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LARGE CAPACITY INCREASE IN AMMONIA AND UREA PLANTS, NEW TRENDS

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ABSTRACT

This paper presents the approach taken by AMMONIA and UREA CASALE to revamp ammonia and urea plants in order to increase their production capacity with a minimum investment cost and the highest benefits.

This approach is based on a number of new technologies developed on purpose by The CASALE companies, that are here illustrated.

INTRODUCTION

AMMONIA CASALE S.A. of Switzerland is an independent engineering company that has been operating world-wide for more than 77 years in the field of ammonia and methanol plants. More recently the range of products has been widened entering also in the field of urea and formaldehyde plants.

For that purpose the company has been split in four, AMMONIA CASALE S.A., UREA CASALE S.A., METHANOL CASALE S.A. and CASALE CHEMICALS S.A., each one taking care of the relevant processes.

All four companies are fully owned by CASALE Holding S.A.

The common targets of CASALE Companies gain substance from the sale of:

* licenses for the exploitation of technologies;
* engineering services;
* equipment and materials;
* complete plant units;
* technical assistance services.

The most outstanding characteristic of all the CASALE Companies is their philosophy of developing new technologies in their field of operation and to market these new technologies.

That is quite different from most engineering contractors that normally obtain licenses from the technology owner. Therefore, the main goal of most contractors is to sell manhours and materials, from which they obtain their profit.

This leads to the fact that when they tackle a revamping job, the result is a very large project, involving the replacement of many items and a lot of engineering man-hours, rendering it an expensive approach.

On the contrary the CASALE philosophy is to find a way to overcome the existing plant constraints with the smallest effort by applying new ideas and technology, thus reducing amount of items to be replaced to a minimum and the man-hours as well.

The general approach of CASALE to plants revamping is to upgrade the efficiency of the plant's key equipment with innovative technology rather than just increasing the size and/or adding additional equipment.
Most of the technologies have been developed by CASALE to accomplish these goals.

Another unique characteristic of CASALE is that disposing of both ammonia and urea technologies, it is the only company worldwide that can offer integrated packages for revamping both plants, without the difficulties due to the presence of two different engineering companies working in the same plants.

Based on these ideas, CASALE has developed a number of solutions that are here illustrated to revamp ammonia and urea plants for capacity increase and energy efficiency improvements.

1. AMMONIA PLANTS

1.1 Natural Gas Filtration

A problem present in some plants fed with natural gas is its filtration. In fact the gas itself is sometimes quite "dirty" carrying solids, etc. If the gas is not filtered, these solids end up in the desulphurisation catalyst, reducing its operating life.

The filtration of the natural gas is not so easy due to the large volume of fluid to be treated. CASALE has developed an innovative humid dust separation system that is characterized by a very low pressure drop and by the fact that it is a continuous process, with no need to replace the cartridge or any other similar item.

The system is based on an innovative fluid dynamic design of a centrifugal separator.

1.2 Primary Reforming

The interventions to primary reforming section that have been developed by CASALE to overcome the most difficult problems of capacity increase or co-production of methanol or hydrogen are the following:

1.2.1 CAMP, Combined Ammonia and Methanol (or Hydrogen) Production

This new technological concept allows ammonia plant owners to produce methanol or hydrogen by means of an existing revamped ammonia plant without affecting their ammonia production capacity or to substantially increase ammonia capacity.

The main concept, followed to reach the above goal, is that the syngas necessary for the additional production (methanol, hydrogen or ammonia) will be produced by a new catalytic steam reformer, which shall be gas heated using the high level heat content of the reformed gas available downstream the secondary reformer, ammonia side *(see figure 1 for co-production, and figure 2 for ammonia capacity increase).*

