How to Increase the Capacity Efficiently in Ammonia and Urea Complexes:

The Ammonia Plant

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ABSTRACT

Since the end of the 70’s, the CASALE Group has gained a world-wide reputation for the revamping of existing ammonia and urea plants, and the Group is proudly a leader in this field of activity.

CASALE’s revamp strategy relies on an attitude and expertise to identify the bottlenecks in the ammonia and urea plants, and on the application of new, advanced technologies to obtain the best improvements in plant performance at the lowest cost. Especially in the last decade, AMMONIA and UREA CASALE have developed and successfully implemented several of these technologies, now consolidated concepts also for the design of new plants.

Thanks to the strong interaction of the two sister companies, AMMONIA and UREA CASALE, the revamp of an ammonia-urea complex can be undertaken as a single, totally integrated design task since the conceptual stage and through the next project stages, a premium advantage that only the CASALE Group can boast, being the only company to license both Ammonia and Urea technologies.

Especially for Indian fertilizer complexes, where typically all ammonia is converted to urea, there is a very strong link between the ammonia and the downstream urea plants: in this case CASALE is the best partner to implement a revamp that requires knowledge of the implications of selected revamp strategy on the whole fertilizer complex.

This paper provides an overview of some of the CASALE technologies for ammonia plants, and some case histories of their application for revamping of existing plants.

FOREWORD

AMMONIA CASALE S.A. is one of the oldest companies active in the field of synthetic ammonia production. It has been established in Lugano (Switzerland) in 1921, for the industrial development and commercialization of Dr Luigi CASALE’s inventions for the catalytic synthesis of ammonia.

AMMONIA CASALE is well-known for its know-how, design and technologies in the field of ammonia plant design and revamping. More recently, the activities of CASALE have also expanded to the fields of urea (and
methanol). Presently CASALE is a Group of companies active in various fields, with its main focus on the development of new technologies for the production of ammonia, urea and other products.

CASALE’s policy has long been based upon the development and application of advanced technologies for plant revamping, to get the best improvements in plant performance at the minimum cost. The improvements include energy consumption reduction, capacity increase, or a combination of both.

The main strength of CASALE lies in the licensing of its technologies, developed in house by a team of very specialized people. Thanks to the innovative trend set by founder Dr Luigi CASALE, plus the heritage and background of subsequent management teams, CASALE invested significantly in technology development. During the last few decades this discipline evolved from an empirical art, with an intuitive sense for good design, into a more rationalized activity.

Process design is now supported by sound insight into the chemistry of the processes, catalyst behaviors, kinetic data, heat and mass transfer phenomena, fluid mechanics, science of construction materials, and cost analysis.

CASALE Technical Services avail themselves of specialists in all the above fields, as well as of sophisticated tools for investigating, analyzing and picturing complex phenomena in a way unachievable with ordinary skilled manual calculations. The process design is based on advanced computer-aided techniques with applications ranging from process flow-sheeting to kinetics, to fluid dynamics simulations and mechanical stress analysis.

In addition to the technology, CASALE can also provide all services required for the completion of a project, from engineering right down to construction, start-up and operation of the plant.

**APPROACH TO THE REVAMP OF AN AMMONIA-UREA COMPLEX**

CASALE’s revamp strategy relies on an attitude and expertise to identify the bottlenecks in the ammonia and urea plants, and on the application of new, advanced technologies to obtain the best results at the lowest cost.

In the last decade, AMMONIA and UREA CASALE have developed and successfully implemented several of these technologies, now consolidated concepts also for the design of new plants.

Thanks to their strong interaction, AMMONIA and UREA CASALE undertake the revamp of an ammonia-urea complex as a totally integrated design task: from the conceptual design stage of the revamp, through all project stages.

Only the CASALE Group can boast this premium advantage, being the only company to license both Ammonia and Urea technologies.

Especially for Indian fertilizer complexes, where typically all ammonia is converted to urea, there is a very strong link between the ammonia and the downstream urea plants: in this case, CASALE is the best partner to implement...
a revamp that requires knowledge of the implications of the selected revamp strategy on the whole fertilizer complex.

In fact, it is essential to identify the most critical bottlenecks both in the ammonia and the downstream urea plant, to ensure the best return on the Client’s investment. Moreover, CASALE can provide a precious help in the conceptual stage, in determining the best revamp strategy and the target performances (ammonia and urea plant capacity and energy consumption) that can be obtained with the best economics.

