Casale Strategies for Complete Ammonia Plant Revamping

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With the current economic situation there is pressure on plant owners to increase their ammonia production at substantially lower cost. In relation to these new demands more and more detailed studies on entire plants are required in order to obtain the maximum from the existing facilities.

For many years CASALE is active in the field and has matured experience in the design and implementation of entire plant revamping, including extensive modifications to the reformer, to the machines and to other critical equipment.

CASALE’s approach in its studies for expanding ammonia capacity and reducing energy consumption is to find a convenient way of upgrading the plant keeping the interventions of costly additional equipment to the minimum, but considering all special customer constraints by applying new ideas and technologies.

CASALE normally proposes more than one alternative, generally at least a minimum investment alternative and a maximum production and energy saving alternative are consolidated. All solutions, in particular the minimum investment alternative, are tailor-made to the plants peculiarities and present customer requirements.

An ammonia plant debottlenecking project, that is the subject of this paper, gives an example of the CASALE approach to the revamping of an entire plant.

1. Introduction

The strategy followed by AMMONIA CASALE in ammonia plant revamping has always been to develop and apply new advanced technologies to improve the plants’ performances at a minimum cost and at maximum benefit.

The performance improvement is normally a reduction in energy consumption, an increase in capacity or a combination of the two.

It is also important to find out what are the most critical items, the improvement of which gives the best return.

Following this strategy AMMONIA CASALE has developed and applied a number of proprietary items that are presented here in Chapter 2.

The paper summarizes then in the remaining Chapters the content and results obtained in some recent projects performed by Ammonia Casale in the field of ammonia production plants.

These projects are related to the revamping of ammonia synthesis converters and to the supply or to the revamping of other special equipment, like pre-reformers, shift converters and others, as well as to the revamping of complete ammonia plants for capacity increase and energy conservation.

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2. **Ammonia Casale Proprietary Technologies**

2.1 **Axial-Radial Catalyst Beds**

The axial-radial catalyst bed is the base of most of the technologies used by CASALE in catalytic reactors.

This technology was developed for ammonia converters, and later applied to methanol, shift, formaldehyde and pre-reformer reactors since it was demonstrated as being flexible, economical and efficient.

At present there are more than 400 axial-radial beds designed by CASALE successfully in service.

In an axial-radial catalyst bed the gas distribution is such that most (about 90 percent) of the gas passes through the catalyst bed in a radial direction, resulting in a much lower pressure drop when compared with the axial flow.

The balance passes down through a top layer of catalyst in an axial direction, thus eliminating the need for a top cover of the catalyst beds, (see figure 1).

Mechanically the bed is very simple, being made only of the two vertical perforated walls and of one closed bottom. There is no top cover. This last feature is an essential factor for an easy and simple construction of any type of converter internal.

The materials used for its construction vary depending on the application and can be carbon steel, stainless steel and Inconel, the latter being used for wire mesh only.

Fig. 1 - Axial-radial Bed, Gas Distribution

2.2 **Pre-Reforming Reactor Technology**

The pre-reforming reactor proposed by AMMONIA CASALE is designed according to the axial-radial technology for catalyst beds.

The advantages of using this technology for pre-reforming reactors are:

- the low pressure drop achievable;
- the use of small-size catalyst;

The low pressure drop is an important energy saving feature and helps the compressors to reach capacities in the case of revamping.

- When there is no natural gas compressor, if the pressure of the gas is close to the reforming pressure, it is important to minimize the DP in all equipment, especially in the added ones, to enable capacity increases without having to install a natural gas blower.
The small-size catalyst has two advantages in comparison with the large-size one:
- a higher sulfur pick-up, that means a longer life since sulfur is the main poison;
- a higher activity.

This means that, with respect to the larger-size catalyst, it is possible to reduce the catalyst volume to have the same life or with the same volume to have a longer life.

Regarding the operation of an axial-radial pre-reformer, it is to be noted that the temperature profile in the catalyst bed can be measured and followed easily, thanks to the presence of thermocouples in different positions in a radial direction in the bed.

Also catalyst loading and unloading is very easy, as the axial-radial bed is completely open on the top granting an easy access to the bed even for small-diameter vessels, while for unloading there are drop out pipes provided at the bottom.

