Linde Ammonia Concept

The Linde Ammonia Concept (LAC) can achieve 20% cost savings compared to the conventional process. It requires less equipment, less instruments, and less foundation materials.

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Introduction

The LAC plant (Figure 1) consists essentially of a hydrogen unit with only a PSA unit for purification of the syngas, a standard nitrogen unit adding nitrogen where it is needed and an ammonia synthesis unit.

Compared with the conventional process route, the LAC process has the following important features (Figure 2):

- Elimination of three catalytic process steps, reducing the total catalyst volume to approximately 50% of that in a conventional plant.
- Provision of a reformed gas purification system by pressure swing adsorption (PSA), which has a proven and unmatched reliability.
- The generation of inert-free synthesis gas, resulting in significant savings in the synthesis loop, and eliminating a purge gas purification step.
- Recovery of CO₂ is possible through an additional washing unit.
- The process condensate treatment is eliminated by routing the condensate directly back to the isothermal shift reactor for production of process steam.
- The simplified flow sheet also results in an overall reduced pressure drop.
- The LAC is a much more direct route to ammonia resulting in a reduced startup time and important savings in feedstock consumption.
- An overall simplification of the classical process route, resulting in savings in investment costs, construction time, site area, maintenance and spare parts costs as well as catalyst replacement costs.
- Pure hydrogen and pure nitrogen are directly available from process streams. Other potential byproducts such as oxygen, argon, carbon dioxide, carbon monoxide, and methanol can be easily integrated (Figure 2).

Concept

The LAC (Figure 3) consists essentially of a modern hydrogen plant, a standard nitrogen unit, and a high efficiency ammonia synthesis loop. The basic gas generation unit is a modern hydrogen plant with proven
and outstanding reliability. The success of this hydrogen process can be judged by the fact that today practically no new hydrogen plant is built with the conventional route including HT- and LT-shift, CO₂ wash and methanation.

Yet, in the modern conventional ammonia process the classical hydrogen generation route is employed with the addition of a secondary reformer. It is interesting to consider why modern hydrogen technology has not been applied more often for the production of ammonia.

Up to now, the major application for PSA based hydrogen plants is in refineries. It seems that most engineering contractors active in the field of ammonia technology tried rather to improve the classical route than to go for completely new solutions.

The pure hydrogen from the PSA unit is mixed with pure nitrogen from a standard air separation unit (ASU) to give inert-free ammonia synthesis gas. The synthesis gas is fed to a high efficiency ammonia synthesis loop based on the Ammonia Casale axial-radial flow converter.

The comparison of the process steps in the LAC and in the conventional process shows clearly the reduction in process steps which is achieved by LAC. The comparison of the temperature profiles through the process steps (Figure 4) demonstrates even to a greater extent why there are savings in investment cost with LAC. The number of temperature changes is less and the temperature levels are lower than in the conventional process. Furthermore, the flow in the conventional plant through the secondary reformer and all the downstream steps is considerably higher than in the LAC plant due to the addition of process air to the secondary reformer.

The trend in the modern conventional process is to increase the duty of the secondary reformer, which increases the flow rate due to the excess air and thus increases the size of downstream equipment. In the LAC process, the nitrogen is introduced where it is needed: just upstream of the ammonia synthesis.

**Process Description**

The numbers in the following paragraphs refer to the numbers shown in Figure 5.

**Desulfurization**

The feedstock is heated and flows through a desulfurization (1) reactor. If nonreactive sulfur compounds are present in the feed, these are first hydrogenated using a small stream of recycle hydrogen. The hydrogen sulfide is removed from the feed by passing through a bed of zinc oxide catalyst.

**Primary reformer**

Reformer Feed Preheating (2). The desulfurized feedstock is mixed with steam produced in the isothermal shift reactor (5), supplemented by makeup from the steam and power system (17) and preheated in the mixed feed preheater.

Reforming (3) (and Figure 6). In the top-fired reformer, the feedstock is reacted with steam over a nickel-based catalyst in high-alloy reformer tubes.

The steam reforming reactions produce a reformed gas consisting largely of hydrogen and carbon monoxide.

Process Gas Cooler (4). The reformed gas leaves the reformer at about 850°C and is cooled before inlet to the isothermal shift reactor by generation of saturated steam. Potential problems in steam superheating by process gas are avoided.

Flue Gas Duct (9). The flue gas from the radiant section of the reformer furnace is used to preheat reformer feed, generate superheated HP steam and preheat combustion air, before being passed by an induced draft fan via a stack to the atmosphere.