AMMONIA and UREA CASALE have done exactly that in many projects, and have applied a number of proprietary improvements which have made these projects successful.

The Projects range from the revamping of specific sections of the ammonia/urea units (e.g. the synthesis section), to the revamping of complete ammonia/urea plants to increase capacity and save energy.

This paper provides an overview of some of the CASALE technologies to revamp ammonia plants, and some case histories of their application for revamping of existing plants. These technologies can be suitably applied for the revamping of typical ammonia plants in fertilizer complexes in India.

AMMONIA CASALE’S PROFILE

Since the very beginning, and for many years now, AMMONIA CASALE has been active in the construction of new plants, with over 200 such plants built worldwide.

In the more recent past, activities were devoted to the revamping of existing plants, with more than 200 plants revamped in the last 25 years, and to the design of new plants. The company is also involved in new plant construction through its licensees.

At the present time, AMMONIA CASALE is a leader in the design of ammonia synthesis reactors and related process loops.

The company is also a leader in ammonia plant revamping, and it owns a vast portfolio of proprietary technologies to upgrade ammonia plants.

Plant modernization is a very important aspect of AMMONIA CASALE’s support to clients. One of the missions of the company is to add value for the Clients by revamping their plants, thereby increasing the capacity and/or reducing energy consumption to within limits where the installation of many additional new pieces of equipment would entail a substantial investment costs.
AMMONIA CASALE’s PROPRIETARY TECHNOLOGIES

AXIAL-RADIAL CATALYST BEDS

The axial-radial catalyst bed is at the core of most of the CASALE technologies.

In an axial-radial catalyst bed, most of the gas (about 90%) crosses the catalyst bed in a radial direction, resulting in much lower pressure drop than in an axial-flow catalyst bed. The balance passes down through a top layer of catalyst in an axial direction, thus eliminating the need for a top cover on the catalyst bed (Fig. 1).

Fig. 1: Gas Distribution in an Axial-Radial Catalyst Bed

Mechanically the bed is very simple, being made only of two vertical perforated walls and of one bottom closure plate. The absence of a top cover greatly simplifies and facilitates the construction of the converter internals, allowing at the same time the full utilization of the catalyst volume.

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 materials used for its construction depend on the application.

The essential advantages of the axial-radial catalyst bed concept are:
• The low pressure drop, and the fact that it is stable with time
• The possibility use of small-size catalyst, more active and more resistant to poisons.

CASALE makes maximum use of the axial-radial bed concept, in all catalytic reactors.

This technology was developed for ammonia converters and later applied to shift converters and pre-reformer reactors, since it was demonstrated as being flexible, economical and efficient. Outside the ammonia field, it has also been applied in methanol and formaldehyde synthesis reactors. To date, CASALE has put more than 500 axial-radial beds into successful service.

Here follows a brief description of each application in the ammonia field.

**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 has introduced breakthrough innovations in the converter design and revamping, such as the "in-situ" modification of bottle-shaped, and the three-bed intercooled configuration that has been used by CASALE for over ten years now.

This activity has been very rewarding: most of the existing (and new) ammonia converters in the world use the CASALE technology.

The most important ingredients for this success are the axial-radial beds, described above (see figure 1), and the three-bed configuration, both adopted to revamp any kind of converters and for new reactors as well.

AMMONIA CASALE has recently introduced into the market the next generation of ammonia reactors, the pseudo-isothermal plate-cooled converters. Three of these converters are already on-stream. Figure 2 shows a sketch of the pseudo-isothermal plate-cooled converter, and of a 3-bed converter.
Pre-Reforming Reactor Technology

The pre-reforming reactor proposed by AMMONIA CASALE is designed according to the axial-radial technology for catalyst beds, taking advantage of the peculiarities of this design: minimum pressure drop, and use of small-size catalyst, which is more active and more resistant to poisons.

The CASALE pre-reformer enables part of the primary reforming reaction (about 10%) to be carried out outside the primary reformer, enabling the increase of the capacity of the existing unit. The pre-reformer transforms all higher hydrocarbons to methane, and performs part of the reforming reactions, thus producing some hydrogen. These features 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.