The utilization of this reactor enables part of the primary reforming reaction to be carried out (about 10%) outside the primary reformer, enabling the increase of the capacity of the existing unit, as well as the reduction of the size of the reformer to be implemented in new plants.

Another advantage of the pre-reformer is that it transforms all higher hydrocarbons to methane, and performs part of the reforming reactions, thus producing some hydrogen. These two actions enable the increase of the preheating temperature of the process gas, and also the reduction of the steam carbon ratio, therefore reducing the energy consumption of the primary reforming section.

2.3 Secondary Reformer Burner

AMMONIA CASALE has developed a new design for secondary reformer burner utilizing advanced fluid dynamic simulation techniques.

The goal was to develop a simple design capable of withstanding the severe operating condition in a safe, reliable and cost effective manner. This has been achieved coupling the Casale experience in burner design with the use of CFD simulations.

The Computational Fluid Dynamic (CFD) allows the simulations of the velocity, temperature and composition fields inside and outside the burner and in the combustion chamber. It was performed interfacing a commercial CFD software with “in house” developed combustion subroutines.

The CASALE Advanced Secondary Reformer Burner achieves the following goals:
- low pressure losses of both air and primary reformer stream;
- low temperature of the burner surfaces exposed to the flames;
- an advanced mixing in the flame;
- reduced flame length in order to avoid catalyst impingement for high load operations;
- soot-free combustion;
- homogeneous gas composition and temperature distribution at catalyst bed entrance;
- protection of the refractory lining from the flame hot core.

The design obtained achieves a recirculation of the reacted gases to protect the refractory and the burner from the hot core and ensures a homogeneous gas and temperature distribution at the catalyst bed entrance (see Figure 2).
The performances of the CASALE Advanced Secondary Reformer are:

- Pressure loss for the air stream: less than 1 bar
- Burner wall temperatures: 700-800°C
- Temperature spread on the catalyst surface: Uniform within a few Celsius degree range
- Composition spread on the catalyst surface: Almost Homogeneous

The application of this design to existing plants enables the reduction of the pressure losses of the process air, thus increasing the air compressor capacity and its energy consumption reduction. Furthermore the very even composition achieved at catalyst inlet and the higher amount of reaction taking place already in the gas phase, make it possible to increase the catalyst life, and to reduce the catalyst volume necessary.

The burner has been applied in two ammonia plants and two more are under construction. The following picture shows a burner before shipment.
2.4 Shift Converters

The new design developed by Ammonia Casale is based on the use of the axial-radial catalyst bed, described above, and can be applied both to revamping and to new converters.

The new axial-radial configuration has an inherently low pressure drop of the catalyst bed, and this makes it possible to use small-size, more active and more resistant to poisons catalyst.
The new designs has also the following additional features:

- protection of catalyst from water droplets carried over from secondary reformer heat recovery train or others;
- possibility to load different volumes of catalyst with no mechanical modifications;
- easy operations.

In case of application to existing plants, the existing shift converters can be easily transformed to axial-radial design by introducing new vertical perforated walls, which are cylindrical and form the inlet and outlet walls, in prefabricated sectors that are assembled inside the existing converter vessel.

The advantages achievable with this revamping are the low pressure drop with consequent energy saving, the low pressure drop also helps eliminating the hydraulic constraints having more flow through the front end, allowing for higher plant throughput.

The small-size, more active catalyst eliminates the possible constraints due to a fixed catalyst volume that may be insufficient for the new operating conditions of high flow and low steam/carbon ratio, furthermore this catalyst is more resistant to poisons, granting a longer catalyst life with smaller loaded volumes, and also a lower average CO concentration at the outlet, with corresponding higher production with the same process gas consumption.
2.5 Ammonia Synthesis Converter

The ammonia converter is one of the most critical items when planning a revamp for energy saving or capacity increase, and in most cases it is the first item to be revamped thanks to the relatively low cost and very high return.

AMMONIA CASALE is very active in this field and has introduced fundamental innovations in the converter design and revamping, such as the "in-situ" modification of bottle-shaped converters such as the Kellogg ones, and the three-bed intercooled configuration that is being used by CASALE for over ten years now.

This activity has been very rewarding and now AMMONIA CASALE has more than 140 converters on stream, out of which about 50 are "in-situ" modifications, and about 40 are three-bed intercooled converters (new or revamped) with full bore opening.

