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Uhde dual-pressure process for large-scale ammonia plants

| Saskferco ammonia-urea complex, Canada

Introduction

The use of fertilizers is essential in meeting global food requirements. All nitrogen fertilizers are based on ammonia, first produced on a commercial scale (30 tpd) in 1913 at a plant in Oppau/Ludwigshafen using the Haber-Bosch process. Worldwide production of ammonia today is around 140 million tpy, 85% of which is processed into fertilizers (urea, ammonium nitrate etc.).

Founded in 1921, Uhde is one of the world's leading technology-based engineering and contracting companies for the design and construction of chemical plants and has played a leading role in the development and application of ammonia technology. Following the construction of a pilot plant, Uhde's first commercial plant went into operation in 1928 with a capacity of 100 tpd. Since then Uhde has installed more than 100 ammonia plants worldwide. The construction of fertilizer complexes, usually consisting of an ammonia plant and a urea plant | see title picture of the report |, is now a mainstay of Uhde's business.

Background to the development

A 2,000 tpd ammonia plant costs around 250 million euros to build and is also very expensive to run due to the extremely energy-intensive nature of the ammonia production process. Virtually all modern-day plants use natural gas as feedstock. Some 1.6% of global fossil fuel consumption is used for the production of ammonia. The complex integration of exothermic and endothermic process steps in the 1970s and 1980s minimized energy consumption, which is now close to the theoretical minimum. From the 1990s, production plants started to be relocated to regions with low-cost natural gas, such as the Middle East, Trinidad/Venezuela and Southeast Asia. One way of significantly boosting production profitability is to increase plant size (economies of scale).

The first significant leap in capacity to approx. 1,000 tpd came in the late 1960s with the use of centrifugal compressors for synthesis gas compression | Fig. 1 |. Since then, maximum plant capacity has risen steadily. The biggest plants today have a capacity of just over 2,000 tpd. Further significant increases are, however, restricted by the production limits of certain units, the reference situation for critical equipment such as compressors, and the availability of standard components for high-pressure piping in the required nominal sizes. Under these conditions, the capacity of single-train plants could be expected to increase to around 2,300-2,500 tpd by 2010.

The ammonia process

Industrial manufacture of ammonia (NH_3) is based on a synthesis of hydrogen (H_2) and nitrogen (N_2) at high pressure in the presence of a catalyst. While nitrogen can be extracted from the air, hydrogen has to be made from natural gas in a complex process | Fig. 2 |. The natural gas is first scrubbed in a desulfurizer. After the addition of process steam, the mixture is preheated, then largely converted into carbon monoxide, carbon dioxide and hydrogen in the primary reformer at temperatures of around 820°C and pressures of approx. 40 bar. The primary reformer consists of a firing chamber and numerous parallel,