**Isothermal shift**

Isothermal Shift Reactor (5). The carbon monoxide in the reformed gas is converted to hydrogen by the shift reaction:

\[ \text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2 \]

The isothermal shift reactor is a Linde development in which the catalyst bed is kept at a constant temperature of about 250°C by a spiral-wound cooling bundle. Inside the tubes of the bundle, process condensate circulates producing steam for the reforming process.
A combination of proven technologies

Figure 1. Combination of proven technologies.

Linde Ammonia Concept (LAC)
Comparison of LAC process with conventional scheme

Figure 2. Possible valuable byproducts.
Heat Recovery and Condensate Separation (6). Further cooling of the process gas takes place with heat recovery by various streams including process condensate. The separated process condensate is recycled to the isothermal shift reactor to generate process steam. No process condensate treatment unit is required.

Pressure swing adsorption (PSA)

Pressure Swing Adsorption (7). The PSA unit consists of a number of adsorbers between 4 and 12, depending on the size of the plant and other operational aspects. The process gas passes through the adsorbers, thus being purified up to 99.999 mol% hydrogen. Meanwhile, the loaded adsorbers are regenerated using a controlled sequence of depressurization and purging steps.

Fuel System (8). Swings in the composition and pressure of the tail gas produced in the PSA unit are leveled out by means of a buffer drum, thus allowing a steady supply of fuel gas to the reformer furnace.

Nitrogen unit

Nitrogen Production (10). High purity nitrogen (1 ppm O₂) is produced by low temperature separation in the air separation unit (ASU). Air is filtered, compressed and purified before being fed to the ASU coldbox. The pure nitrogen product is further compressed and mixed with hydrogen to give ammonia synthesis gas of stoichiometric composition.

Ammonia synthesis

Synthesis Gas Compressor (11). Synthesis gas and recycle gas are compressed to synthesis pressure for supply to the ammonia converter.

Gas-Gas Interchanger (12). Synthesis gas is preheated to the ammonia converter inlet temperature by heat exchange with converter exit gas.

Ammonia Converter (13) (and Figure 7). The ammonia converter is the high efficiency Ammonia Casale design, with axial-radial flow beds and interbed exchangers.

Heat Recovery (14). The hot gas leaving the ammonia converter is used to generate HP steam.

Product Separation (15). By cooling and refrigeration of the converter exit gas, the ammonia product is liquified and separated. Unconverted gas is recycled by the synthesis gas compressor (11). Traces of impurities in the synthesis gas (e.g., argon) leave the loop dissolved in the liquid product. No purge gas needs to be taken from the loop.

Utility systems

Product Chilling (16). The ammonia product is flashed to low pressure and pumped to consumers or storage. The flash vapors are condensed in the refrigeration unit (19).

Power System (17). Superheated HP steam is used to generate power for drives in the ammonia plant. Some steam is extracted as makeup to the process. All steam condensate is sent to the condensate system (18).

Condensate System (18). Steam condensate from the plant is collected and, together with makeup BFW, is deaerated for supply to steam generators.

Ammonia Refrigeration Unit (19). The refrigeration unit is powered by energy generated within the plant.

Special Features

Three sections of the LAC are exclusive Linde developed technology, and are introduced to the fertilizer industry through the LAC plant for GSFC with 1,350 mtd capacity of ammonia (Figure 11). These are the Linde isothermal shift reactor, the Linde PSA unit, and the Linde air separation unit.

The Ammonia Casale Converter represents an equally important contribution to this advanced technology.

Linde isothermal reactor

This reactor (Figure 8) is used for the CO shift reaction, and allows conversion to below 0.7% CO (dry basis) in a single step. Thus, the conventional series of HT and LT shift reactors with heat recovery between the beds is replaced by a single reactor with built-in steam generation.

Furthermore, the process condensate is far less
Conventional Ammonia Plant

Feed
Air

Linde Ammonia Concept (LAC)

Feed
Desulfurization
Primary Reformer
Isothermal Shift
PSA
Ammonia Synthesis

Air
 Nitrogen Unit

Cost related facts:
- number of temperature changes
- temperature levels
- flowrate
- number of equipment and catalyst

Efficiency related facts:
- heat exchange losses
- pressure drops

Downstream this point the flowrate of a conventional plant is 30 to 80% higher compared to the LAC-process

Figure 3. Comparison of LAC process with conventional scheme.

Figure 4. Comparison of LAC process with conventional scheme.
contaminated than in the conventional process with secondary reformer and HT shift. A small amount of methanol is present, but after degassing, the condensate is used to generate process steam. Thus, the process condensate treatment unit in the conventional plant is eliminated.

