The Casale Full-Condenser™ and Split-Flow-Loop™ Concepts

In the HP loop of the CO2 stripping plants all the vapours leaving the stripper are sent to the reactor after a partial condensation in the HP Carbamate Condenser (HPCC). All the inerts introduced into the HP loop of the plant, therefore, reach the reactor.

A new HP loop configuration to reduce the amount of inerts present in the reactor has been developed, together with a new configuration for the HPCC in order to obtain a more favourable condensation regime and improve its efficiency.

With those new concepts a drastic increase in the plant efficiency is obtained and, with little changes, the plant is de-bottlenecked for large capacity increases. At the same time the energy consumption is significantly reduced.

The paper gives a description of these newly developed concepts highlighting its advantages and its application to CO2 stripping plants. The paper also describes applications of this new concept.

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Introduction

Urea Casale S.A. is a sister company of Ammonia Casale S.A., established in 1991 to carry on the urea technology activities started by Ammonia Casale S.A. in 1985.

Since the beginning, efforts were mainly directed to the revamping of existing plants, with almost 70 plants being revamped since 1985.

Capacity increase, energy conservation, corrosion control, pollution abatement and product quality are the key areas for upgrading plant performance.

As the main strength of Urea Casale lies in licensing its technologies and following the trend set by Ammonia Casale, Urea Casale invested and is still significantly investing in technology development, putting also a lot of effort into developing the right process design tools.

Urea Casale Technical Services avail themselves of the right specialists and of advanced tools for investigating, analyzing and picturing complex phenomena, including such tools as computer-aided techniques with applications ranging from chemical process design to fluid dynamics evaluations.

The technology that is discussed in this paper is a typical example of how the combination of above mentioned tools and expertise could lead to the development of innovative concepts.

In order to make plant revamping more and more efficient, there is a constant need to improve the efficiency of the key equipment of the plants.

Following this need, possible ways of improving the efficiency of vertical HP condensers typically used in CO_2 stripping plants have been investigated. Those condensers are one of the key items of the plant HP loop that is the most important section of such type of urea plant.

In its standard, and most used, configuration, the HPCC of a CO_2 stripping plant is a counter-current falling film condenser with the following features:

- The vapours (from HP stripper) and the liquid (fresh ammonia and carbamate mixture from Scrubber and Reactor) enter on the top of the condenser.

- Only part of the vapours condenses along the tubes to keep the heat balance in the reactor.

- Liquid and not-condensed vapours leave the Condenser from the bottom separately and go to the reactor.

The standard design of the HPCC has the advantage of being mechanically simple and well proven but has the following disadvantages:

- Low Heat Transfer Coefficient
  The transfer of heat and mass is limited by the transfer surface that is the surface of the film only. Moreover, the distribution of the liquid in all the tubes is a crucial problem. The distribution is not so easy and with a bad distribution part of tubes is wetted or, in some cases, full of liquid, and part is dried, resulting in low heat exchanger surface between liquid and gas elsewhere with a consequent low Heat Transfer.

- Lower efficiency of converter
  As the HPCC is obtaining only a partial condensation, all inerts, introduced into the HP loop, go to the reactor, and inerts are known to be detrimental for the efficiency of the reactor.

As a result of its investigation, it was possible to find a way to achieve the desired improvement with a simple transformation of the condenser from its original falling film configuration into the more efficient submerged bubble-flow configuration.

With this transformation it is possible to increase the efficiency of the existing unit by at least 50%.

The possibility of transforming the HP condenser, as mentioned above, opened the way to improve also another key item in the HP loop.

Operating the HP condenser with a submerged bubble-flow configuration gives the opportunity to operate it as a total condenser and, with a simple piping modification, to reduce the amount of inerts present in the reactor.

Both changes result in an increase in the efficiency of another important piece of equipment in the HP loop, which is the reactor. The increase in efficiency corresponds to about 3 % points in the CO_2 conversion.