The most important ingredients for this success are the axial-radial beds, described above (see figure 1), and the three-bed configuration, both adopted for revamping of any kind of converters and for new reactors as well (see figure 5).
These two elements give the highest utilization of the catalyst volume available, thanks to the axial-radial configuration, and the most thermodynamically efficient cartridge configuration, the three-bed interchanger one, with cooling achieved by means of heat exchanger both between 1st and 2nd bed and between 2nd and 3rd bed.

The design of the cartridge, based on a lay-out with three adiabatic beds and two interchangers, and the use of 1.5÷3 mm size catalyst, makes it possible to obtain a high ammonia conversion with the smallest catalyst volume and a low pressure drop.

The Casale converters are designed also to have fully independent control of the inlet temperature of each catalyst bed, making it possible to always run the converter in the optimal safest conditions during any operating situation that may happen in the plants’ life. This is true even if the plant is very different from the original design, as it may happen due to a change in feedstock composition, plant capacity, ambient conditions, etc.

The peculiar design of these converters also enables the recovery of the reaction heat at the highest temperature level, generating high-pressure steam.

2.6 Catalysts

Ammonia Casale accepts to operate its plants and equipment with any first-class catalyst, and during its long experience Casale has accumulated a unique experience related to the catalysts performances. This experience translates into the possibility of assisting the clients in the catalysts choice.

In addition to this experience the CASALE group markets exclusively a selected Chinese catalyst for ammonia synthesis.

This catalyst is being more widely accepted than ever in the market worldwide, and in fact, already 47 charges are in service in CASALE converters, plus several other charges in converters of other technologies.

Out of these 47 charges, 21 are in China, the oldest one in service since 1987, the others are in Asia, Eastern Europe, USA, Brazil, Australia, and New Zealand.

AMMONIA CASALE, the Company marketing this catalyst, is fully responsible for the quality control, and guarantees the delivery and installation supervision, the reduction supervision and all of the after sales services.
3. Casale Technologies: Case Histories

3.1 Pre-reforming Installation

Ultrafertil, a fertilizer Company in Brazil, already an AMMONIA CASALE Client, has a 450 MTD nominal capacity ammonia plant based on steam reforming technology and fed by both refinery off-gas and naphtha. The actual load was of about 520 MTD.

The flow rate and composition of the off-gas were changing quite often, reflecting the change in feedstock, load and products range of the upstream refinery. As a consequence, the primary reforming run was also unsteady, requiring the use of very high steam to carbon ratio to protect the reforming system from a possible sudden increase in the carbon content of the feedstock.

The Client approached AMMONIA CASALE with the request to increase the plant capacity and reduce the energy consumption, asking for a detailed study to find the best revamping options, with a capacity target of 800 MTD, to be reached in two steps, the first one being 600 MTD.

The primary reformer, running in such conditions, became immediately one of the revamping targets.

The revamping had to deal with the unsteady operating conditions, and with the desire to abandon naphtha as feedstock or fuel, being too expensive.

In these conditions the choice of installing a pre-reformer appeared to be natural, in fact the two main benefits of its installation are:

- a) stabilization of the composition of the gas entering the primary reformer;
- b) reduction of the duty of the primary reformer.

**Point A):** the first point is due to the fact that all hydrocarbons entering the pre-reforming are cracked down to methane, and some reforming reaction takes also place. The product is, therefore, methane plus some CO, CO₂ and hydrogen, steam always being present.

The product of the pre-reformer can enter the primary reformer with a much lower steam carbon ration as there is no more danger of carbon deposit on the catalyst.

The fact that the only hydrocarbon fed to the primary reformer is methane allows for the use of a normal natural gas catalyst that is more active and gives fewer problems than the naphtha one.

**Point B):** reforming reaction starts and proceeds to a certain extent in the pre-reformer, reducing the load on the radiant section of the primary reformer.

Thanks to the pre-reformer installation, it is, therefore, possible to operate the primary reformer smoothly, with stable operating conditions, to reduce the steam carbon ratio to the primary reformer (since the only feed gas is methane plus steam, CO, CO₂ and hydrogen. This holds true also for the use of the non-reactive natural gas type catalyst and to increase the reforming capacity.
3.1.1 Other Plant Modifications

Other main plant modification in order to reach the higher capacity and lower energy consumption goals are:

**FIRST STEP, 600 MTD**
- modification to the existing primary reformer convection section;
- replacement of reformer burners;
- NH$_3$ converter replacement with a high efficiency one.

