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## New Developments in Stamicarbon's Urea 2000 plus <sup>TM</sup> process

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La conservation de l'énergie a été un objectif majeur pendant plus de 30 ans dans l'élaboration des unités d'urée pour Stamicarbon. Généralement, la conservation d'énergie s'accompagne d'investissements plus lourds.

L'introduction du procédé de stripping de CO<sub>2</sub> a été une percée majeure dans le domaine à la fois de la conservation de l'énergie ainsi que des coûts d'investissement. Une économie d'énergie d'environ 60% a été réalisée par cette introduction.

Le nouveau concept Urea 2000 plus <sup>TM</sup> parvient à réduire encore plus les coûts d'investissement. Les opérations de l'unité utilisées dans ce concept relèvent d'une technologie éprouvée dans le domaine de la conservation d'énergie dans une unité d'urée.

Une nouvelle compilation de technologies éprouvée entraîne une économie d'énergie d'environ 20% avec presque aucune variation des coûts d'investissement. Cet exposé traite des changements historiques dans les aspects énergie et investissement des procédés Stamicarbon de production d'urée et fait entrer le lecteur dans ce que l'on appelle le développement N=3.

Cet exposé familiarise aussi avec les développements autour de la disposition du rez de chaussée du réacteur d'urée horizontal.

### Summary

Conservation of energy has been a major objective for more than 30 years in designing urea plants by Stamicarbon. Usually conservation of energy comes along with higher investment costs.

Introduction of the well-known CO<sub>2</sub> stripping process was a major breakthrough in the field both for energy conservation as well as investment costs. An energy saving of about 60% was reached by this introduction.

The new urea 2000*plus*<sup>TM</sup> concept succeeds also in reducing investment further. The unit operations used in this concept are proven technology today and can be combined with other proven developments in the field of energy conservation in order to gain once more on energy consumption in a urea plant.

A new compilation of proven technologies results in an energy saving of about 20% in combination with hardly a change in investment costs. This paper will deal with the historic changes of the energy and investment aspects in Stamicarbon urea processes and introduces the reader into the so called N=3 development.

This paper also introduces the developments around the ground floor level arrangement of the horizontal urea reactor.

All technical and other information contained herein is based on general Stamicarbon/ DSM experience and within this limit is accurate to the best of our knowledge. However, no liability is accepted therefore and no warranty or guarantee is to be inferred.
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## 1. Developments Background

Starting with the once through urea process in the very beginning, the massive amounts of undesired by-production of ammonium nitrate as a result of the part conversion of ammonia into urea, have led soon to the development of the partial recycling process and consequently to the total recycle urea process of the so called conventional type. This process wherein all non-converted reactants are reprocessed was developed by our parent company DSM.

In the early sixties Stamicarbon licensed this type of urea process more than 50 times. Since then a number of revolutionary developments took place in a continuous and gradual evolution of improvements in the process.

- We saw the replacement of the conventional process by the revolutionary urea CO<sub>2</sub> stripping plant saving 50% of energy and lowering the investment costs.
- The helicoil type HPCC that was part of the stripping process synthesis was replaced by falling film type HPCC, clearing the way for large scale plants.
- More recently we saw the replacement of this type of HPCC by the revolutionary pool condenser, combining condensation and urea formation simultaneously and eliminating a few nasty behaviours of the synthesis process, such as serious crevice corrosion in the high pressure condenser and minor synloop instability.
- The pool reactor again is a logical follow up of the pool condenser concept, reducing again on investment and clearing the way for smooth heating up and starting up of the synthesis, while retaining the attractive low energy consumption figures of the CO<sub>2</sub> stripping process.
- Stamicarbon is now on the brink of introducing another 20% energy reduction explained in this paper.

