ras Al Khair, Saudi Arabia</td>
<td>Ammonia</td>
<td>3,300 t/day</td>
<td>E, P</td>
<td></td>
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<tr>
<td>2008</td>
<td>Misr Oil Processing Co.</td>
<td>Damietta, Egypt</td>
<td>Ammonia</td>
<td>1,200 t/day</td>
<td>Turnkey</td>
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<tr>
<td>2008</td>
<td>Kuibyshev Azot</td>
<td>Togliatti, Russia</td>
<td>Ammonia</td>
<td>1,800 t/day</td>
<td>E</td>
<td>Expansion</td>
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<tr>
<td>2007</td>
<td>Duslo a.s.</td>
<td>Sala, Slovakia</td>
<td>Ammonia</td>
<td>Expansion by 300 t/day</td>
<td>E</td>
<td>Expansion</td>
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<tr>
<td>2007</td>
<td>Helwan Fertilizer Co.</td>
<td>Helwan, Egypt</td>
<td>Ammonia</td>
<td>1,200 t/day</td>
<td>Turnkey</td>
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<td>2006</td>
<td>Egyptian Fertilizer Co. (EFC II)</td>
<td>Ain Sukhna/Suez, Egypt</td>
<td>Ammonia</td>
<td>1,200 t/day</td>
<td>Turnkey</td>
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<td>2006</td>
<td>Alexandria Fertilizers Co. (AlexFert)</td>
<td>Alexandria, Egypt</td>
<td>Ammonia</td>
<td>1,200 t/day</td>
<td>Turnkey</td>
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<td>2006</td>
<td>Saudi Arabian Fertilizer Company (SAFCO IV)</td>
<td>Al Jubail, Saudi Arabia</td>
<td>Ammonia</td>
<td>3,300 t/day</td>
<td>Turnkey</td>
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<td>2004</td>
<td>Turkmendokunhimiya via Gap Insaat</td>
<td>Tecen, Turkmenistan</td>
<td>Ammonia</td>
<td>600 t/day</td>
<td>E,P</td>
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<td>2004</td>
<td>Qatar Fertiliser Company (QAFCO IV)</td>
<td>MESAIEED, Qatar</td>
<td>Ammonia</td>
<td>2,000 t/day</td>
<td>Turnkey</td>
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<td>2003</td>
<td>ASEAN Bintulu Fertilizer Sdn Bhd (ABF)</td>
<td>Bintulu, Malaysia</td>
<td>Ammonia</td>
<td>Expansion by 30 t/day</td>
<td>E</td>
<td>3rd Expansion</td>
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<td>2000</td>
<td>Egyptian Fertilizer Co. (EFC)</td>
<td>Ain Sukhna/Suez, Egypt</td>
<td>Ammonia</td>
<td>1,200 t/day</td>
<td>Turnkey</td>
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<td>1999</td>
<td>Istanbul Gübre Sanayii A.S. (IGSAS)</td>
<td>Körfez, Turkey</td>
<td>Ammonia</td>
<td>Expansion by 50 t/day</td>
<td>E, P</td>
<td>Expansion</td>
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<td>1998</td>
<td>Abu Qir Fertilizers and Chemical Ind. (AFC) (Abu Qir III)</td>
<td>Abu Qir, Egypt</td>
<td>Ammonia</td>
<td>1,200 t/day</td>
<td>Turnkey</td>
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<td>1997</td>
<td>ASEAN Bintulu Fertilizer Sdn Bhd (ABF)</td>
<td>Bintulu, Malaysia</td>
<td>Ammonia</td>
<td>Expansion by 120 t/day</td>
<td>E, P</td>
<td>2nd Expansion</td>
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<tr>
<td>1997</td>
<td>Saskferco Products Inc.</td>
<td>Belle Plaine, Canada</td>
<td>Ammonia</td>
<td>Expansion by 300 t/day</td>
<td>E</td>
<td>Expansion</td>
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<tr>
<td>1997</td>
<td>SASTECH (Pty) Ltd.</td>
<td>Sasolburg, South Africa</td>
<td>Ammonia</td>
<td>830 t/day</td>
<td>E</td>
<td>Expansion</td>
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<tr>
<td>1997</td>
<td>Qatar Fertiliser Company (QAFCO 3)</td>
<td>MESAIEED, Qatar</td>
<td>Ammonia</td>
<td>1,500 t/day</td>
<td>Turnkey</td>
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