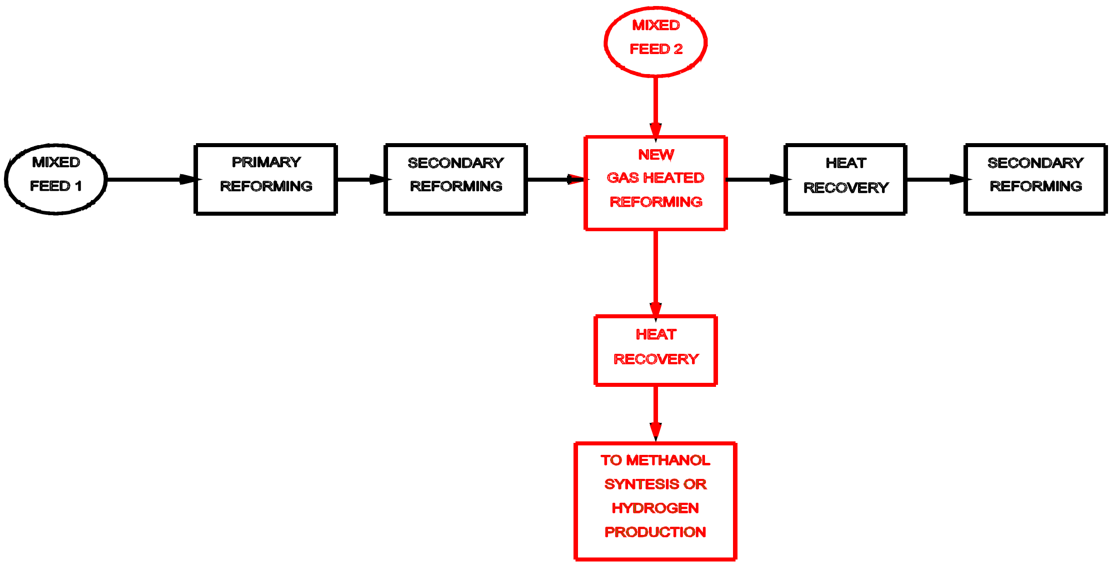

Fig. 1

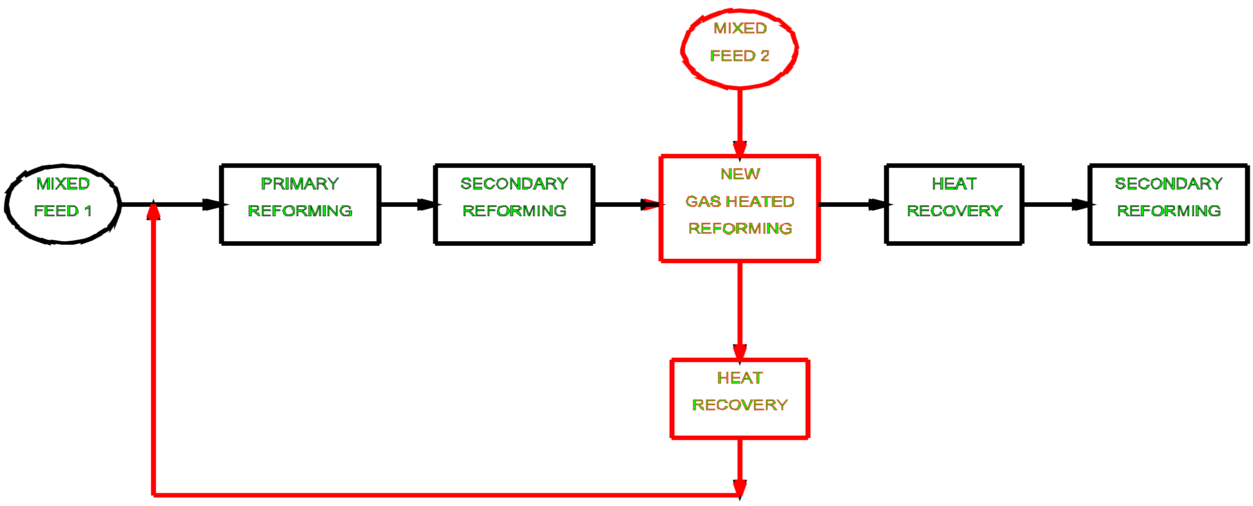

Fig. 2

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The gas existing to the ammonia secondary reformer, typically at about 1'000°C, flows to the gas heated reforming exchangers, shell side. The hydrocarbon feed stock and steam feed the tube side of this reforming exchanger where they come into contact and react upon conventional primary reforming catalyst.

In principle, the reformed gas waste heat boilers' bundles, in which the ammonia train actually use the heat released by the ammonia secondary reforming to raise high pressure steam, may be relocated downstream of the new gas heated primary reformer.

A new package boiler will be added to increase the Medium Pressure steam generation in order to be able to drive the steam turbine of the new methanol loop centrifugal compressor/circulator (when present) and to close the steam balance.