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.
Further to the typical features of the axial-radial configuration (low pressure drop, use of small-size catalyst), the new design has the following features, specific for the shift converters:

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

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 important. The low pressure drop is stable with time. It entails a saving of syngas compressor power, and most importantly eases the hydraulic constraints in the front end, allowing for higher flow rate and plant throughput.

**SECONDARY REFORMER BURNER AND AUTOTHERMAL REFORMER**

Among its technology portfolio, AMMONIA CASALE also has a secondary reformer burner with advanced design. The CASALE Advanced Secondary Reformer Burner achieves the following goals:

- low pressure losses in both air and primary reformer streams (<1 bar in the air stream);
- low temperature of the burner surfaces exposed to the flames;
- superior mixing in the flame;
- reduced flame length, avoiding catalyst impingement even at high operating loads
- soot-free combustion;
- homogeneous gas composition and temperature distribution at catalyst bed entrance;
- protection of the refractory lining from the hot core of the flame.

Introducing this design into an existing plant reduces the pressure loss in the process air, thus increasing the air compressor capacity and/or reducing its energy consumption. On account of the very even gas composition at the surface of the catalyst bed and the greater amount of the reaction that has already taken place in the top space of the reactor, it is possible to obtain greater service life from the catalyst and/or to reduce the catalyst volume.

At present, there are 11 CASALE burners in operation (the first since 2002) and more are being installed.

CASALE has also a proprietary design for autothermal reformers, which achieves the same advantages highlighted above. In this case, the burner tip is water cooled, ensuring longer expected life for this highly critical piece of
equipment. CASALE autothermal reformer is already in operation in several ammonia and methanol plants.

Fig. 3: CASALE design for secondary reformer burner

AMMONIA WASH SYSTEM

The Ammonia Washing Unit is another proprietary technology of AMMONIA CASALE. It removes water and carbon dioxide from the syngas before entering the loop. Carbon oxides in synthesis gas are almost completely removed by the CO₂ Removal and Methanation sections, while some moles of water still remains in make-up gas and they could poison ammonia converter catalyst decreasing its performances.

The Ammonia Wash System takes advantage of the ammonia-water/carbon dioxide reciprocal solubility to completely remove them from make-up gas. The oxygenated compounds (H₂O and CO₂) are completely dissolved in the liquid ammonia; thanks to the CASALE patented ejector, the unit is designed exploiting the differential pressures between the liquid ammonia and make-up gas in order to optimize the nebulization of liquid ammonia and allow an intimate contact between the two phases.
Due to the fact that undesired compounds have been removed, syngas can be fed directly to the ammonia converters, without crossing the ammonia chilling section.

Summarizing, the expected benefits from the installation of AMMONIA CASALE AWU, are the following:

- Reduction of synthesis gas compressor energy consumption, thanks the lower suction temperature at the H.P. casing inlet.
- More favorable conditions for ammonia condensation in the chilling section, since the ammonia concentration in the converter effluent stream is no more reduced by the make-up gas mixing (reduction of energy consumption in the refrigeration compressor).

**SPECIFIC KNOW-HOW**

Besides these proprietary technologies, AMMONIA CASALE has specific know-how in all the critical sections of an ammonia plant:

- Primary reforming
- CO2 removal section
- Air compressor debottlenecking
- Cryogenic gas cleaning

This knowledge is applied in all the revamping jobs in order to find the best solution to remove plant bottlenecks.
CASE HISTORIES

ULTRAFERTIL, CUBATÃO (now VALE)

Ultrafertil, a fertilizer company in Brazil and already a client of AMMONIA CASALE, has an ammonia plant based on steam reforming technology at Cubatão, Brazil, fed by both refinery off-gas and naphtha. Originally designed for a capacity of 450 t/d, the plant was operating at about 520 t/d at the time the revamp project was approved.

The flow rate and composition of the off-gas fluctuated considerably as a result of changes in feedstock, load and product range in the refinery. To safeguard the primary reformer from the ill effects of a possible sudden increase in the carbon content of the feedstock, it had to be operated at a very high steam:carbon ratio.

The client requested AMMONIA CASALE to find the best revamping options for increasing the plant capacity in two stages, first to 600 t/d and then to 800 t/d, while reducing energy consumption and phasing out the use of naphtha as feedstock on account of its cost.