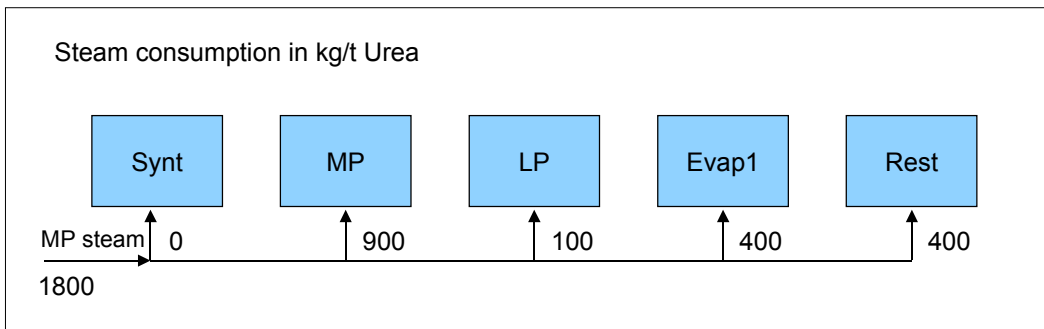
## 2. Energy consumption over the years

### 2.1 Conventional urea plant with evaporation

Figure 1 shows in principal the energy consumption of the total recycle conventional urea plant having two recirculation stages and two evaporation stages for prilling. The whole plant is divided in simple unit blocks each consuming part of the required energy expressed in kg steam per ton produced urea.

- The adiabatic synthesis block containing the mixer and reactor and receiving fresh ammonia, CO<sub>2</sub> and recycle carbamate.
- The MP stage, capable of dissociation of the non-converted reactants, condensing and pumping carbamate, separating excess ammonia and liberating process inert gases from ammonia.
- The LP stage also capable of further dissociation, condensation and pumping carbamate.
- The 1<sup>st</sup> stage evaporation block, evaporating the major part of the formed and recycle water. The last block called Rest representing the 2<sup>nd</sup> stage evaporation, the vacuum equipment, desorption and tracing also requiring part of the energy.

Figure 1. N=1, Conventional urea plant (evaporation)



As can be seen, the specific steam consumption was basically 1800 kt/t urea (13 bar, 190°C).

There was no conservation of heat whatsoever applied. Therefore this type of process has been called N=1, indicating the number of multiple effects applied in the plants. Steam is simply added and the condensation heat is thrown away in the cooling water.

## 2.2 Conventional urea plant with evaporation and partial heat recovery

It was soon realised that heat conservation could be applied easily by using the latent heat of the dissociated gases in the MP stage for evaporation of part of the water in the 1<sup>st</sup> stage evaporation.

Figure 2. N=1, conventional urea plant improved (evaporation)

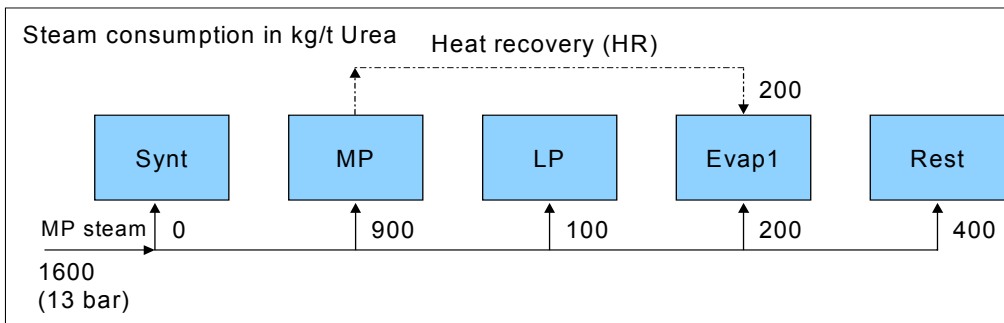


Figure 2 shows the effect on the steam consumption by applying this minor heat recovery method. This type of plant has been licensed many times and some of those plants are still running. This type of plant is still called N=1 as indicated in the head of the figure, but could be called something like N=1.1.