The main advantage is that in case of co-production, the front end (gas preparation section) of the ammonia train will not be affected by the revamping intervention, and therefore, the operating conditions relevant to the ammonia production will remain substantially unchanged.

Moreover, there will be no hydrogen decreased flow to the ammonia unit and thus the production level, as well as optimized synthesis conditions, can be maintained.

The methanol synthesis loop and distillation units can be completely new or revamped ones.

In case of hydrogen co-production, a new shift system and gas purification section has to be added.
A high flexibility of the complex is guaranteed. The methanol synthesis or hydrogen production may be activated and deactivated at will.

When co-production is deactivated or reduced, the natural gas, reformed in the gas heated reformer tube side, will be routed upstream of the ammonia production primary reformer.

This will have the additional beneficial effect of decreasing the ammonia primary reformer energy consumption.

Moreover the purge gas from the methanol synthesis loop can be added to the ammonia primary reformer feed, allowing either an increase in ammonia production capacity or a reduction in ammonia primary reformer energy consumption.

In case ammonia capacity increase is the goal, the reformed gas exiting the gas new heated reformer will be rerouted to the entrance of the existing fired primary reformer.

This will enable to increase the ammonia plant capacity up to about 40-50%, even when the primary reformer furnace is a bottle neck.

The main advantages of the CAMP approach, if compared to other potentially available options for the integration of methanol production in ammonia plants (as, for instance, the methanolation), are:

a) The possibility to produce methanol or hydrogen without affecting ammonia production capacity;

b) The possibility to produce methanol or hydrogen without effecting optimized ammonia production process conditions;

c) The flexibility in product diversification: a range of production capacities for methanol can be obtained without effecting ammonia production;

d) The possibility to increase ammonia plant production and/or reduce its energy consumption.

1.3 Secondary Reformer Burner

The secondary reformer burner may be improved in many plants by reducing its pressure drop.

The pressure drop value of this item is critical, because it directly influences the maximum capacity of the air compressor that is very often the plant main bottle neck.

On the other hand, is not easy to design a burner having a low pressure drop, and at the same time, a good performance in terms of gas temperature distribution in the combustion area and low temperature of the burner skin itself.
Thanks to the experience in solving difficult fluid dynamic problems, and to the expertise in combustion technology of its staff, CASALE succeeded in this task and is now ready to offer a burner with a low pressure drop and that ensures a uniform temperature field at the catalyst bed inlet and low temperatures in contact with the burner and the refractory lining.

1.4 Shift Converters Revamping

The revamping of the shift converters, high temperature, low temperature and possibly guard bed, consist in the transformation of the existing axial bed to axial radial configuration *(see figure 3).*

This new configuration has an inherently low pressure drop of the catalyst bed, and in addition, makes it possible to use small-size, more active catalyst.

The low pressure drop helps eliminate the hydraulic constraints in having more flow through the front end, while 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.

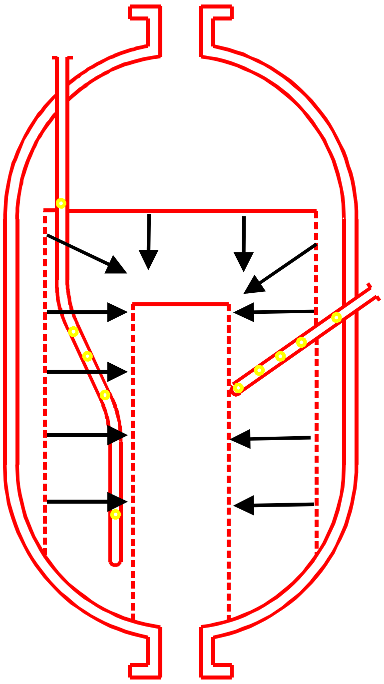

Fig. 3 - Revamped Shift Converter

In an axial-radial catalyst bed the gas distribution is such that most (about 90%) 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 4).*