The development and successful design of the transformation of an existing HP falling film condenser into a submerged condenser was possible through a very accurate fluid dynamic simulation of the system combined with the modeling of the chemical-physical equilibriums and of the heat transfer phenomena.

The above was combined also with a process analysis, through simulation, of the HP loop, which made it possible to find out the way to improve, in combination with the transformation of the condenser, also the reactor.

State of the Art

Vertical HP condensers have been used in the HP loop of urea plants designed according the CO_2 stripping technologies for many years.

In such plants (see Fig. 1), the effluent of the reactor is stripped in the HP stripper using CO_2, together with heat, as stripping media.

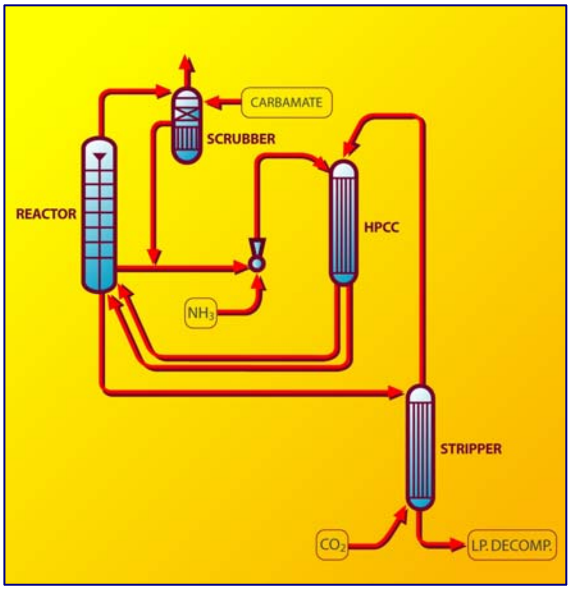

Fig. 1: HP loop of CO_2 stripping plants

In this way it is possible to recycle a good quantity of un-reacted NH_3 and CO_2 straight back to the reactor.

All the vapours leaving the stripper need to be partially condensed before they are sent to the reactor in order to keep heat balance of the latter.

In order to obtain this partial condensation, all the vapours from the HP stripper are sent to a falling film condenser, namely the HP Carbamate Condenser (HPCC).

A certain quantity of inerts (including some air for passivation) is present in the CO_2 that is fed to the HP stripper.

All those inerts introduced into the HP loop of the plant are reaching, through the HP stripper and the HPCC, the reactor.

In its standard, and most used, configuration (see Fig. 2), the HPCC of a CO_2 stripping plant is a counter-current falling film condenser with the following characteristic:

- The vapours to be condensed (coming from the stripper) are entering the condenser from the top together with a liquid stream, consisting of the recycle carbamate, coming from the HP scrubber, and the ammonia feed.

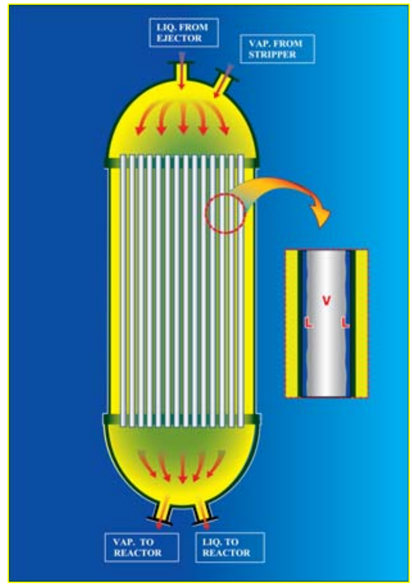

Fig. 2: HPCC of CO_2 stripping plants – Most used configuration

The liquid and the vapours are distributed in each tube. In the tubes a liquid film is formed from the condensing vapours and the entering liquid stream.

- In the bottom of the condenser the remaining vapours are separated from the liquid and both the liquid and vapours leave the condenser separately.

Theoretical considerations about different configurations for condensation

In order to find a way to improve the performance of the HPCC, Casale examined,

from a theoretical point of view, the performance of different types of condensation.
It is well known that the condensation using a falling film configuration (see Fig.3) does not give the best condensation efficiency, and that the condensation efficiency could be improved if a bubble flow configuration (see Fig.4) is adopted.