The NH$_3$ converter had to be completely replaced because of metallurgical reasons, since the pressure shells of the old one had shown extensive cracking and its operation could no more be considered safe.

The new converter is based on the well-known AMMONIA CASALE axial-radial technology.

**SECOND STEP, 800 MTD**
- reformer tubes replacement;
- shift converters revamping;
- CO2 converter revamping;
- feed gas, air and synthesis gas compressors revamping;
- new purge gas recovery unit.

Also other minor changes to exchangers, pumps and piping are planned.

The plant is now on stream after revamping since July 2001 and the main performance achieved are the following:

<table>
<thead>
<tr>
<th>Table 1 – Pre-reformer Summary Performances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process guarantees</td>
</tr>
<tr>
<td><strong>Conversion of C$_2$H$_6$</strong></td>
</tr>
<tr>
<td><strong>Conversion of C$_3$+</strong></td>
</tr>
</tbody>
</table>
Table 2 - Synthesis Loop Summary Performances

<table>
<thead>
<tr>
<th>Converter capacity (total of the 3 reactor)</th>
<th>Test run</th>
</tr>
</thead>
<tbody>
<tr>
<td>Converter capacity (total of the 3 reactor)</td>
<td>MTD 600</td>
</tr>
<tr>
<td>Ammonia concentration at 3rd converter outlet</td>
<td>% 15.8</td>
</tr>
<tr>
<td>Converter pressure drop</td>
<td>bar 2.8</td>
</tr>
</tbody>
</table>

Figure 6 - Axial-Radial Pre-Reformer
FIG. 7 - New Axial-Radial Pre-reformer in Ultrafertil Cubatao

FIG. 8 - New Ammonia Synthesis Converters at Ultrafertil Cubatao
3.2 Shift Converters

3.2.1 Shift converter revamping

Ultrafertil ammonia plant in Araucaria is based on partial oxidation of heavy fuel oil. Ammonia Casale had already performed a revamping of the ammonia converter in this plant from the old two-bed quench radial design to the modern three-bed two-interchangers axial radial design.

The Shift section of the oil gasification plant of ULTRAFERTIL plant in Araucaria was composed of two axial flow high temperature shift reactors. The flow pattern of the first reactor was changed to the CASALE design, an axial radial type, with the objective of reducing the pressure drop across the catalyst bed, as well as extending the catalyst life.

The gasification process used in ULTRAFERTIL’s plants causes more severe operating conditions for the high temperature shift reactors than in the more common steam reforming plants. The reason for this high severity of operation is that the concentration of carbon monoxide at the shift section inlet is very high, about 50 \% vol. dry basis, implying high operating temperatures, and the fact that the shift reaction is carried out in two stages, both with high temperature catalyst. The first shift converter, which is the subject of the revamping presented here, operates with outlet temperatures exceeding 500 °C (932 °F).

The gasification process consists in a gasification reactor, where the feedstock is gasified with pure oxygen in presence of a little steam. The resulting gas is saturated with water first, then more steam is added before proceeding to the shift section to achieve sufficient water content in the gas. This sequence of operations implies the possibility of having impurities being carried over, and reaching the catalyst bed, increasing the severity of operation for the first shift converter in addition to the high temperature.
As a result, the first converter shift catalyst has a relatively short life, and a significant increase in pressure drop over the operating period.

The main purpose of the retrofit was to significantly decrease the pressure drop over the first high temperature shift reactor. This would allow increased gas flow through the ammonia process loop and increased ammonia production. The feasibility analysis and calculation of the Return Over Investment (“ROI”) was based on this increased production.

Another important factor taken into consideration was the expected longer expected life of the high temperature catalyst. In the past the life of this catalyst was about 1.5 years but never longer than 2 years. After the retrofit the catalyst life expected to be at least 2 years and probably longer. The CO slip after 2 years is guaranteed not to exceed 7.66% (volume). Prior to the retrofit, the CO slip after 1.5 to 2 years was more than 8% and sometimes approximately 9%.

Legal requirements dictate that this boiler be inspected every 2.5 years and ULTRAFERTIL’s goal was to extend catalyst life to match the mandatory boiler inspections. This goal has been actually achieved and exceeded.