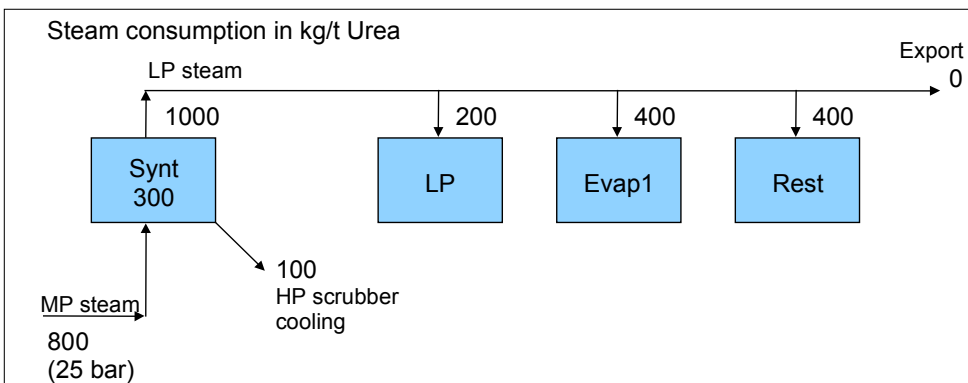
This heat recovery method should be memorised now, because this subject will come back later on in this paper.

## 2.3 Stripping urea plant with evaporation

Figure 3 shows the revolutionary change of the process in the late sixties.

The synthesis block contains now a stripper, an HPCC, a reactor, a HP scrubber and in most plants now a HP ejector.

Figure 3. N=2, urea stripping plant (evaporation)



The molar ratio in the synthesis has been reduced from 4 in the conventional plant to about 3 (azeotropic condition).

The total amount of recycled carbamate is about 4 times smaller in quantity and the synthesis is not adiabatic anymore, indicated by a net heat generation of 300 kg steam/t urea. On top of that 800 kt/t MP steam (25 bar, 225°C) is consumed by the HP stripper, taking over the function of the dissociation heater in the MP stage in figures 1 and 2. Most of the heat supply is taken out by the HPCC forming LP steam of 4.5 bar and 147°C.

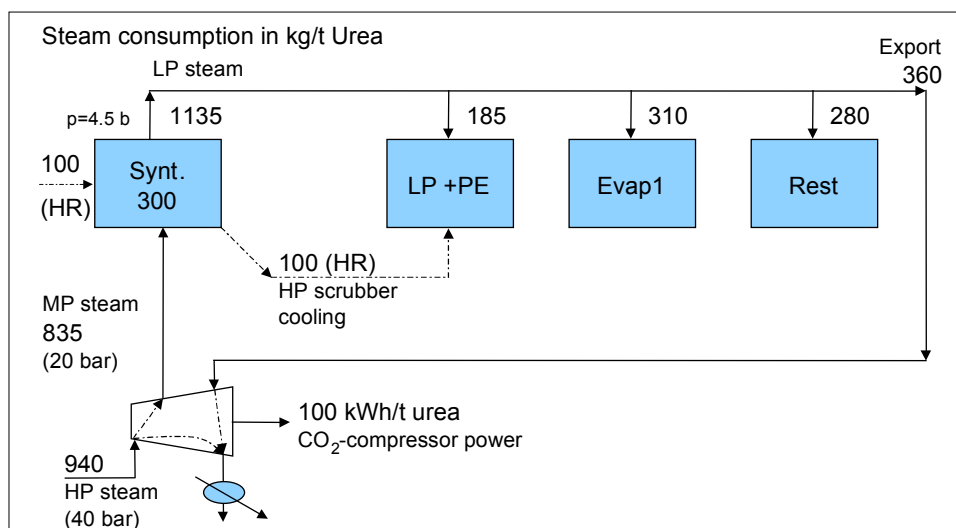
A small part (100 kg/t) is just destroyed in the conditioned cooling water of the HP scrubber. We see an energy reduction of 50%. All introduced steam is transferred into LP steam which is reused again. The heat management system in this plants is called N=2 as is indicated in the head of the figure.

#### 2.4 Stripping urea plant with granulation and maximum heat conservation

In time granulation is slowly replacing prilling, eliminating the need for a second stage evaporation, but introducing the need for pre-evaporation in order to reduce the free ammonia content in the meltfeed for the granulation unit.

The pre-evaporation (PE) is, in reference to heat duty, seen here as part of the LP recirculation stage.

Figure 4. Stripping Urea plant with maximum heat recovery (granulation)



In figure 4 the energy situation at the plant site is such that an electrical drive CO<sub>2</sub> compressor is replaced by a turbine drive.