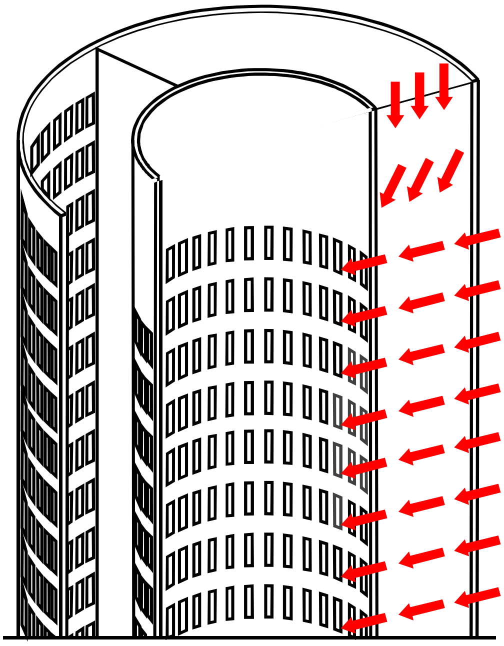

Fig. 4 - Axial-radial Bed, Gas Distribution

This feature is an essential factor for an easy and simple construction of any type of converter internal and for an effective elimination of the catalyst caking problem.

The main features of CASALE patented design for both H.T.S. and L.T.S. converters which lead to the following advantages, are:

* an axial-radial flow path of the gas crossing the catalyst resulting in a low pressure drop;
* use of small-size, more active and more resistant to poisons catalyst;
* protection of catalyst from water droplets carried over from secondary reformer heat recovery train or others;
* possibility to load different volumes of catalyst easy operation.

1.4.1 <u>Advantages of the Axial-Radial Shift Converters</u>

There are many advantages of the axial-radial technology over the axial one, both when revamping plants for capacity increase and for energy savings, as well as for new converters, and they can be summarised as follows:

<u>Revamping for capacity increase</u>

* no pressure drop limitation due to lower differential pressure within the axial-radial technology;
* no bigger catalyst volume required because of the use of smaller catalyst size with higher activity;
* longer operation at equilibrium with higher product purity (H_2 plants) or higher production rates (NH_3 plants);
* longer operation at equilibrium with the consequence of higher plant capacity;

* longer catalyst life due to higher catalyst activity and poison resistance
* protection of catalyst from water droplets with the consequence of an extended catalyst lifetime

Revamping, same capacity

* energy saving, thanks to the lower pressure drop
* reduced catalyst volume (30-50%) for the same catalyst life
* same catalyst volume for longer life

New converters

* reduced catalyst volume
* multi-bed configuration in one vessel
* internal heat exchangers for lower capital cost

General

There are no drawbacks with respect to the axial converters, in fact:

* converter operation is equal to that of axial bed configurations
* catalyst loading unloading is equal that of an axial bed
* catalyst life monitoring is equal to that of an axial bed

A further advantage present in all cases is that there are no possibilities of channeling in the catalyst bed thanks to the very low velocity of the gas.

AMMONIA CASALE has already revamped two shift converters trains, respectively in spring 1995 and 1996, each made by one H.T.S. and one L.T.S., in two Kellogg ammonia plants in the P.R. of China.
The performances obtained during the test run of one the two trains:

TABLE 1	PRESSURE DROP (bar)		
	HTS	LTS	TOTAL
Before revamping	0.55	0.55	1.10
After revamping	0.25	0.22	0.47
Decrement	0.30	0.33	0.63

The test-run CO leakage from the L.T.S. was 0.11%, whereas before revamping it was 0.25%, thus realizing a decrement of 0.14%. In both cases the revamping was carried out within a normal turnaround.

Please note that thanks to the higher catalyst activity, the inlet temperatures after revamping were lower then before, lowering the CO leakage due to the more favorable equilibrium concentrations at low temperature.
Another plant revamp is under way and will be started up in late 1998 in the USA, at the AGRIUM plant in Borger, Texas and will run according to the following parameters:

TABLE 2			PRIOR TO REVAMP	AXIAL-RADIAL REVAMP
	Plant Capacity	[stpd]	1450	1600
	Catalyst Size	[mm]	9 × 6	6 × 3
SOR	Inlet Temperature	[°C]	360	360
	Pressure Drop	[bar]	0.55	0.45
	CO Leakage, dry	[vol%]	2.45	2.45
EOR	Inlet Temperature	[°C]	372	370
	Pressure Drop	[bar]	0.82	0.45
	CO Leakage, dry	[vol%]	3.0	2.95

1.5 Ammonia Synthesis Converter

The ammonia converter is, of course, one of the most important items when planning a revamp for energy saving or capacity increase, and in fact it is, in most cases, 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 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 then 100 converters on stream, out of which about 50 are "in situ" modifications, and the majority of the others are revamps of full-bore opening converters.