Another good reason for doing this retrofit, which would justify the investment, was the expected higher suction pressure in the suction of the Synthesis Gas Compressor (due to the lower pressure drop in the shift loop). The savings in steam in the Steam Turbine of the Synthesis Gas Compressor would result in gains that justify the investment (in itself).

Although the increase of ammonia production was the primary justification for the retrofit, either the extended life of the catalyst or the steam savings on the Synthesis Gas Compressor Turbine would also have justified the retrofit.

Fig. 10 – New Axial-Radial Configuration
3.3. Results Achieved

The results achieved were better than expected, mainly regarding the pressure drop, which had a value guaranteed by CASALE of 1.1 bars [16 PSI], although the expected value was 0.9. This value before was in between 1.5 and 2.5 bar [21.8 and 36.3 PSI] (Start of run and End of run). The pressure drop is in the range of 0.6 to 0.8 bars [8.7 to 11.6 PSI], according to the load, and this value has been stable since the start-up. During the start-up, the CO slip value was in the range of 5.9 to 6 %.

One year after the retrofit this value was in an average of 6.5 volume.

These good results enable ULTRAFERTIL to get the expected increase of capacity in it's ammonia plant, and moreover, to keep the average capacity in a higher value than expected, due to the good conditions of the Shift Section in the ammonia plant.

Another benefit achieved from the lower pressure drop was the resulting higher pressure improved the operation of the next sections of the plant including the physical absorption CO₂ removal system (Rectisol Process) and N₂ Wash Removal.

The higher pressure at the suction of the synthesis gas compressor lowered the steam consumption of its turbine driver.

The expected increased lifetime of this reactor by 0.5 to 1 year is a very important additional benefit and represents a significant improvement to ULTRAFERTIL.
3.4 Ammonia Converter Industrial Experience

AMMONIA CASALE has revamped and started up more than 140 converters of different types with capacities ranging from less than 300 MTD to more than 2000 MTD.

As an example of this activity, the revamping of four 900 MTD M.W. Kellogg ammonia converters at CFI Industries, Louisiana, USA is here illustrated.

These converters were already revamped by AMMONIA CASALE in 1986 adopting the first generation of internals (4 beds, 3 quenches), and then at the end of their catalyst life they were revamped again adopting new and more efficient internals: 3 beds, quench and interchanger.

In the following Table 3, the achieved performances of these converters have been indicated.

<table>
<thead>
<tr>
<th>CASE</th>
<th>ACSA-MWK 4 beds</th>
<th>3 beds retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia production [MTD]</td>
<td>1287</td>
<td>1475</td>
</tr>
<tr>
<td>Catalyst age [years]</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Inerts concentration at 105-D inlet [mol%]</td>
<td>9.8</td>
<td>7.7</td>
</tr>
<tr>
<td>NH₃ concentration at 105-D inlet [mol%]</td>
<td>2.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Temperature at 105-D inlet [°C]</td>
<td>139</td>
<td>148</td>
</tr>
<tr>
<td>NH₃ concentration at 105-D outlet [mol%]</td>
<td>14.4</td>
<td>16.9</td>
</tr>
<tr>
<td>Pressure at 105-D outlet [bar a]</td>
<td>137</td>
<td>138</td>
</tr>
<tr>
<td>Temperature at 105-D outlet [°C]</td>
<td>299</td>
<td>371</td>
</tr>
</tbody>
</table>

As mentioned above, Ammonia Casale has also on-stream converters running in excess of 2000 MTD, like the one in Germany, at the Yara plant in Brunsbuettel, running at 2050 MTD since 1989, recently further upgraded to 2200 MTD.

Within this activity Ammonia Casale has revamped converters of practically all types, including two-bed traditional radial designs in 11 plants and even added a booster converter in the Brunsbuettel plant in Germany. This latter revamping, which is normally not considered economical, can sometimes be justified in order to achieve large capacity increases.
4. Complete Plant Revamping

In 2002 AMMONIA CASALE had completed the revamping of a 1000 MTD ammonia Plant based on M.W. Kellogg’s technology at the AL-JUBAIL FERTILIZER COMPANY (SAMAD), located in Al-Jubail, Kingdom of Saudi Arabia.