The condensation of the vapours entering the HPCC, containing NH_3, CO_2 and water, requires the transfer of mass (and heat) from the vapour bulk into the liquid phase, where NH_3 and CO_2 are condensed into carbamate, and the overall heat transfer depends also from this mass transfer.

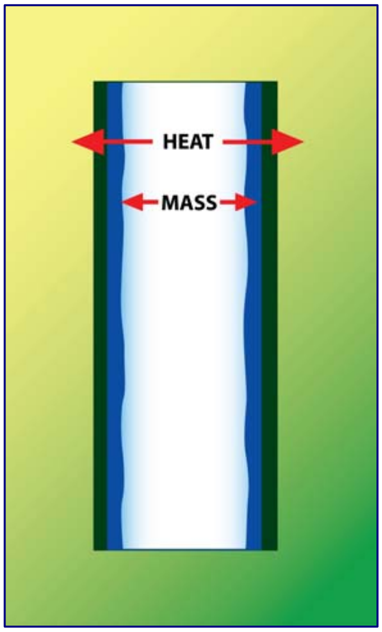

Fig. 3: falling film configuration

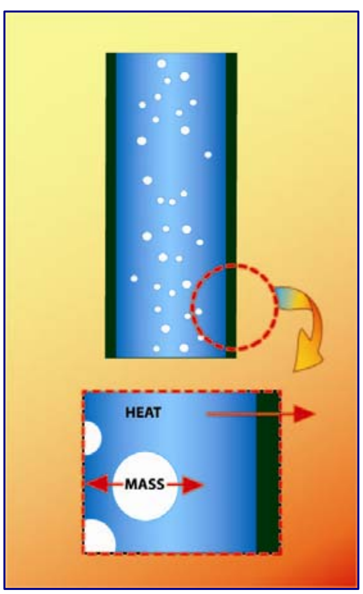

Fig. 4: bubble flow configuration

In fact, if the mass transfer is not efficient the condensation rate will be low.
The lower efficiency in the mass transfer will, therefore, be reflected in a low value of the apparent heat transfer coefficient.

In case of a falling film type of condenser, this transfer of mass becomes a limitation as the surface at disposal for the transfer is limited by the external surface of the film.

In case of a bubble flow configuration, on the contrary, the surface at disposal for the mass (and heat) transfer is much more.

Furthermore, even if the heat transfer from the liquid film to the tube wall is pretty good with the falling film configuration, it is lower than with the bubble flow configuration due to the high turbulence generated by the bubble flow and by the fact that the film can have laminar flow conditions.

The falling film configuration is also sensitive to the distribution. An even distribution of liquid and vapour over all the tubes is not always easy to obtain and a non-optimal distribution negatively influences the transfer efficiency.

Due to the above reasons, the tube side heat transfer coefficient can be, with bubble flow configuration, 4 to 5 times higher than with a falling film configuration.

Using a commercial package for the simulation of heat exchanger combined with its physical-chemical equilibrium models for urea, rigorous simulations of the two configurations mentioned above have been made.

From the modelling it became clear that with the falling film configuration the tube side heat transfer coefficient is the limiting factor in the overall heat transfer coefficient, and, therefore, an improvement of the tube side coefficient would lead to an improvement in the overall coefficient.

The simulations also showed that changing the flow regime inside the tubes to the bubble flow regime could significantly increase the overall heat transfer coefficient.

Full Condenser™ concept

In order to improve existing HPCC by changing the falling film configuration to the more efficient bubble flow configuration, Casale developed the **Full Condenser™** concept according to which the condenser operates as a submerged condenser with a natural circulation replacing the standard falling film condensation regime.

In order to fully develop the **Full Condenser™** concept, Casale included in its model, mentioned in the previous section, also the fluid dynamic simulation. In this way, it was possible to optimise the new design in all its aspects and it has now at disposal all necessary tools to best design any further application of the new concept.