The most important ingredients for this success are the axial radial beds, described at point 1.4 above *(see figure 4)*, and the three-bed configuration adopted both for revamping of any kind of converters and for new converters as well *(see figure 5)*.

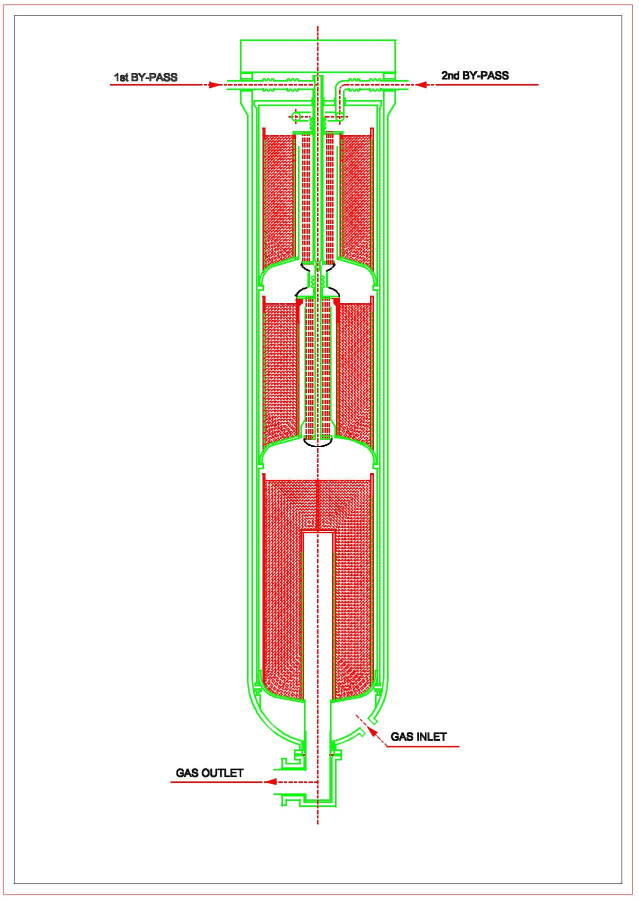

Fig. 5

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.

It is possible to use small-size, more active catalyst with the axial-radial configuration, and it is well known that small-size catalyst is more efficient than the large-size one.

Therefore, the design of the cartridge 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 and a low pressure drop.

A particular feature of the design is its simplicity: the catalyst-containing baskets are easy to be handled and have a low cost. Moreover, the use of a reverse bottom increases the catalyst filling efficiency *(see figure 5)*.

1.5.1 <u>Three Bed Converter</u>

For several years CASALE has been using a three catalytic bed cartridge configuration with interchange design, which leads to considerably higher thermodynamic efficiency compared to other designs.

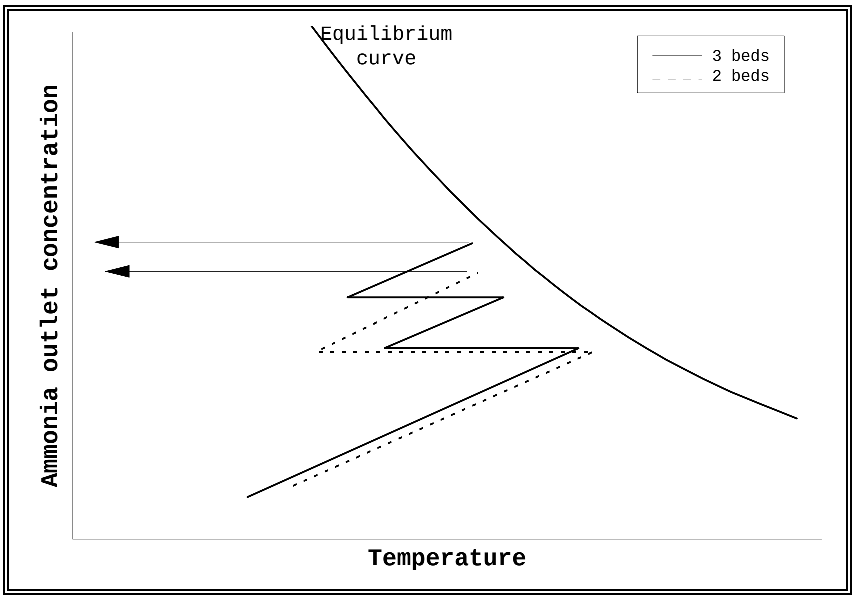

Fig. 6 - Three beds versus two beds performance comparison (same total catalyst volume)