Maximum heat recovery in such urea plant consists of:

- Waste steam condensate heat can be recuperated via heating up of the fresh ammonia to the synthesis (HR)
- The waste heat of the HP scrubber can be easily recuperated in the pre-evaporator (HR)
- The export LP steam can be used to reduce the inlet steam to the turbine in order to cover the power demand of the CO<sub>2</sub> compressor.

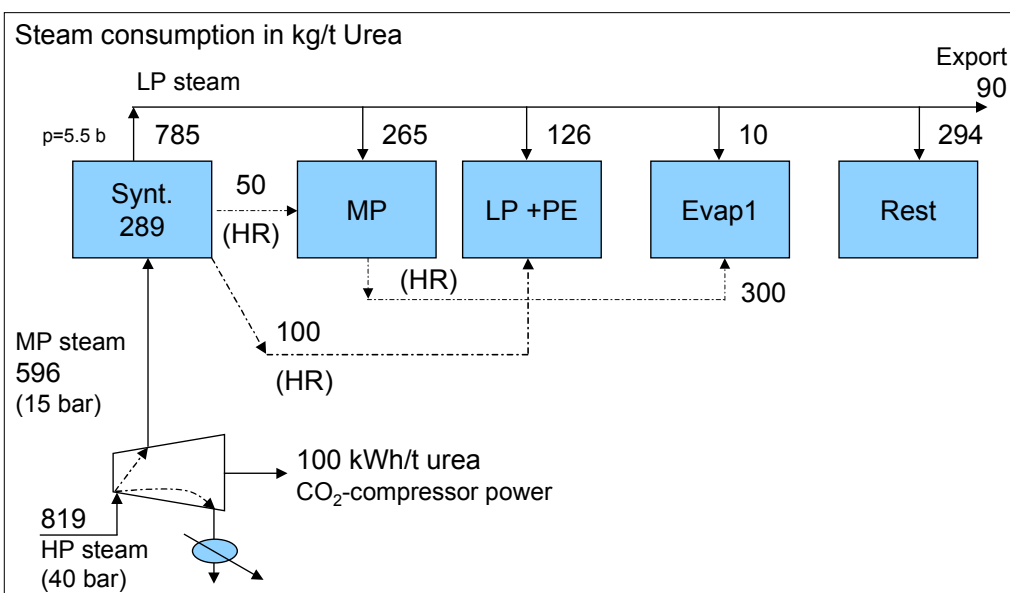
Basically the amount of steam to the BL of the urea plant itself remains at about 800 kg/t steam (835 kg/t at 20 bar).

### 3. New N=3 process

#### 3.1 Energy situation in the N=3 concept

Figure 5 represents the simple energy balance for the new process, making use of the higher pressure of the generated LP steam in the pool condenser type plant. The performance of the pool condenser not only benefits the behaviour of the synthesis, it also generates a higher pressure LP steam (5.5 bar instead of 4.5 bar) and instead of using this advantage to reduce the cooling area in the pool condenser the higher pressure LP steam is utilised for carbamate dissociation at medium pressure.

Figure 5. New urea stripping process (granulation)