The Linde isothermal reactor is now proven in ten plants worldwide for which the following characteristics have been demonstrated:
• The temperature profile in the reactor corresponds to kinetic ideal conditions and gives optimum catalyst performance.
• The isothermal mode of operation produces the least possible stress on the catalyst and increases its lifetime.
• The operation temperature of the reactor is regulated by simple control of the steam pressure.
• Under all operating conditions including startup and partial load, the water cycle ensures absolute temperature stabilization.
• Simple and rapid catalyst reduction without danger of overheating.
• A startup heater is not necessary. The catalyst bed is brought to temperature by steam injection to the water circuit.
• The reactor concept enables the largest possible amount of catalyst to be accommodated per unit reactor volume.

Linde pressure swing adsorption (PSA)

Linde PSA technology is widely used for hydrogen purification duties. Capacities of about 112,000 Nm³/h hydrogen product at 1 ppm CO purity, suitable for a 1,350 MTD ammonia plant, require a 12 bed system. Systems of this type, such as the UKW plant in Germany (Figure 9), have now demonstrated over 10 years of trouble-free operation.

The extremely high reliability of the PSA system results from the use of high quality equipment and the completely automatic switching and monitoring of the unit performance by a programmable logic controller (PLC). Should a disturbance occur in any of the operating sequences, the faulty item is identified and taken off-line, without interrupting the supply of product. A 12 bed system can switch automatically to operation on a lower number of beds with only a slight reduction in efficiency, but maintaining quality of hydrogen. This proven automatic control system gives 100% availability in Linde PSA units.

Furthermore, the PSA unit is able to produce pure hydrogen directly from reformed gas, so that disturbances in the front-end steps would not interrupt production. This is in sharp contrast to the conventional plant where failure of the CO shift or CO₂ removal cause a high temperature trip on the methanator and complete plant shutdown.

Equally, the startup is much faster, since pure hydrogen is produced as soon as reformed gas is available.

**Linde air separation unit**

The Linde air separation unit is a state-of-the-art low temperature separation process such as is used worldwide for the production of industrial gases. As the inventor of the air separation process, Linde does not need to emphasize its expertise in this field. Figure 10 shows a simplified flow sheet for such a unit.

**Ammonia Casale axial-radial flow converter**

This converter is a development of the classical radial flow type (Figure 7).

In the Ammonia Casale converter, as opposed to the pure radial flow converter, the catalyst bed has no top cover, and some gas enters axially. The amount of gas flowing axially is controlled by proper design of the perforation pattern, and is such that the “seal” catalyst works under similar conditions to the catalyst in the radial flow part of the bed (Figure 7).

The Casale design therefore obtains the maximum performance from the catalyst volume charged in the converter.

In addition to the process design advantages of the Casale converter, the mechanical design features give the following advantages for operation and maintenance compared with competitive designs:
• All proven catalysts can be used.
• High thermodynamic efficiency due to the presence of three beds; optimal gas distribution in catalyst beds; maximum utilization of catalyst volumes.
• Maximum utilization of converter vessel volume.
Figure 5. Simplified process flow diagram.

Figure 6. Section view of top-fired reformer.
Table 1. LAC Comparison of Catalyst Volumes 1,350 MTPD NH₃

<table>
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<tr>
<th>Process</th>
<th>Conventional Plant</th>
<th>LAC Plant</th>
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<tbody>
<tr>
<td></td>
<td>m⁴</td>
<td>m³</td>
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<tr>
<td>Desulfurization</td>
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<td>Primary Reformer</td>
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<td>HT Shift</td>
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<tr>
<td>LT Shift</td>
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<td>Methanation</td>
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<td>Ammonia Synthesis</td>
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<td><strong>Total</strong></td>
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<td><strong>200.9</strong></td>
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Table 2. LAC Comparison of Equipment Items

<table>
<thead>
<tr>
<th>Item</th>
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<tbody>
<tr>
<td>Exchangers</td>
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<tr>
<td>Vessels</td>
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<td>Reactors</td>
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<td>5</td>
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<tr>
<td>Big Machines (Compressors,</td>
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<td>4</td>
</tr>
<tr>
<td>Turbines, Generator)</td>
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<td></td>
</tr>
<tr>
<td>Pumps</td>
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<td>25</td>
</tr>
<tr>
<td>Other Machines</td>
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<td>12</td>
</tr>
<tr>
<td>Air Separation Unit</td>
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<td>1</td>
</tr>
<tr>
<td>Inert Gas Unit</td>
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<td>--</td>
</tr>
<tr>
<td>Purge Gas Separator</td>
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<td>--</td>
</tr>
<tr>
<td>PSA Unit</td>
<td>--</td>
<td>1</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>155</strong></td>
<td><strong>105</strong></td>
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Linde Ammonia Concept (LAC)  
Nitrogen Generation Unit (Cryogenic)

Figure 7. Ammonia Casale 3 bed converter.