As it is well known, the synthesis reaction of ammonia is limited by adiabatic equilibrium and the conversion achievable in each bed is limited by this equilibrium. Therefore, the higher the bed number, the higher the total conversion per pass in the converter.

The three-bed converter gives large advantages in process performance. This means that with the *same catalyst volume a higher conversion per pass* is reached by the three-bed converter *(see figure 6)*, or that to reach *the same conversion per pass, a smaller catalyst volume* is necessary with the three bed converter.

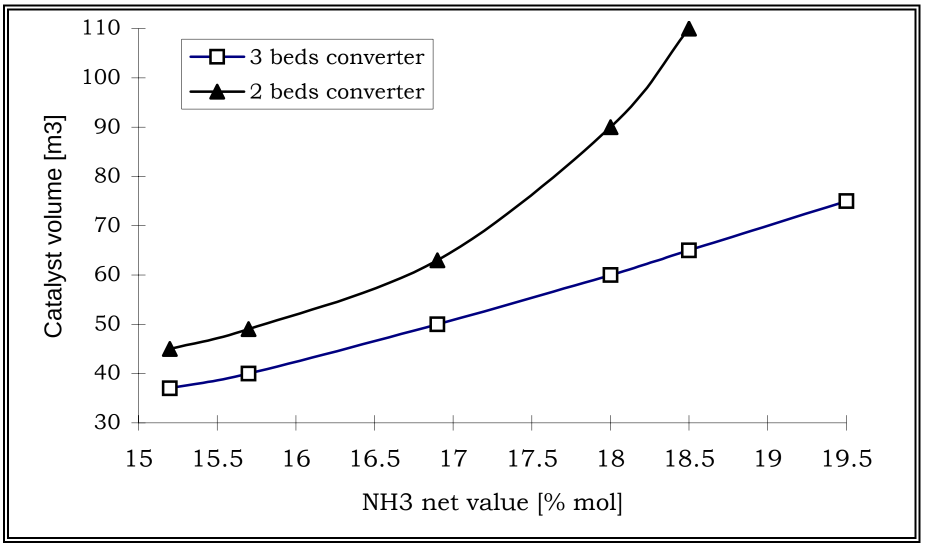

Fig. 7 - Catalyst volume versus NH_3 net value

The three-bed configuration leads, therefore, to smaller, less expensive ammonia reactors.

Figure 7 shows the required catalyst volumes as a function of the ammonia conversion, applying three-bed and two-bed lay-outs.

It is worthwhile evidencing that ammonia conversion is always larger with a three-bed lay-out and that this difference is increasing continuously with increasing conversion.

2) UREA PLANTS

UREA CASALE has been active in the urea field since 1985, first as AMMONIA CASALE and from 1991 as an independent company.

From the very beginning, the activity of the company has been concentrated on revamping existing urea plants.
In the current situation, with a constantly increasing urea demand and economical uncertainty, there is, in fact, a high demand for plant upgrading which can give additional capacity at a cost lower than through new plants construction.

Thanks to a team of very skilful people, most of them with a long experience in the urea field, UREA CASALE developed several innovative and very competitive technologies to revamp urea plants.

The general approach of UREA CASALE to urea plant revamping is to upgrade the reaction section in order to increase its efficiency, rather than just adding additional equipment, and most of the technologies have been developed to accomplish this goal. UREA CASALE revamping technologies can be applied to plants originally designed according to any kind of urea process.

A quick overview of the most advanced CASALE technologies is given considering the main classes of possible revamping:

* **SMALL TO MODERATE CAPACITY INCREASES (UP TO 30-35%)**

CASALE High Efficiency trays *(See figure 8)* drastically increase the efficiency of the urea reactor (up to 4-5 percentage points) debottlenecking the HP synthesis section allowing to achieve capacity increases up to 30-35% with only minor (and limited to the synthesis section downstream equipment) additional modifications to the plant.