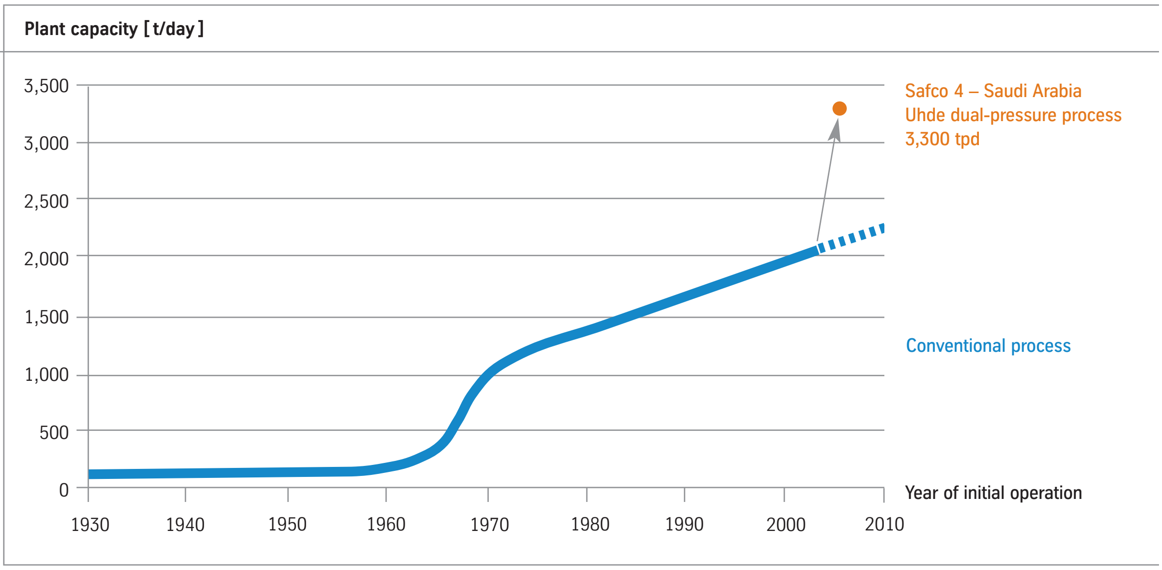

Fig. 1 | Development of plant capacity; expected capacity increase due to Uhde dual-pressure process (marked red) vertically arranged, catalyst-filled tubes. The residual methane is converted in the secondary reformer with the addition of process air. The air flow is adjusted to produce the stoichiometric H_2:N_2 ratio of 3:1 required for ammonia synthesis. The process gas, now consisting largely of hydrogen, nitrogen, carbon monoxide, carbon dioxide and steam, is cooled from around 1.000°C to 370°C by the generation of superheated high-pressure steam. It is then fed to the CO shift reactor, where catalysts convert the carbon monoxide and steam into carbon dioxide and hydrogen. The carbon dioxide is finally removed by scrubbing and emitted to atmosphere or fed to a urea synthesis process. In the subsequent methanation stage, the residual carbon monoxide and carbon dioxide, which act as catalyst poisons in ammonia synthesis, are converted back into methane, which is inert in the ammonia synthesis process. The synthesis gas exiting the methanation stage consists of hydrogen and nitrogen in a ratio of 3:1 plus a small amount of residual methane.

Ammonia synthesis from hydrogen and nitrogen is an exothermic reaction involving a reduction in volume. Reaction equilibrium is therefore favored by high pressures and low temperatures. However, temperatures of between 390°C and 520°C and the use of catalysts are essential to achieve technically acceptable reaction rates. Most modern plants operate with a synthesis pressure of around 200 bar using magnetite catalysts. In the conventional Uhde process, the synthesis gas is compressed from around 32 bar at the exit from the methanation unit to a synthesis pressure of 210 bar in a large, steam turbine-driven centrifugal compressor. The drive rating in a 2,000 tpd plant is around 27 MW. Due to the maximum permissible bearing spacing and the number of impellers required, the synthesis gas compressor is split into two casings. The first casing contains the first two compression stages with a total of 8 impellers, while the second casing contains the third compression stage with 7 impellers as well as a recycle compressor. Even at very high pressures, only a part