The strategy selected by CASALE included a new pre-reformer, to stabilize the composition of the gas entering the primary reformer and to reduce the duty on the primary reformer. To attain the first capacity increase target (600 t/d), the reforming furnace burners were replaced, some alterations were made to the reforming furnace heat recovery train and a new, high-efficiency ammonia converter with CASALE axial-radial technology was installed.

The converter was completely replaced because the pressure shell of the old
one was extensively cracked and could no longer be considered safe. This phase of the work was completed in July 2001. The performance of the pre-reformer and the new synthesis converter are shown in Tables 1 and 2.

### Table 1: Pre-Reformer Performance

<table>
<thead>
<tr>
<th>Process Guarantees</th>
<th>Test-Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversion of C₂H₆, %</td>
<td>&gt;85</td>
</tr>
<tr>
<td>Conversion of C₃+, %</td>
<td>&gt;95</td>
</tr>
</tbody>
</table>

### Table 2: Synthesis Loop Performance

<table>
<thead>
<tr>
<th>Process Guarantees</th>
<th>Test-Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>Converter Capacity, t/d</td>
<td>600</td>
</tr>
<tr>
<td>NH₃ at 3rd bed outlet, %</td>
<td>15.8</td>
</tr>
<tr>
<td>Converter pressure drop, bar</td>
<td>2.8</td>
</tr>
</tbody>
</table>

The second phase of the work (expansion to 800 t/d) comprised replacing the reformer tubes, revamping the shift converters, CO₂ removal system and the feed gas, air and synthesis gas compressors, and installing a new purge gas recovery unit. Minor changes to the heat exchangers, pumps and piping were also planned.

Fig. 6: The three new converters and the HP waste heat boilers
In 2002, AMMONIA CASALE completed the revamp of a 1,000-t/d (original capacity) ammonia plant based on Kellogg technology at the Al-Bayroni Fertilizer Company, located in Al-Jubail, Kingdom of Saudi Arabia. This plant originally started up in March 1983. It uses natural gas for both feed and fuel.

The plant had been revamped once before in 1989 by replacement of the converter internals with a traditional two-bed one-interchanger design, (not a CASALE design) and installation of a membrane-type hydrogen recovery unit, which allowed it to operate at a capacity of about 1,170 t/d.

The main goal of the project was to increase production capacity to 1,300 t/d. Further targets were energy saving, reducing cooling water consumption and improving reliability.

A second step of capacity increase was also considered, meanwhile the natural gas quality of the Al-Bayroni plant has considerably changed with a higher content of nitrogen. CASALE adapted their studies on plant production and efficiency improvement to the new design basis. 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 in September 2001. A turnaround took place in January 2002, and all modifications were made during the period of a standard shut-down. Start-up followed immediately after.

Since every modification to machinery is very expensive, and since it would have been quite uneconomic to reharp the reformer because the existing tubes were almost new, CASALE prepared a minimum-investment revamping option according to the following guidelines:

- Main rotating equipment would not be revamped or replaced;
- No modifications would be made 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;
- The plant should be able to operate at original capacity when new sections were isolated;
- Possible trips in new sections should not trip the existing plant.

The capacity expansion was limited to 1,300 t/d by the suction capacity of the existing synthesis gas compressors.

The feed gas desulphurization, feed gas compression, secondary reformer and methanation sections were suitable for the new operating conditions and needed no modifications.

The following modifications were implemented:
Pre-reforming and Primary Reforming
The primary reformer of the Samad ammonia plant is a typical Kellogg top-fired unit with 416 catalytic tubes arranged in eight rows. The reformer tubes were replaced in 1997 with new HK40 tubes identical in every respect with the original tubes.

Without upgrading the reformer tubes the heat flux to the primary reformer could be increased only marginally. Therefore, to increase the capacity of the reformer up to the level needed for the capacity expansion, the steam : carbon ratio had to be decreased. On account of the high concentration of higher hydrocarbons in the natural gas, this could only safely be done by installing a pre-reformer. (Fig. 6).

The advantages of the use of the pre-reformer and of the fired heater can be summarized as follows:
- the S/C ratio could safely be reduced;
- every possible change in natural gas composition could be accommodated.

Process Air
This section was designed to provide sufficient process air for a production of 1,000 t/d of ammonia under normal conditions. Any increase in plant capacity therefore required debottlenecking of this compressor. This was accomplished by the following main modifications:
- addition of an air booster driven by a back-pressure steam turbine;
- addition of an after-cooler downstream the new air booster;

The booster was sized to be able to accommodate the prospective future major expansion up to 1800 MTD.