According to the **Full Condenser™** concept, an existing HPCC is modified so that a mixed two-phase flow rises up in most of the tubes.

A very small amount of tubes are left without vapour phase, and in those tubes liquid flows downward, thanks to the density gradient with the other tubes. This produces an internal natural circulation.

Consequently, the new internal flow regime is a bubble flow inside a continuous liquid. In this way, the interfacial area between two phases (liquid and gas) is significantly increased, so that the transfer performance of the exchanger is highly improved.

Moreover, the HPCC will be even better protected from corrosion in the new configuration, as all tubes surfaces will be better wetted.

The new flow pattern of the HPCC is shown in the sketch of Fig.5, and can be summarized as follows:

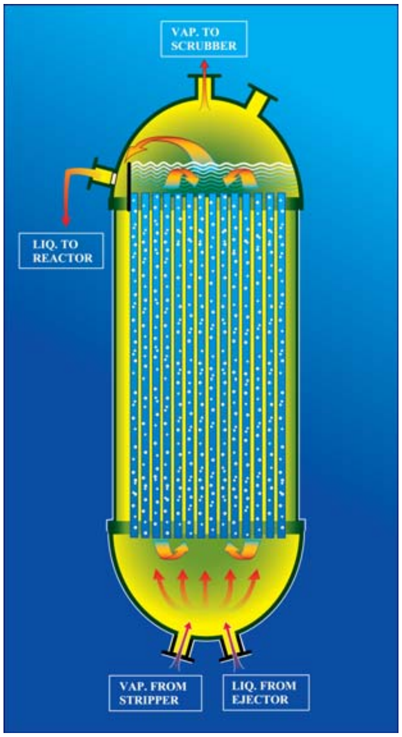

Fig. 5 **Full Condenser™** configuration

- Vapours coming from HP stripper are fed through one of the bottom nozzles and distributed inside the continuous liquid phase by a distributor at the bottom of the HPCC.
- The two-phase flow, due to its lower density, flows upward and along the tubes the vapours condense.
- A two-phase flow exits the tubes from the top tube sheet and the inerts separate from the condensed liquid and exit the condenser from the top nozzle.
- Fresh liquid (ammonia and carbamate mixture) enters the exchanger through the second nozzle in the bottom and is distributed in all tubes.

- A top weir defines the liquid level in the top part of the condenser, the overflowing liquid exits the condenser through a new nozzle.

The optimal circulation ratio is determined in order to achieve optimal condition for the heat transfer in the two-phase upward tubes.

Once transformed to the **Full Condenser™** configuration, the HPCC can easily operate as a total condenser with only inerts and a small amount of vapours leaving the condenser uncondensed. This opens the way to a further improvement in the HP loop, which is described in the next section

Split Flow Loop™ concept

Having the possibility to operate the HPCC in **Full Condenser™** configuration it is possible and also advisable to operate it as a total condenser.

A new configuration of the HP loop was, therefore, studied in order to best fit with the new configuration of the condenser and to take most advantage from it, obtaining, at the same time, an increase in the efficiency of the loop, and in particular of the reactor.

In the new configuration of the HP loop that has been developed, called the **Split Flow Loop™** concept, the HPCC is practically a total condenser and only the amount of vapours that actually has to be condensed in this equipment will go to the condenser. This is about 2/3 of the total vapour coming from the stripper.

The rest of the vapours, which in the standard configuration would leave the HPCC un-condensed, bypasses the condenser and goes directly to the reactor.

Total condensation in the condenser is not possible because of the presence of inerts, so that a small amount of not condensed vapours leaves from the top of the condenser and is sent directly to the scrubber together with the inerts.

In this way, about 2/3 of the total amount of the inerts present in the CO_2 are not sent to the reactor, and consequently the urea conversion increases.

Operating full of liquid, the **Full Condenser™** is also, contrary to a falling film HPCC, contributing to the formation of urea as the operating conditions and the hold-up are such to start forming urea.