The plant was originally started up in Al-Jubail in March 1983. It is a natural gas based plant, i.e. using natural gas for feed and for fuel. Before revamping, the plant was operating at a capacity of about 1170 MTD after an initial revamping of the converter internals in 1989 with a traditional two-bed one-interchanger design, (not a CASALE design), and addition of a membranes-type Hydrogen Recovery Unit.

The production increase to 1300 MTD was the main goal of the project. Further targets were the energy saving, the cooling water consumption reduction and the reliability improvement. A second step of capacity increase up to 1800 MTD had also been considered, and may be taken into consideration in a short while. All the new equipment had therefore to be designed for the highest capacity.

An important requirement was the very tight project schedule. The project started in October 2000. All the Engineering and Procurement services for the De-bottlenecking project were completed within September 2001. Turnaround took place in January 2002. All modifications were implemented during the period of a standard shut-down. Start-up followed immediately after.

Since every modification to machinery results in very expensive interventions and a rehauling of the almost new primary reformer tubes in the short-term would have been uneconomical, CASALE’s minimum investment revamping option was prepared according to the following guidelines:

- Avoid revamping or replacement of the main rotating equipment;
- No modifications to the primary reformer section;
- Modifications to the equipment had to be suitable for the further capacity expansion;
- Possible variations in natural gas quality had to be considered;
- Plant shall be able to operate when new sections are isolated;
- Possible trip of new sections shall not involve the trip of the existing plant.

The 1300 MTD ammonia production was selected since this value was positioned at the very limits of the existing syngas compressor suction capacity and of the refrigeration compressor capacity.

The modifications implemented are the following:

Feed gas desulphurisation

The desulphurization section and the feed gas compression were suitable for the new operating conditions and needed no modifications.

Prereforming and Primary reforming

The Primary Reformer of the SAMAD Ammonia Plant is a typical Kellogg top-fired unit with 416 catalytic tubes arranged in 8 rows. The reformer tubes were replaced in 1997 using HK40 material (the same as per original design) and the tubes thickness is also identical to the original design.

The heat flux to the primary reformer without replacing the reformer tubes could only be marginally increased. Therefore, to increase the capacity of the reformer up to the level needed for the capacity expansion, the steam to carbon ratio had to be decreased from 3.7 to 3.2.

Having a high concentration of higher hydrocarbons in natural a pre-reformer unit was installed to enable safe S/C reduction. Prereformer feed has to be preheated to about 440°C, therefore a fired heater was installed for this scope, as illustrated below.
The advantages of the use of the pre-reformer and of the fired heater can be summarized as follows:

- safe reduction of the S/C ratio;
- increased superheating of steam without interventions on steam superheating coil;
- increased process air preheating;
- mixed feed coil replacement could be avoided (only a mechanically simple tube rows removal will be necessary);
- BFW preheating level could be maintained;
- flexibility for every possible change in natural gas composition.

**Process Air**

The section was designed to provide in normal conditions sufficient process air for a production of 1000 MTD of ammonia.

In 1989 after the first plant revamping the plant production has been ranging between 1170 and 1220 MTD of ammonia. The air compression section that was constantly operated at its maximum suction capacity limited the production.

For the capacity increase the section needed to be debottlenecked.

The intervention consisted in the addition of a booster on the suction of the air compressor. The booster was sized so as to be suitable also for the major expansion planned in the future.

The following modifications have been implemented in the air compression section:

- installation of a new intake air filter;
- addition of 1101-J air booster driven by 1101-JT back-pressure steam turbine;
- addition of 1129-JC aftercooler downstream the new air booster;
- installation of a flow deviator to connect air booster to existing air compressor.

The performance of 101-J existing compressor have been also improved by the replacement of 129-JC first interstage cooler; the remaining intercoolers will be replaced in near future.
Secondary reformer

No modifications were necessary to the secondary reformer and to its burner. The downstream waste heat boiler 101-C was replaced for maintenance.

Shift converters

The shift converters had a relevant pressure drop, 0.5 bar for H.T. Shift and 1 bar for L.T. Shift. These high values were due to the axial design of these converters and to the large catalyst volumes installed. Their retrofit with CASALE axial-radial internals was necessary to reduce the pressure drop.

The pressure drop after revamping is about 0.3 bar each, that will correspondingly increase the suction pressure of the syngas compressor. This pressure increase is very important to allow this machine achieving the higher capacity without any modification to the make-up stages.