Shift Conversion
The high pressure drop in the shift converters (0.5 bar in the HTS and 0.6 bar in the LTS for new catalysts; and >1.0 bar each for the aged catalysts for both reactors) was due to the axial-flow design of these converters. Retrofitting
with CASALE axial-radial internals reduced the pressure drop to about 0.3 bar, correspondingly increasing the suction pressure of the synthesis gas compressor. This pressure increase was very important to allow this machine to 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;
- longer catalyst life;
- catalyst protection against water droplets.

**CO2 Removal**
The carbon dioxide removal system was an inhibited MEA system. The CO₂ content of the purified gas was satisfactorily low (around 120 ppm) but corrosion problems were observed. For the revamp, the BASF aMDEA process was adopted by means of a simple solvent swap. None of the equipment needed modification. This change reduced the specific energy consumption, making it possible to reduce the S/C ratio.

**Synthesis Loop**
The reduction of the steam / carbon ratio and the revamping of the shift converter internals allowed an increase in plant throughput without appreciably increasing the system pressure drop. To allow the synthesis loop to handle the increased flow new synthesis converter internals were provided. The existing cartridge was a two-bed inter-cooled design installed in the 1989 revamp. This was replaced by a new three-bed axial-radial cartridge with one quench inlet between the first and second beds and one interchanger between the second and third beds. The greater conversion efficiency and lower pressure drop of the new converter internals meant that both the required gas recycle rate and the energy needed to drive it round the system were reduced, so the recirculator wheel of the main compressor was replaced by a new one designed for the revised flow conditions. The spare energy, resulting from the reduced recirculation power requirement, provided the additional power needed to maximise the discharge pressure of the make-up gas compression stages at the increased suction flow rate without any other modification to the compressor or its turbine drive.

On account of the better converter performance and higher loop operating pressure, not only the ammonia concentration but also the temperature at the converter outlet was higher. The latter was above the design value for the metallurgy of the existing converter outlet pipe and for the boiler feed water preheater, so both were replaced.

The improved performance of the synthesis loop significantly reduced the specific chiller duty, allowing the plant capacity increase to be borne by the refrigeration compressor and its steam driver without any modification.

Table 3 compares the performance of the plant before and after the revamp.
### Table 3: Al-Bayroni Plant Performance Before and After Revamp

<table>
<thead>
<tr>
<th></th>
<th>Before revamp</th>
<th>After revamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production, t/d</td>
<td>1170</td>
<td>1312</td>
</tr>
<tr>
<td>Specific energy consumption, Gcal/tNH₃</td>
<td></td>
<td>about 6 % reduction</td>
</tr>
<tr>
<td>Sea water consumption, m³/tNH₃</td>
<td></td>
<td>about 7 % reduction</td>
</tr>
</tbody>
</table>
PCS NITROGEN TRINIDAD, O3 PLANT

The O3 ammonia plant is an original C.F. Braun design that was constructed in 1965 in Brea California. The plant was relocated to Trinidad in 1994. The design capacity at that time was 680 MTD. Some minor modifications increased the plant’s production rate to 753 MTD.

Following the plant revamp by AMMONIA CASALE, the plant production is now 953 MTD, and the energy consumption has been decreased by 10%. The revamp involved converting the plant from the original Braun purifier design (operating with 50% excess air in the front end) to a conventional ammonia plant operation. The purifier was idled, and a hydrogen recovery unit was installed to treat the purge gas from the synthesis loop. The two existing converters were retrofitted with CASALE isothermal design converter baskets. These are the first of their kind to be installed in ammonia service. They provided reduced pressure drop and improved conversion.

Revamp Scheme

The Braun process is characterized by the introduction of excess air in the secondary reformer. This reduces the load of the primary reformer and requires a cryogenic purifier, downstream of the methanator, to remove the excess nitrogen. This purifier removes almost all of the inerts contained in the gas. There is however, an expander located immediately upstream of the purifier and this creates a large pressure drop.

Therefore, the two main areas that needed to be improved were the reforming section and the synthesis loop.

The following major changes were required for the revamp:

1. Installation of a Pre-reformer.
   This was comprised of:
   a. A reactor with CASALE designed axial-radial internals.
   b. A new fired heater to recover the resulting temperature drop

2. Revamp of the Primary Reformer:
   a. Replacement of the catalyst tubes.
   b. Extension of the radiant section.
   c. Replacement of the mixed feed coil.
   d. Installation of a combustion air blower to supplement the gas turbine exhaust (GTE).