The liquid from the total condenser is sent to the reactor through a new ejector that enhances the driving force for the circulation. The new ejector is driven by part of the NH_3 feed that is bypassing the condenser.

A sketch of the **Split Flow Loop™** configuration is shown in Fig.6.

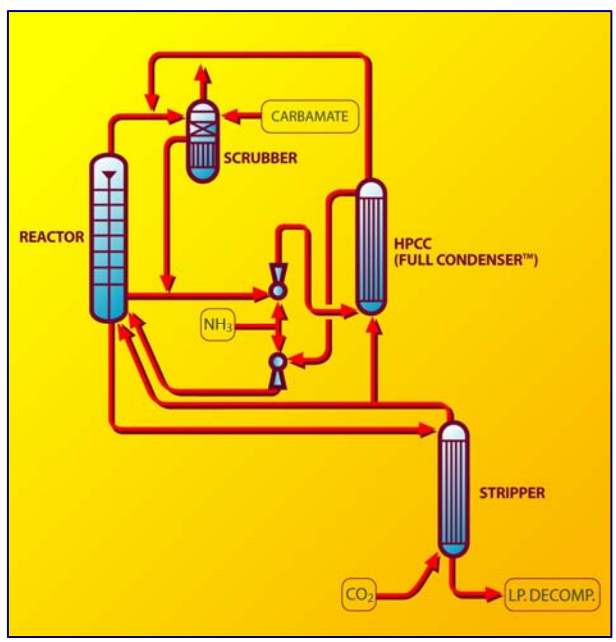

Fig. 6 **Split Flow Loop™** configuration

Even though only 1/3 of the inerts are reaching the reactor and, therefore, also only 1/3 of the passivation oxygen is reaching the reactor, this amount is more than enough to guarantee the passivation of the reactor.

The amount of oxygen fed to the CO_2 is, in fact, calculated to guarantee proper passivation of the stripper that is the most critical equipment in terms of corrosion, and this amount is much more than the amount required for the passivation of the reactor.

Performances of the Full Condenser™ and Split Flow Loop™

As said above, the **Full Condenser™** concept has been developed to improve the efficiency of vertical HPCC used in CO_2 stripping processes.

The parameter that indicates the efficiency of such kind of equipment is the overall Heat Transfer coefficient (OHTC), and thanks to the **Full Condenser™** concept, the OHTC of vertical HPCC can be increased by at least 50%.

This means that the capacity of existing condensers can be drastically increased or new units for the same capacity can be made of smaller size.

The **Split Flow Loop™** concept is, on the other hand, increasing the efficiency of the HP loop that is indicated by the CO_2 conversion in the reactor and by the NH_3 efficiency of the stripper. With the **Split Flow Loop™** concept it is possible to improve the efficiency of the HP loop increasing the CO_2 conversion in the reactor by 2.5÷3 percentage points and increasing also the stripper efficiency.

The higher efficiency of the HP loop reduces the energy consumption of the urea plant and de-bottlenecks the plant for capacity increase.

It has to be mentioned that the **Full Condenser™** concept is also further contributing to increase the HP loop capacity as, contrarily to the falling film design, urea is formed in the condenser boosting the capacity of the existing reactor.

Revamping of CO_2 stripping plants with the Full Condenser™ and Split Flow Loop™ concepts

Thanks to its performances, the combination of the **Full Condenser™** concept with the **Split Flow Loop™** concept is a very powerful tool to debottleneck CO_2 stripping plants.

The plant can be easily transformed into the **Split Flow Loop™ / Full Condenser™** configuration by:

- Addition of internal parts in the HPCC to transform it to the **Full Condenser™** configuration

- Some piping modification to re-route some lines according to the **Split Flow Loop™** concept
- Addition of a new ejector

In combination with other Casale technologies such as the High Efficiency Trays, the **Split Flow Loop™ / Full Condenser™** configuration is applied for increasing the capacity of CO_2 stripping plant with very low investment.