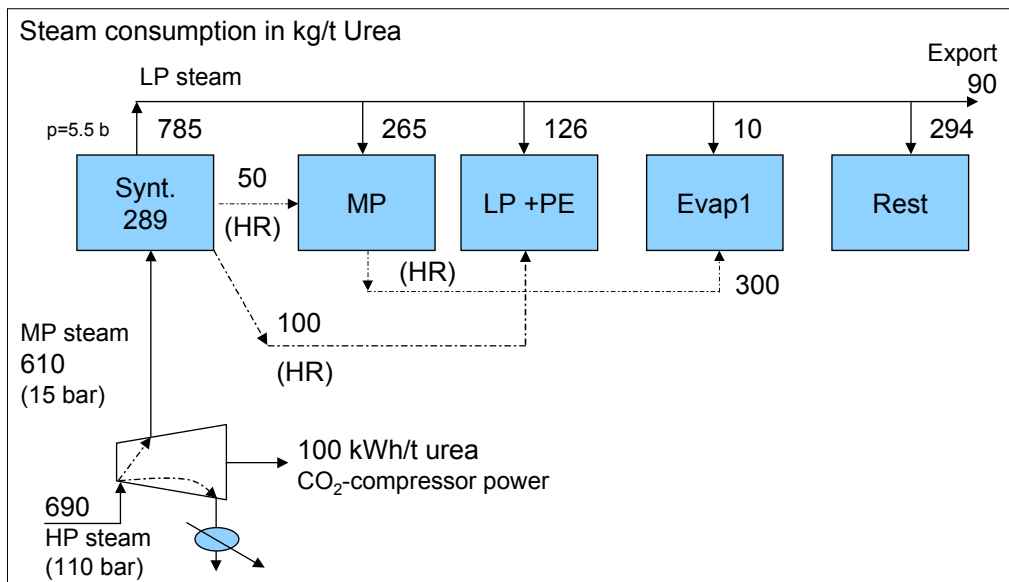
- By introduction of the MP stage from the sixties and by applying the LP steam of 5.5 bar on the dissociation heater in this stage, aided by heat from the hot condensate from the HP stripper, MP dissociation gas is generated. The latent heat of this gas is used again for evaporating water in the 1<sup>st</sup> stage evaporation. In order to generate enough MP dissociation gas, the functionality of the HP stripper has to be reduced a bit by simply reducing the steam pressure on the HP stripper shell.
- The waste heat of the HP scrubber is again used in the pre-evaporator.

- The rather simple heat recovery in the evaporator unit has been modified since the sixties into a heat exchanger capable of recovering all required heat from the mentioned dissociation gas. This heat exchanger type, unknown to most of the readers, is performing for many years now at a capacity of 400 MTPD at Geleen and at 2100 MTPD in Bontang, Indonesia.

As a result, the steam reduction at the BL of the plant will be about 28% compared to the present situation as given in figure 5.

At the turbine the steam consumption shows a saving of about 13%, based on the same quality of HP steam supplied to the turbine. (40 bar, 440°C). The heat management applied in this type of plant is called N=3 because the multiple heat exchange effect is one score higher.

Figure 6. A new urea stripping process (granulation)



### 3.2 Flow diagram of the pool condenser synthesis

Figure 7. Flow diagram of the pool condenser synthesis

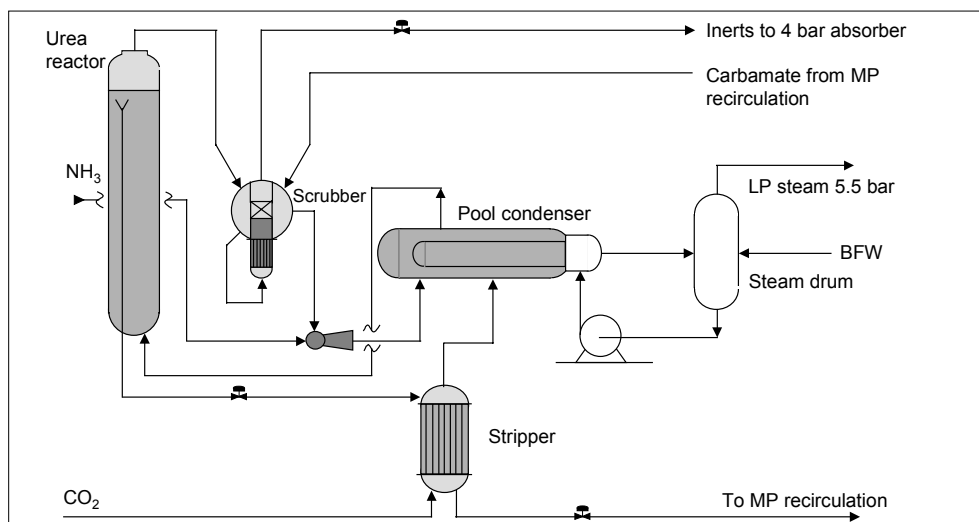
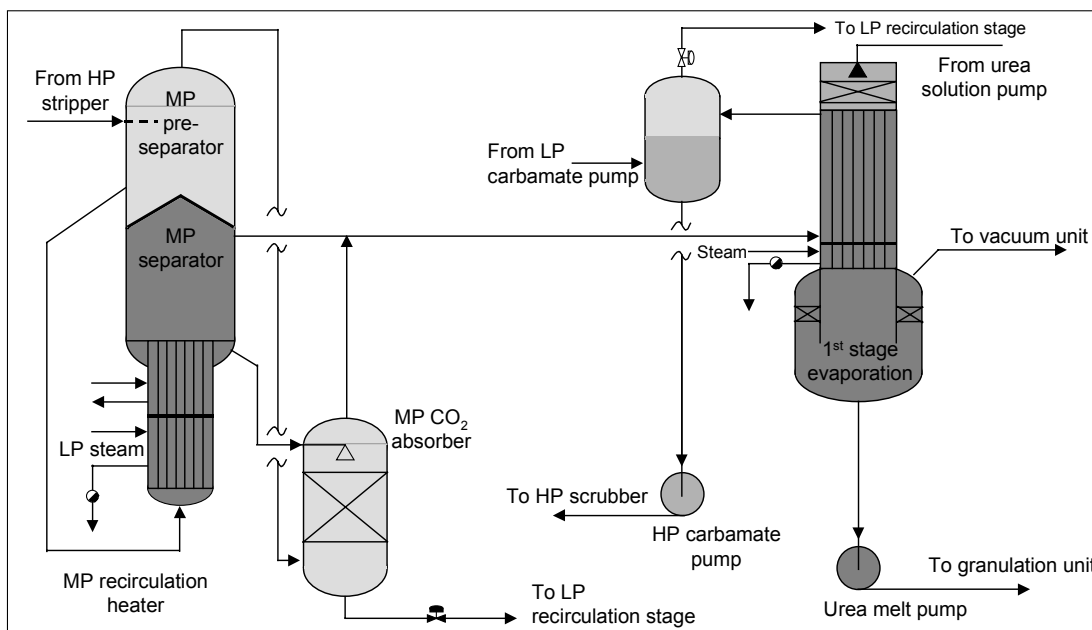