3. Installation of a quench nozzle on the HTS quench.

4. Upgrade of the CO₂ removal system:
   a. Replacement of the trays in the MDEA Regenerator.
   b. Installation of an additional steam reboiler.
   c. Installation of two additional Regenerator Overhead Condensers.
   d. Installation of an additional Regenerator Overhead Separator
5. Idling of the Purifier section.
6. Replacement of the synthesis gas compressor HP rotor.
7. Replacement of the existing two converter internals with the CASALE isothermal basket design. This consists of an arrangement of exchanger plates in the axial-radial catalytic beds.
8. Installation of a BFW heater.
9. Installation of a Hydrogen Recovery Unit. This is a used unit that was refurbished and was handled as a joint effort between Air Products and PCS Trinidad.
10. Changes in the ammonia recovery section.
   a. Replacement of the MP ammonia absorber with a high pressure absorber.
   b. Installation of a new HP Absorber feed pump.
11. Replacement of the ammonia product pumps.
    This was handled as an internal project at PCS.
12. Replacement/Addition of control valves and PSVs.

**Process Details - Pre-Reforming**

The pre-reformer section was installed to increase the total reforming capacity of the plant. The pre-reformer is an AMMONIA CASALE designed axial-radial adiabatic reactor, with a very low pressure drop.

The gas leaving the pre-reformer is partially reformed. It then flows to the fired heater, which supplies the heat necessary to increase the temperature to the reformer tube inlet temperature.

![Fig. 8: PCS axial-radial pre-reformer](PDF created with pdfFactory trial version www.pdffactory.com)
Primary Reformer

The primary reformer was an original Foster Wheeler. The tubes were at their end-of-life and the frequent failures were causing severe plant reliability issues. The major changes were:
- Tube arrangement changed from staggered to inline.
- Number of tubes increased
- Extension of the radiant box.
- Installation of additional burners.
- Replacement of the old burner tips.
- Replacement of the mixed feed coil.

![Fig. 9 - Pre-Reformer Arrangement, new items in red.](image)

The radiant box extension was shipped in sections with insulation pre-installed, ready for assembly. The insulation however was damaged in shipping and was replaced on site.

The composition of the fuel gas to the burners was changed with the elimination of the waste gas from the purifier section. The gas from the HRU is much less and the burner tips were changed as a result. The gas turbine exhaust, which supplies oxygen to the burners, was deemed to be insufficient and an auxiliary air blower was installed to supplement the oxygen supply. The exhaust of this blower was tied into the GTE ducting.
Shift Conversion

The shift converters, both HTS and LTS, were found to be adequate for the revamp and the only change made in this section was the installation of a BFW quench system to control the HTS inlet temperature. This was necessary because of the limitation of the secondary reformer waste heat boiler.

CO2 Removal

In reviewing the CO$_2$ removal system the key parameter used for design was the specific energy consumption, the revamp sought to maintain this at the old rates. To do so, an additional demand was required. This was supplied by installing an additional steam reboiler. In keeping with the increase in reboiler duty, the capacity of the MDEA Regenerator Overhead Condensers had to be increased. This was achieved by installing an additional cooler.

To maintain stripping efficiency, the MDEA strength was increased and the circulation rate was increased. The system hydraulics was reviewed and it was necessary to replace the MDEA Regenerator trays with new high efficiency design trays.

Synthesis Gas Compressor

The LP stage of the compressor was found to be suitable to the capacity increase. This was primarily due to the significant increase in suction pressure, caused by the decommissioning of the purifier section.

The HP stage was limiting with the increased volumetric flow and had to be retrofitted. A new rotor was installed.

Synthesis

The plant is fitted with two ammonia converters operating in parallel. The revamp of the synthesis section demanded a very significant efficiency improvement because of:
- The large capacity increase and
- The higher concentration of inerts in the circulating gas due to the front-end transformation.

This entailed the retrofit of the converter internals with AMMONIA CASALE isothermal design. This new design allowed a significant reduction in the circulation flow and consequently a considerable decrease in the specific duties of the exchangers. The lower recycle flow resulted in a smaller heat recovery in the synthesis waste heat boiler. To overcome this, a BFW pre-heater was installed. Additionally, the increased ammonia conversion in the synthesis loop translated into no additional load on the refrigeration system, which in turn meant no modification to the refrigeration compressor.