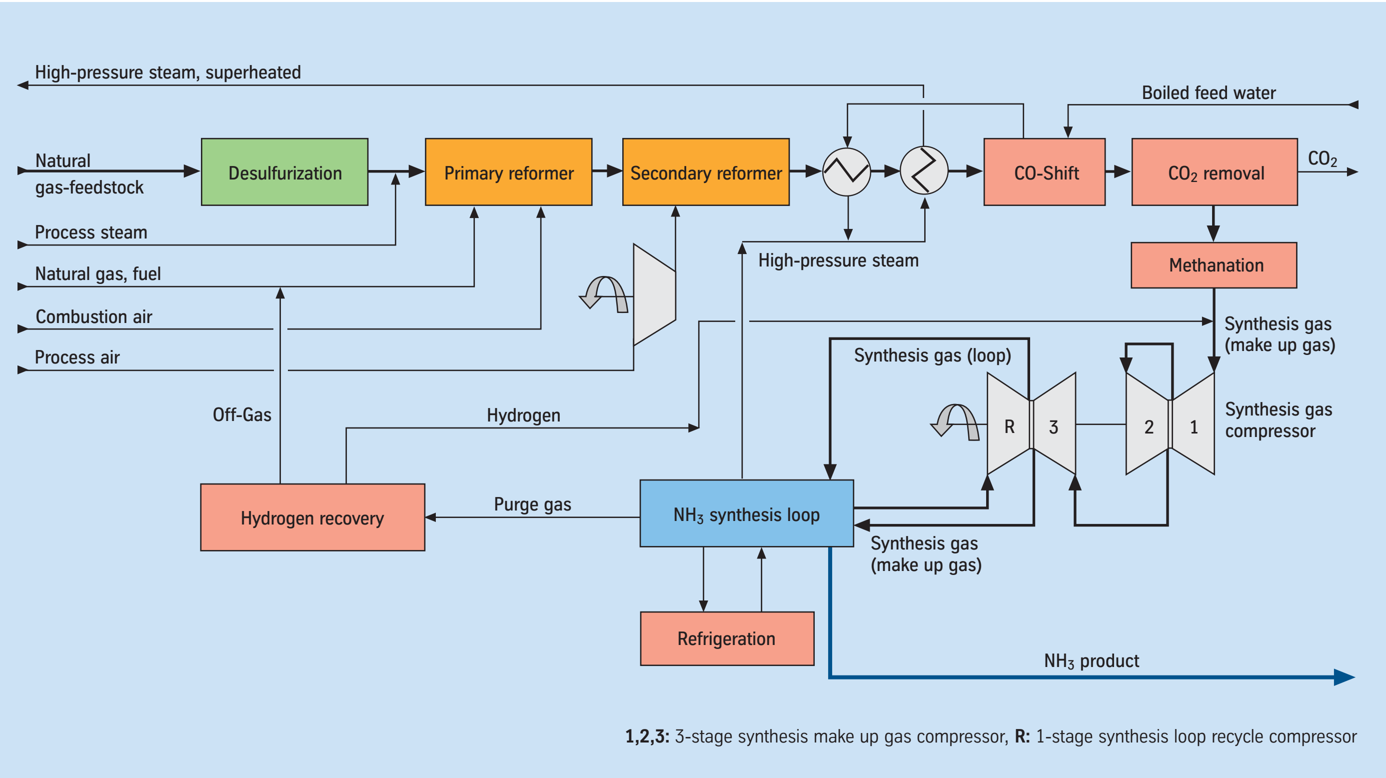

Fig. 2 | Block diagram of the conventional ammonia process

Fig. 3 | Ammonia synthesis plant, capacity 2,000 tpd, operating pressure 210 bar

of the hydrogen and nitrogen is converted to ammonia due to the chemical equilibrium. This means that the ammonia formed must be condensed out by refrigeration and the remaining gas mixture fed back to the reactor with fresh synthesis gas. This loop process is used in principle in all current ammonia synthesis plants. The pressure losses in the loop are compensated by the recycle compressor in the second compressor casing. Since the residual methane in the synthesis gas would be enriched in the loop, a small amount of so-called purge gas is taken from the loop to discharge the methane. After the hydrogen has been recovered from the purge gas and returned to the process, the remaining methane gas is fed to the primary reformer as fuel. The condensed-out and separated liquid ammonia is expanded and fed as a product to the storage tanks or further production equipment.

Scale-up limitations

A comparison of the process steps in ammonia production with those of similar processes, e.g. methanol production, shows that synthesis gas production is not the real scale-up problem. For example, Uhde has built primary reformers for methanol production with 960 tubes, whereas only 408 tubes are needed for an ammonia plant with a capacity of 3,300 tpd. Other synthesis gas production units such as desulfurizing reactors and CO_2 scrubbing columns have also been realized in the required size for other processes. By contrast, there are no current references for the required synthesis gas compressor larger than 2,050 tpd. In a conventional scale-up without process modification, a prototype would have to be used for this critical compressor (responsible for 20% of all plant shut downs), which is too great a risk for plant operators and investors in the case of a significant capacity increase.