Figure 7 shows a flow diagram of the pool condenser synthesis as is operational in Bangladesh.

- Here we see the HP stripper receiving the urea solution from the reactor stripping with  $\text{CO}_2$  the non-converted reactants aided by HP steam.
- The off gas is condensed in the pool condenser generating 5.5 bar LP steam from the condensed gas and received ammonia and recycle carbamate. In this condenser a large quantity of urea is already formed.
- The reactor finishes the conversion of urea to about 95 % of equilibrium
- The off gas from the reactor, containing the inert gas and anti corrosion air, is washed by the recycle carbamate. The inert gas is further washed in the 4 bar absorber not shown in figure 7.
- The HP ejector transfers the effluent from the HP scrubber into the pool condenser.

### 3.3 Flow diagram of the medium pressure recirculation stage

Figure 8 shows the re-introduced MP stage, however now without the large  $\text{NH}_3$  recycle of the conventional plant.



MP dissociation and condensation side:

- The effluent of the HP stripper flows to the MP pre-flash separator operating at about 16 bar.
- The effluent of this separator is led to the MP dissociation heater where it is heated up to about  $150\text{ }^\circ\text{C}$  by means of the 5.5 bar LP steam and further by hot stripper steam condensate to about  $154\text{ }^\circ\text{C}$
- The dissociated urea solution is separated from the dissociation gas in the MP separator located below the MP pre-separator and led to the MP  $\text{CO}_2$ -absorber from where it is expanded into the LP recirculation stage.
- The off gas from the MP pre-evaporator is rich in  $\text{CO}_2$  whilst the urea solution from the MP separator has a rather low  $\text{CO}_2$  concentration. Part of the  $\text{CO}_2$  is re-absorbed in this absorber to create better carbamate condensation conditions in the Low Pressure Carbamate Condenser in the LP recirculation stage.



- The off gas from the MP absorber, combined with the off gas from the MP separator is almost completely condensed in the shell of the 1<sup>st</sup> stage evaporator while evaporating the water present in the urea solution fed to the tube side of the same evaporator.
- The condensed carbamate is collected in the MP carbamate level tank. Here it is combined with the LP carbamate from the LP recirculation stage and all is pumped with the HP carbamate pump to the HP scrubber. A little non-condensed gas is expanded into the LP carbamate condenser in the LP recirculation stage.