The Isothermal Ammonia Converter (IAC) design abandons the use of multiple adiabatic catalyst beds, commonly used in the ammonia industry for the pseudo isothermal design, and offers a higher conversion per pass. The new design is based on the use of plates immersed in the axial-radial catalyst bed to remove the reaction heat while it is formed.

As indicated in the diagram above, the temperature profile achieved in the catalyst bed follows the line of maximum reaction rate, so obtaining the highest possible conversion per pass from a given catalyst volume.

![Temperature Profile of the IAC](image)

**Fig. 11 - Temperature Profile of the IAC**

The use of plates for cooling, allows the design of a pseudo isothermal converter without tubesheets, eliminating the size restriction and simplifying the construction of the internals and the operation of catalyst loading and unloading. In addition, the non-adiabatic beds are axial-radial, featuring a low pressure drop and allowing the use of small size, high activity catalyst.
**Purge Gas Treatment**

With the change in front end operating philosophy, the concentration of inerts in the loop was significantly increased, resulting in a much higher purge gas flow from the loop. To recover the hydrogen in the purge, a Hydrogen Recovery Unit, HRU, has been installed. The hydrogen product is recycled back to the synthesis gas compressor and the rejected or waste gas is used for dryer regeneration and sent to the primary reformer burners as fuel.

**Steam System**

HP steam generation has increased, but no equipment modifications were necessary.
INTEGRATED REVAMPING STRATEGY FOR AN AMMONIA-UREA COMPLEX

As a single licensor with knowledge and technologies for both ammonia and urea, CASALE is the best partner for the revamp of a fertilizer complex.

This is even more relevant in India than in other countries in the world, because in a typical ammonia-urea complex in India, all ammonia is converted to urea, i.e. there is no export of ammonia. Moreover, the production of ammonia and CO2 should be balanced for the downstream urea production.

Hence, there is a very strong link between the ammonia and the downstream urea plants, both in the operation and in the impacts of a revamp of the units. A capacity increase of one of the two units cannot provide the expected return if the other cannot cope.

In this case, the bottlenecks must be identified and overcome jointly in the ammonia and the downstream urea plants, in the best Client’s interest, to avoid that capital is spent unnecessarily.

AMMONIA and UREA CASALE can undertake the revamp of an ammonia-urea complex as a totally integrated design task, thereby providing the best revamp strategy case by case, depending on the actual bottlenecks in the complex. The deep interaction between AMMONIA and UREA CASALE in the conceptual design stage is a priceless tool to devise, in a unique manner, the best process modifications for the revamp of the complex.

The ammonia and urea plants are closely linked. AMMONIA and UREA CASALE consider, among others, the following main aspects in the revamp of the ammonia/urea train

- The conditions and flow rate of the process streams from the ammonia plant to the downstream urea (CO2, ammonia, passivation air stream)
- The integration of the overall ammonia/urea steam balance, to minimize the load on the utilities boiler
- The identification of the optimum target capacity and energy consumption reduction of the complex, which maximize the attractiveness of the investment for the client

These are only the main areas where the activity of AMMONIA and UREA CASALE, as a single point of responsibility for the overall project, yield the most attractive revamp results.

Only the CASALE Group can boast this premium advantage, arising out of its ability to license and supply advanced technologies both for Ammonia and Urea production.

Needless to say, the revamp of the ammonia and urea plants can be undertaken separately and at different times, depending on the specific factors normally considered for implementation of the projects (major turnarounds, windows for interventions in specific areas and the like).
CONCLUSIONS

The cases described here above are only examples of the different and possible schemes of the modifications that can be applied to any ammonia plant to improve the performances thereof.

Moreover, development of new technologies is always ongoing at CASALE, to further improve the existing plants capacity, consumption, reliability and operation.

The CASALE approach is to customize the revamping to the real needs of the plant, by taking into proper consideration the major bottlenecks in the ammonia and urea plants, which can be overcome cost-effectively.

Thanks to its unique position as the licensor of technologies for ammonia and urea, CASALE is the best partner to implement a revamp of an ammonia/urea train, which requires knowledge of the implications of selected strategy on the whole fertilizer complex.