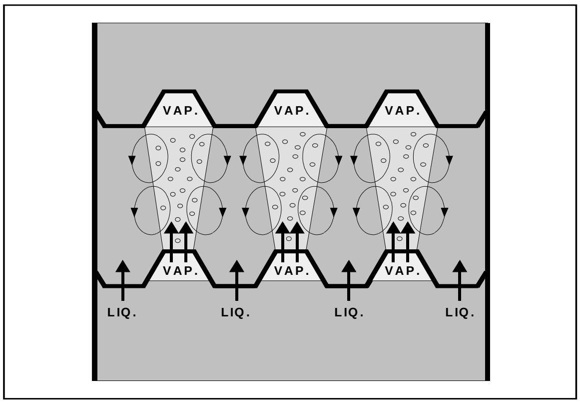

Fig. 8 - High Efficiency Reactor Trays

* **LARGE CAPACITY INCREASES (60% OR MORE)**

CASALE **HEC Process** and **Vapour Recycle System (VRS)** obtain an even higher increase in the urea reactor efficiency.

The HEC process, used for the revamping of conventional total recycle plants *(see figure 9)*, combines a very efficient "once through" synthesis section with the conventional reactor obtaining an average conversion of 72% (at increased capacity).

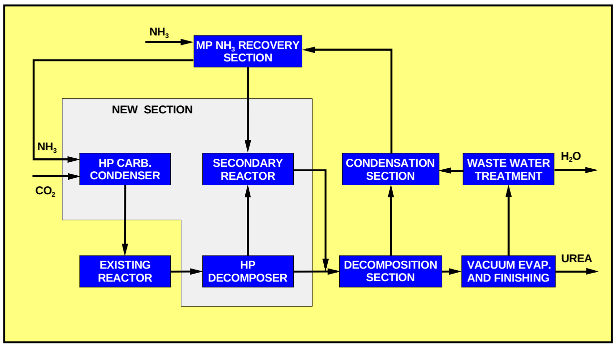

Fig. 9 - Conventional Total Recycle plant revamped with the HEC concept

The VRS, used for the revamping of stripping plants *(see figure 10)*, eliminates the water from the recycle carbamate before sending it to the synthesis section obtaining conversions up to 67-68% (at increased capacity).

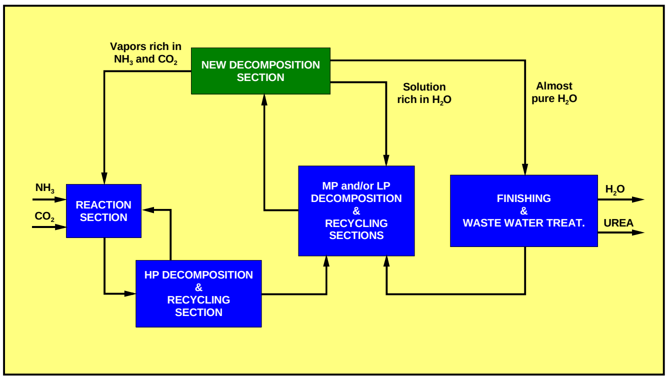

Fig. 10 - Stripping plant revamped with the VRS concept

For both approaches, thanks to the conversion increase a large capacity increase can be obtained with minimum amount of additional equipment and minimum shut down time.

* **ENERGY SAVING**

With the use of the above mentioned **CASALE High Efficiency trays** the specific steam consumption can be reduced. Reductions up to 200 kg/MT have been obtained.

* **POLLUTION CONTROL**

With the use of **CASALE High Efficiency Hydrolyser**, it is possible to eliminate completely NH_3 and urea from the process condensate before discharging it.
If a complete reduction of urea is not required, very low urea contents can still be obtained using the **UREA Recovery System**.

* **IMPROVEMENT IN PLANT RELIABILITY**

With the **Carbamate Condenser Passivation System** it is possible to increase the corrosion resistance of horizontal HP condensers.

The competitiveness and the success of UREA CASALE revamping technologies highlighted above is proven by the fact that, in the last ten years, 50 urea plants, with capacities ranging from 250 to 2400 MTD, have been or are being revamped utilising these technologies.
Of these plants, 70% were originally designed according to stripping technologies.