The advantages that resulted from this revamping can be summarized as follows:

- lower pressure drop;
- lower CO slip and thus lower inerts concentration in the make-up gas for the whole catalyst life;
- longer catalyst life;
- catalyst protection against water droplets.

4.1 Synthesis Gas Purification System

Carbon Dioxide removal

The CO₂ from the ammonia synthesis gas was scrubbed using Union Carbide licensed MEA Amine Guard (AG II) system. The CO₂ content of purified gas was satisfactorily low (around 120 ppm) but corrosion problems were observed.

The BASF aMDEA process was best suited for revamping the MEA unit by a simple solvent swap, keeping the existing section configuration. There was no need of any equipment modification.
The specific energy consumption was decreased from 36'900 to 30'700 kcal/kmol CO₂. Thanks to this energy saving it was possible to reduce the S/C ratio. This reduction resulted also in a significant saving in the sea cooling water fed to the stripper overhead condenser.

**Methanator**

No modifications were required to the heat exchangers and to raw syngas separator. Also the 106-D methanator was suitable for the new operating conditions.

### 4.2 Ammonia Production System

#### Compression of purified synthesis gas

The reduction of the steam to carbon ratio and the revamping of the shift converters internals allowed an increase in the plant throughput without appreciably increasing the system pressure drop.

The only modification to the syngas compressor was the replacement of the recycle wheel by a new one that allowed the synloop to be operated at the maximum discharge pressure achieved by the M.U.G. stages at the increased suction flow rate. The new recycle wheel was designed for the lower recycle flow rate and lower head necessary with the revamped synthesis converter internals.

With the new wheel the loop operated at a higher pressure and this reduced the power requirement in the 103-J machine as well as in the 105-J machine.

#### Synthesis

The main modifications regarding the ammonia synthesis loop were the converter internals retrofit and the recycle wheel replacement with a smaller one. These two interventions allowed the 105-D synthesis converter to reach higher performances, thus resulting in a higher ammonia outlet concentration and temperature. The increased outlet temperature made necessary the replacement of the converter outlet pipe and the replacement of the BFW preheater 123-C.

The benefits achieved by these modifications were:

- reduction of the power consumption in the 103-J machine, that allowed avoiding the revamping of this compressor and of its driving turbine;
- reduction of the loop chillers duty, necessary to avoid the revamping of the existing 105-J compressor (refrigerant ammonia compressor).
Ammonia Converter

The ammonia converter was revamped to a two bed-intercooler design in 1989. The performance of the converter was further enhanced by installing the CASALE technology, transforming the internals to a three bed-quench-intercooling design.

The cartridge configuration was changed to a modern axial-radial design with intermediate cooling. The new cartridge configuration was 3-bed with one quench between the first and the second bed and one interchanger between the second and the third bed. Due to the better converter performance and higher operating pressure the temperature at converter outlet is higher and above the design values for the existing converter outlet pipe and 123-C exchanger. For the above reason it was necessary to replace the outlet pipe with one with improved metallurgy.

Refrigeration
The higher performance of the synthesis loop after converter revamping allowed a significant reduction of the chillers specific duties, thanks to this improvement, the plant capacity increase has been born by the 105-J ammonia compressor and by its steam driver without any modification.

4.3 Performances of the Revamped Plant

The following table 4 gives a summary of the main plant performances compared to the Base Case (i.e. before revamping).

<table>
<thead>
<tr>
<th>Description</th>
<th>Base Case</th>
<th>Revamped</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MTD</td>
<td>1170</td>
<td>1312</td>
</tr>
<tr>
<td><strong>ENERGY CONSUMPTION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gcal/MT$_{NH3}$</td>
<td>9.77</td>
<td>9.23</td>
</tr>
<tr>
<td><strong>SEA COOLING WATER</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m$^3$/MT$_{NH3}$</td>
<td>416.0</td>
<td>388</td>
</tr>
</tbody>
</table>
5. Bibliography


2. RICARDO PRADO SANTOS, Ultrafertil S.A., Araucaria, Brazil. FILIPPI, Ammonia Casale S.A., Lugano, Switzerland, Retrofit Of A High Temperature Shift Reactor, AIChE Ammonia Symposium. Safety in ammonia plants and related facilities 2002, San Diego, USA


Lugano, October 2004
Anvil/paper/conf/amm/FAI2004/casalestrategies