The production capacity of the ammonia synthesis loop is determined by the conversion rate of the synthesis reactor and the loop gas volume. The conversion rate depends on the size of the reactor. The greater the catalyst volume, the closer the reaction can be brought to equilibrium, which in turn increases the conversion rate. However, capacities in excess of 3,000 tpd would involve reactor sizes which present-day equipment manufacturers would be unable to manage. Handling and erecting the units, which weigh several hundred tons, and installing the catalyst beds and internal heat exchangers in the reactors from above would quickly exceed the crane capacities available on remote sites. As an example of current plant sizes, | Fig. 3 | shows a 2,000 tpd ammonia synthesis plant.

The other capacity parameter – the circulation rate – cannot be increased indefinitely either, as the pressure losses would rise disproportionately. Nor is it possible to increase pipe diameters, as standard high-pressure piping elements are only available up to 24 inch diameter. In addition, the diameter of the heat exchangers would also have to be increased, which would inevitably lead to a disproportionate increase in costs and quickly come up against design limits.

Uhde dual-pressure process

When both conversion rate and loop volume come up against their practical limits, the only remaining possibility is to produce additional ammonia outside the actual synthesis loop. One way of doing this is to use the fresh synthesis gas, known as the make up gas. By installing a once-through synthesis reactor upstream of the conventional synthesis loop, total ammonia production can be split into a low-pressure once-through synthesis and the conventional synthesis loop, allowing the latter to be maintained at the current size. Although once-through synthesis at 200 bar would offer the advantage of requiring only very low catalyst volumes, due to the high educt partial pressures the reaction would take place so quickly that an ammonia injection system would be required upstream of the reactor to moderate it. Moreover, this would not reduce the duty of the synthesis gas compressor.

The key innovation in Uhde's new dual-pressure process is the inclusion of a medium-pressure once-through synthesis between synthesis gas generation and the synthesis loop | Fig. 4 |. The pressure of 110 bar between the two synthesis gas compressor casings can be used. Around one third of the total production can be produced at this pressure and condensed out by refrigeration before the remaining synthesis gas is further compressed for the synthesis loop. This significantly reduces the duty of the synthesis gas compressor. Using refrigeration units upstream of the two compression stages of the first compressor casing allows compressors of the same size and type currently used for 2,000 tpd plants to be maintained for the entire train.

The Uhde dual-pressure process allows the construction of 3,300 tpd single-train ammonia plants with no critical high-pressure equipment exceeding the sizes of a current 2,000 tpd plant. This greatly reduces