With the transformation of the HP loop to the **Split Flow Loop™** configuration, the transformation of the HPCC to the **Full Condenser™** design and the introduction of the Casale High Efficiency reactor trays, the HP loop is drastically debottlenecked even for a large capacity increase (Up to 50% over its original design).

In addition, in case it is required to replace the existing HPCC of falling film type for maintenance reasons, it becomes very convenient to buy the new HPCC designed according to the **Full Condenser™** configuration.

In this way, a simple maintenance expenditure becomes a way to improve the plant by increasing its efficiency.

Industrial application of Split Flow Loop™ / Full Condenser™ approach for increasing the capacity of a CO_2 stripping plant

In 1997, a Ukrainian company asked Urea Casale to study the revamping of its 1000 MTD Urea plant to increase the capacity by 35% decreasing the energy consumption and increasing plant reliability.

The plant was originally designed according to the CO_2 stripping technology.

After having studied the problem, Casale decided to follow its approach for small/moderate capacity increase. This would allow obtaining the desired capacity increase with the lowest investment.
Casale, therefore, foresaw to install the Casale-Dente High Efficiency Trays in order to debottleneck the HP synthesis section.

This allowed avoiding any further modification to the existing HP equipment.

The rest of the plant was studied in great detail in order to identify the additional modifications required in the sections downstream the HP synthesis loop.

In addition to modification/addition to the HP pumps and CO_2 compression, additional heat exchange surfaces were required for the LP decomposer and condenser and for the vacuum evaporators and condensers, and some modifications were required for the desorbers (WWT section) and the prilling system.

The revamping was carried out in two phases as per choice of the client:

- During 1997 the HET have been installed in the reactor achieving the energy saving and creating the potential for the capacity increase with a significant increase of reactor conversion.

- During 1999 the rest of the modifications for the capacity increase were carried out achieving the 35 % capacity increase.

All the modifications for the revamping were carried out in a normal shutdown and the plant is successfully operating at the new capacity since 1999.

In 2001 the client asked Casale for a new capacity increase, wishing to reach a capacity of 1500 MTD.

As a margin for future capacity expansion was built in by the modifications carried out in 1999, the bottleneck for further capacity increase was the HP loop and particularly the HPCC that had its original surface reduced by plugged tubes.

Thanks to the **Split Flow Loop™** / **Full Condenser™** concept, Casale was able to propose a very low cost solution to reach the desired capacity of 1500 MTD.

Just with the transformation of the HPCC to the **Full Condenser™** design and of the HP loop to the **Split Flow Loop™** configuration, the plant is now operating at 1500 MTD.

The CO_2 conversion reached in the reactor is 3 percentage points higher than the value previously obtained with the High Efficiency Trays at 1350 MTD.

The stripper efficiency also increased accordingly allowing the de-bottlenecking of the downstream sections.

The performance of the plant has shown the improvement in heat transfer coefficient that was predicted by the simulation made by Casale confirming also the validity of the concept.

Due to the increase in the heat transfer coefficient it was also possible, in addition to the increase in the capacity, to increase the pressure of the LP steam produced in the HPCC, and this also contributed to debottleneck the downstream sections.

Split Flow Loop™ / Full Condenser™
Concept in operation in Ukraine

All the above improvements made it possible to reach, as foreseen by the Casale design, the additional capacity increase without any other modification than the one to the HPCC and to the Loop configuration.

Conclusion

The development of the **Split Flow Loop™ / Full Condenser™** concepts was a good example of how the combination of ideas/expertise with modelling capabilities could lead to the development of innovative technologies.

The capability of being able to properly model the various type of condensers with the correct chemical-physical relations was a key point to come to the successful development of the **Split Flow Loop™ / Full Condenser™** concept.

This new concept has proven to be a very powerful tool to debottleneck the HP loop of CO_2 stripping plants, and offer to the owner of such plants a very convenient way to increase the capacity.

This last development is the latest example of how Urea Casale has taken up the same spirit of commitment to excellence and achievement as Ammonia Casale and its founders, being in a position to offer to the world the most advanced state-of-the-art technology and expertise.