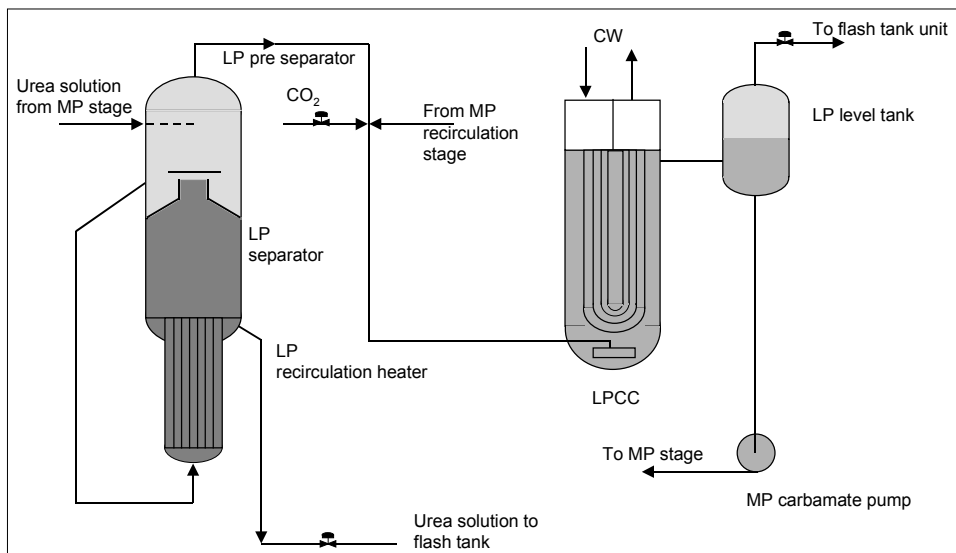
Evaporation side:

- The urea solution coming from the urea storage tank is pumped over the distributor in the top of the evaporator. The water in this solution is evaporated by the liberated heat of condensation on the shell side.
- A small tuning evaporator is placed under the falling film evaporator operating on LP steam in the shell.
- Urea melt and gas is separated in the evaporator separator working at normal vacuum for this purpose.
- The off gas from the separator is fed to a vacuum condenser and the urea melt is pumped to the granulation unit.

Note: As can be seen, this heat exchanger fulfils 2 function simultaneously:  
The MPCC-function and the evaporation function

### 3.4 Flow diagram of the low pressure recirculation stage

Figure 9 is representing the now much simpler LP stage



- The dissociated urea solution from the MP stage is flashed in the LP pre- separator.
- The flashed urea solution is fed to the LP dissociation heater where almost all of the present CO<sub>2</sub> and NH<sub>3</sub> are dissociated together with a certain amount of water.
- Gas and urea solution are separated in the LP separator below the LP pre-separator
- The combined gases from the LP pre-separator and the LP separator are fed to the LPCC. In order to bring up the boiling temperature of the carbamate and to be able to cool it with normal cooling water a little CO<sub>2</sub> is also introduced in this LPCC.
- Remaining gas and carbamate are separated in the LP level tank

- The formed LP carbamate is pumped with the MP carbamate pump into the MP carbamate level tank.
- The remaining gas, containing some inert from the CO<sub>2</sub> is expanded into the atmospheric absorber.

Note: Due to a complete change in N/C-ratio in this LP carbamate in comparison with that in a normal stripping plant, there is no more need for a tempered water circuit including it's cooler and circulation pumps.