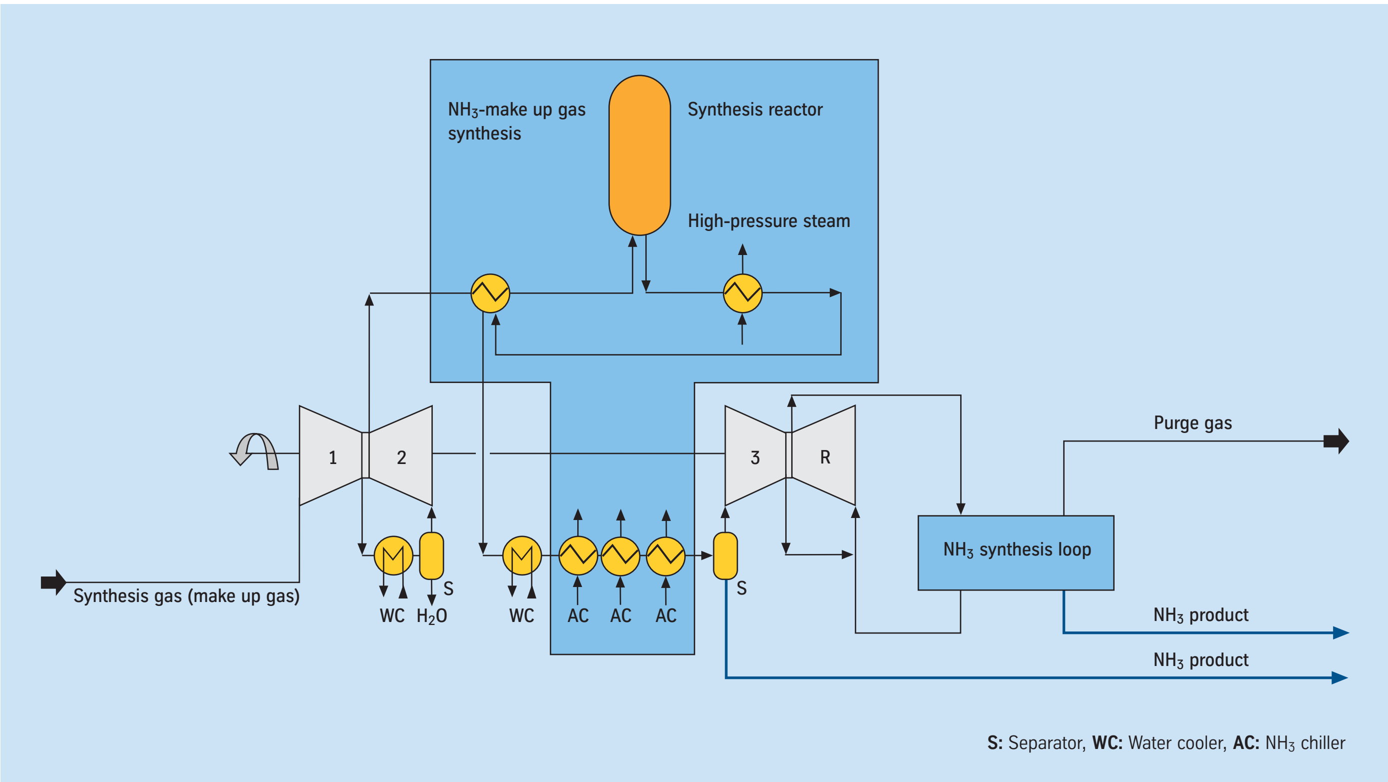

Fig. 4 | Principle of the Uhde dual-pressure process

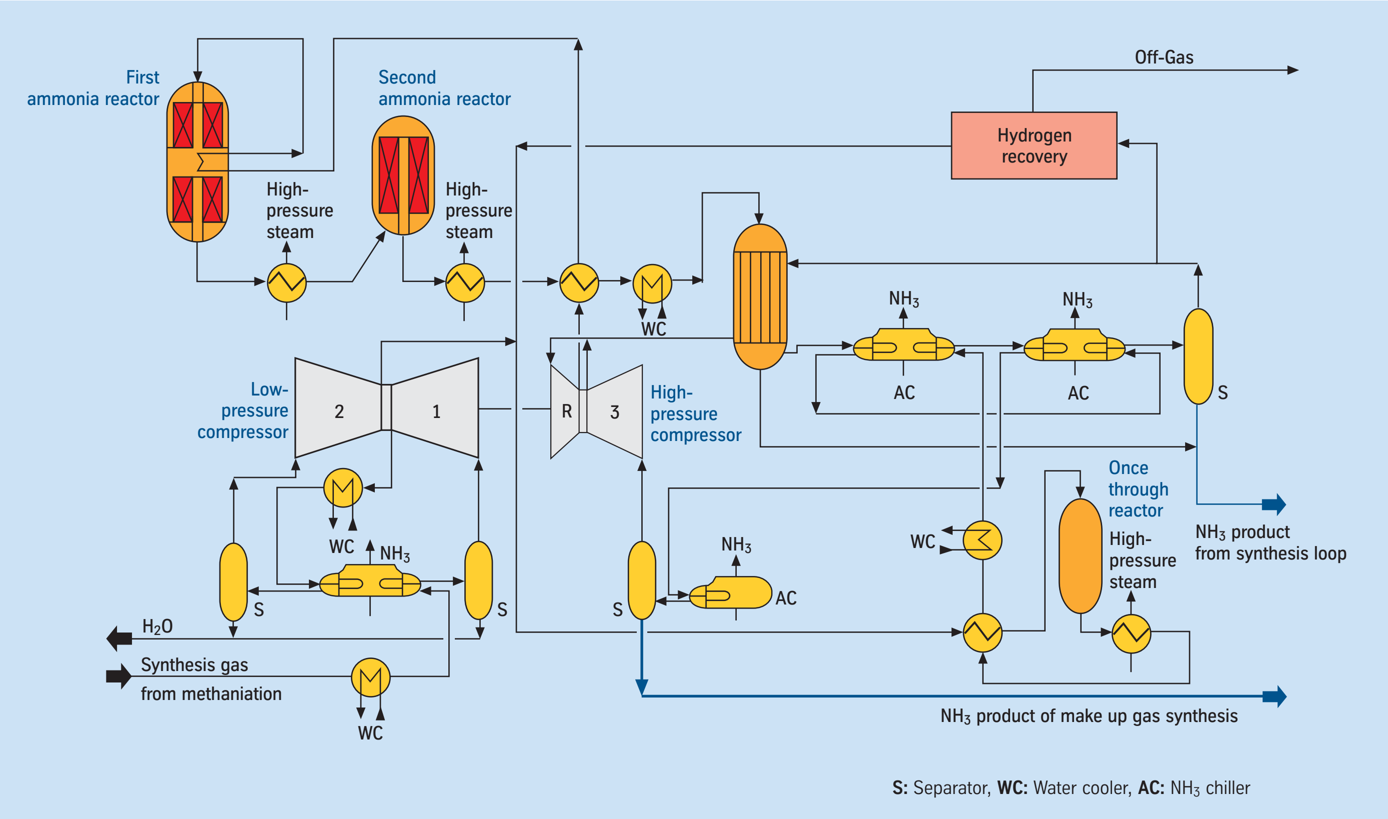

Fig. 5 | Uhde dual-pressure process flow sheet

the scale-up risk. The new process also provides more efficient recycling of the hydrogen recovered from the purge gas | Fig. 5 |. This, combined with better utilization of the installed catalyst volume, leads to a 4% reduction in the energy consumption of the ammonia plant. A comparison of specific production costs shows that based on the same depreciation, raw material and personnel costs, ammonia production per ton costs 11% less in a 3,300 tpd plant integrating the Uhde dual-pressure process than in a conventional 2,000 tpd plant.

First plant realized

The minimized scale-up risk of the Uhde dual-pressure process prompted the Saudi Arabian Fertilizer Company (Safco) to place an order with Uhde in April 2003 to build a major fertilizer complex at Al-Jubail in Saudi Arabia, comprising a 3,300 tpd ammonia plant and a 3,250 tpd urea plant. The basic engineering for this order has already been completed, and work has now started on the detail engineering and manufacture of the equipment. On-site activities have also begun. Handover of the complex to the customer is planned for early 2006.

With a capacity of 3,300 tpd, the new facility will be by far the world's largest single-train ammonia plant. The largest plant currently in operation is located in Argentina and has a capacity of 2,050 tpd. The realization of the first plant with the Uhde dual-pressure process thus represents a similar breakthrough to the leap to 1,000 tpd capacity in the 1960s | Fig. 1 |.

Outlook

The constantly rising world population and with it the increasing need for fertilizers mean that global ammonia production is expected to grow at a rate of around 2% p.a. or 2.65 million tpy. There is also high potential for replacing old plants in high-cost energy regions such as the USA or Europe with new plants in areas with low natural gas prices. Production profitability can be significantly improved by using single train plants with as high a capacity as possible. With the new dual-pressure process – based exclusively on existing equipment and thus greatly reducing the scale-up risk to capacities over 3,000 tpd – Uhde has laid an important foundation stone for this market trend.