Linde Ammonia Concept (LAC)  
Possible valuable By-Products

CO₂
CO
H₂

CO-Recovery

H₂ Unit
with
PSA Purification

MEOH-Unit

Ammonia
Synthesis
Loop

Pure N₂
Pure H₂

N₂-Unit

Atmosph.
Air

Methanol

Hydrocarbon
Feed

Figure 8. Linde isothermal reactor.
Figure 9. PSA plant for the production of hydrogen.

Figure 10. Nitrogen generation unit (cryogenic).
• Maximum mechanical reliability of cartridges.
• Use of "rod-baffle" internal heat exchangers to improve heat transfer and to eliminate vibration problems.

Valuable byproducts

Valuable byproducts can be produced either directly from process streams in the LAC plant, or by simple integration of the necessary facilities (Figure 2).

High purity hydrogen and nitrogen are produced within the LAC process, and flows from both these streams can be made available for other consumers if required.

The potential for production of oxygen, argon, and rare gases from the air separation unit can be easily integrated at the design stage.

For CO₂ byproduct, Linde has selected the MDEA wash process licensed by BASF for several recent plants. This high efficiency CO₂ wash step is included in the LAC plant being built for GSFC in India.

According to the CO₂ demand of downstream consumers, the gasflow to the absorber column is controlled with a bypass.

The installation of a cold box for CO product, or of a methanol synthesis and distillation unit, can be easily integrated with the LAC process.

Operating Aspects

The LAC meets the target of 7 Gcal/NH₃ for modern ammonia plants in steady operation. This figure, valid for moderate climates, includes utilities and also the energy required for the N² unit, which represents approx. 0,33 Gcal/t (less than 0,1 Gcal/t NH₃ on top of the power for conventional secondary air compression).

The LAC is a much more direct route to ammonia than the conventional process (Figure 3). This results in rapid startup and consequently important savings in feedstock consumption. The elimination of many hours of unproductive feedstock consumption per year has an important benefit for the actual achieved consumption per ton of product. Further, the annual pro-
duction capacity is increased by rapid startup.

The advantages of LAC from the operators point of view arise from the reduction in the number of process steps, and the ability of individual parts of the plant to operate independently. For example:

- The nitrogen unit (ASU) can be operated to generate inert gas (and other products) for other consumers, when the ammonia plant is shutdown.
- The isothermal shift reactor can be preheated by steam injection to the water circulating through the coils.
- The PSA unit can produce pure hydrogen directly from reformed gas, without the CO shift or the CO₂-wash. The startup of the PSA unit is automatically performed by the PLC.
- The startup of the ammonia synthesis loop can therefore proceed about 2 h after feed is introduced to the reformer, a time which is unmatched by any other ammonia process.

Cost Savings

Detailed studies made during the proposal stage of the LAC process for GSFC in India showed clearly the cost savings which are achieved with the LAC process.

The absolute figures of this project are, however, not sufficiently representative for the U.S. market conditions to be presented with this article.

Comparisons with the conventional process showed cost reductions of approximately 20% in the LAC process for

- Fewer catalytic steps resulting in 50% less total catalyst volume (Table 1).
- Reduced number of equipment items (Table 2).
- Reduced piping quantity.
- Reduced number of control loops and instruments.
- Less structural steel.
- Less foundation materials.

The total weight of the plant, and the site area required (Figure 11), show similar reductions compared to the conventional process.

Note: Table 2 is simplified such that each case includes two packages not detailed in the items.

Conclusions

Linde has already earned a special position in the fertilizer industry through the introduction of the high pressure gasification route to ammonia, designed and built by Linde for the first time in the world at the GNFC site in India.

The GNFC 1,350 mtd ammonia plant based on heavy residue has now achieved over ten years of record production, and the process is recognized worldwide as the accepted route to ammonia from heavy feedstocks.

In comparison to the LAC process, the high pressure gasification process introduced challenges of an extremely high technical nature. It is confidently expected that, within the decade, the LAC process, which is a combination of proven process steps, will become the established route to ammonia from light hydrocarbon feedstocks.