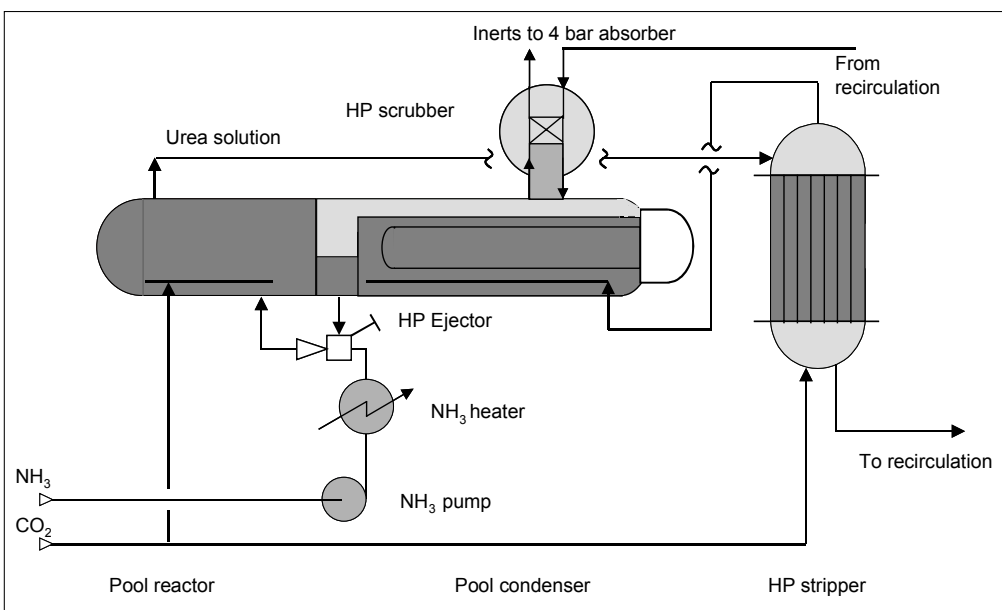
The water balance in this process is such that a rectifying column for knocking out the water in the dissociation gasses is not required anymore.

#### 4. Low level synthesis arrangement

Lately the benefits of the pool condenser and of the further development of the pool reactor, have been used to work out the old idea of the so called

#### 'low level arrangement'

Figure 10 is representing the low level synthesis arrangement.



Urea solution from the pool reactor is fed to the HP stripper. Non converted reactants are stripped by the major part of the fresh CO<sub>2</sub> and by heat. The stripper off gas is condensed while mixed with the recycled carbamate from the recirculation entering the synthesis via the HP scrubber. LP steam is generated in the pool condenser part of the pool reactor. The ammonia present in the off gas of the HP stripper together with the ammonia present in the recycled carbamate lead to an overall N/C-ratio of about 2.3.

The system NH<sub>3</sub>-CO<sub>2</sub>-H<sub>2</sub>O-Urea is a 4 component system with a binary azeotrope.

At constant pressure a topridge line exists. On this topridge line the boiling temperatures and thus the kinetics are maximum. The N/C-ratio of 2.3 happens to be closer to this topridge line ratio at the beginning of the formation of urea, thus leading to faster formation of urea.

After reaching an approach of about 60 % of the chemical equilibrium, the urea solution is transferred to the second part of the pool reactor with the HP ammonia ejector driven by the fresh NH<sub>3</sub>.

The overall N/C-ratio is boosted up to the required value of about 3 to 3.1 and is again close to the topridge line so the formation of urea will take place at optimum speed.

Part of the fresh CO<sub>2</sub> is added to this part of the reactor in order to supply the required heat for urea formation by carbamate condensation.

The discharge pressure of the HP ejector is high enough to push the urea solution and introduced inert gas into the top of the HP stripper.

All inert gasses finally pass the pool condenser part of the pool reactor and will be washed in the HP scrubber by the recycled carbamate. This tail gas is further washed in the 4 bar absorber.

The urea solution leaving the HP stripper can be sent to either an LP stage or an MP stage as in the N=3-concept.

## 5. Conclusions

Using one of the many advantages of the pool condenser, the re-implementation of the MP stage, together with the perfection of the ancient 1<sup>st</sup> stage evaporation waste heat exchange will lead to a HP steam import reduction of more than 200 kg/t urea.

All the equipment used in the N=3 process is proven in commercial plants and most of them has been in Stamicarbon standard design packages for years, there is no fear for a change in product quality and the investment will remain very low.

- We see an expected steam saving of 13 % compared to N=2 in a modern CO<sub>2</sub> stripping plant including the energy for CO<sub>2</sub>-compression and an expected saving of 28 % on steam to the urea plant battery limit.
- All equipment and concepts are commercial proven
- All components can be used in case of revamping
- Although not yet proven design, the low level arrangement opens possibilities for less expensive and safer operations and can be combined with the advantages of N=3.
- The N=3 process is available for licensing