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## STAMICARBON'S NEW PROCESS UREA 2000plus™

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### RESUME

*Comme cette communication traite complètement de nouveaux aspects du procédé de fabrication d'urée, il peut être intéressant de mettre d'abord l'accent sur la synthèse existante d'urée par séparation de CO<sub>2</sub> très compétitive. Ce procédé a été licencié 115 fois par Stamicarbon.*

113 unités classiques de CO<sub>2</sub>  
1 unité de séparation de CO<sub>2</sub> avec condenseur-bassin  
1 unité de séparation de CO<sub>2</sub> avec réacteur-bassin  
115 unités de séparation de CO<sub>2</sub>

*Le chapitre quatre résume la technologie du condenseur-bassin et du réacteur-bassin dans une unité moderne d'urée Stamicarbon. Les avantages du condenseur-bassin et du réacteur bassin sont les suivants :*

- Environ 10 % d'investissements en moins
- Un équipement HP plus petit ou en moins grand nombre
- Une plus grande souplesse dans les opérations
- Bâtiments moins hauts
- Écoulement entièrement par gravité dans la section de synthèse.



### 1. INTRODUCTION

Stamicarbon has succeeded in vastly improving its CO<sub>2</sub> stripping urea process. The feedstock consumption figures are almost equal to the stoichiometric values for ammonia and carbon dioxide, leaving no scope for any further reduction. The utility consumption figures have also been reduced to acceptably low values. Further reduction of steam consumption would require additional investment in relatively new heat exchange methods resulting in a more complicated and investment wise more expensive process instead of a simpler process.

The Stamicarbon CO<sub>2</sub> stripping process has extremely low effluent and emission figures. Being almost zero, they, too, leave no scope for any significant improvement. Because of these excellent key features the industry already agrees that this process is technically the best there is and leaves nothing to be desired.

The new Urea 2000plus™ process includes a number of significant improvements, which ultimately result in lower investment costs for a new urea plant. The main improvements are a superior reactor tray design, a pool condenser and a pool reactor. The first two improvements are already commercially proven, whilst the pool reactor is to be incorporated in DSM's new urea plant at Geleen, the Netherlands, which will be commissioned in 1997.

Because the pool condenser and pool reactor technology is purely urea synthesis technology this paper deals with the urea synthesis only.

### 2. HISTORY OF THE CO<sub>2</sub> STRIPPING PROCESS

The CO<sub>2</sub> stripping urea process was developed in order to reduce the steam consumption of the conventional urea process (which was about 1,600 kg/tonne). This development resulted indeed in a steam consumption reduction by 600 to 800 kg/tonne. The process has been a success ever since and more than 100 units were built. Another breakthrough in the late sixties was the introduction of type 25-22-2 tube material in the stripper. This material really lived up to its expectations and is still, successfully used.

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*\*All technical and other information contained herein are 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.*

Typical features of the CO<sub>2</sub> stripping process:

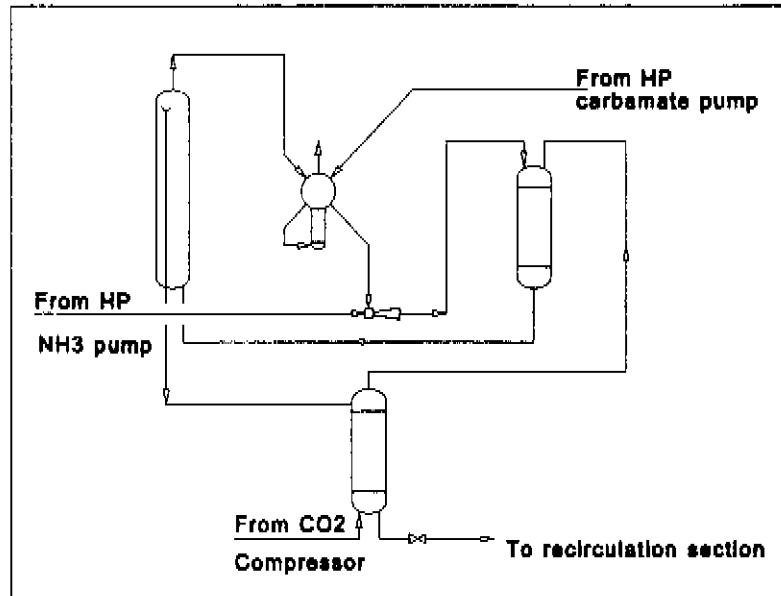
- Reaction pressure about 140 bar.
- Ammonia/carbon dioxide ratio in the reactor about 3.
- Non-converted NH<sub>3</sub> and CO<sub>2</sub> recycle at reaction pressure.

The evolution of the CO<sub>2</sub> stripping process, up to the introduction of Urea 2000plus™ technology can be summarized as follows:

- Small scale plants with helicoil carbamate condenser above the reactor (total gravity flow).
- Large scale plants with vertical falling film condenser (total gravity flow).
- Large scale plants with vertical falling film condenser and a low elevation for the HP scrubber (partial gravity flow).

Basically this last plant type is still being built today. The basic flowsheet of this type of synthesis is given in Figure 1.

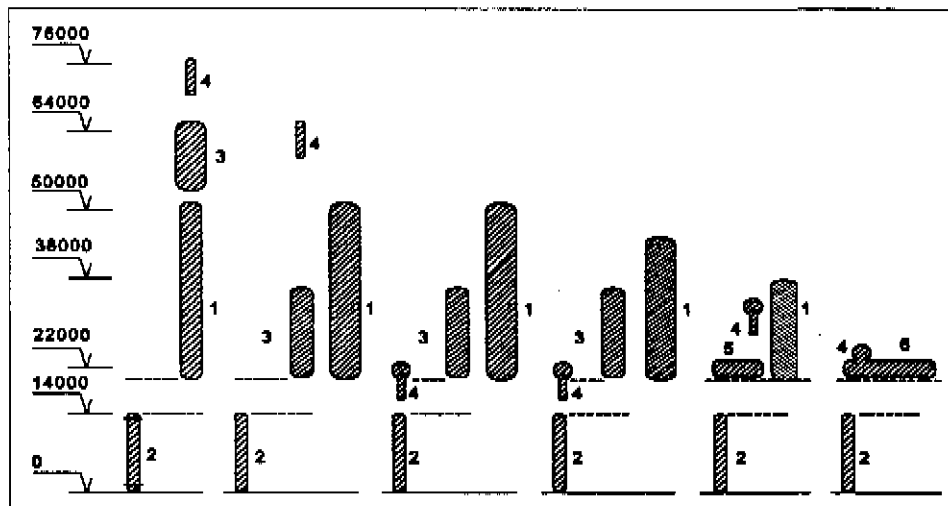
Figure 1 - Falling film HP carbamate condenser



Because many plants have been built with this flowsheet as a basis, this paper will not elaborate on this synthesis configuration but will deal only with the innovative Urea 2000plus™ technology.

The skyline of the Stamicarbon CO<sub>2</sub> stripping process plant has changed dramatically over the years (Figure 2).

Figure 2



1. Reactor 2. Stripper 3. Condenser 4. Scrubber 5. Pool condenser 6. Pool reactor

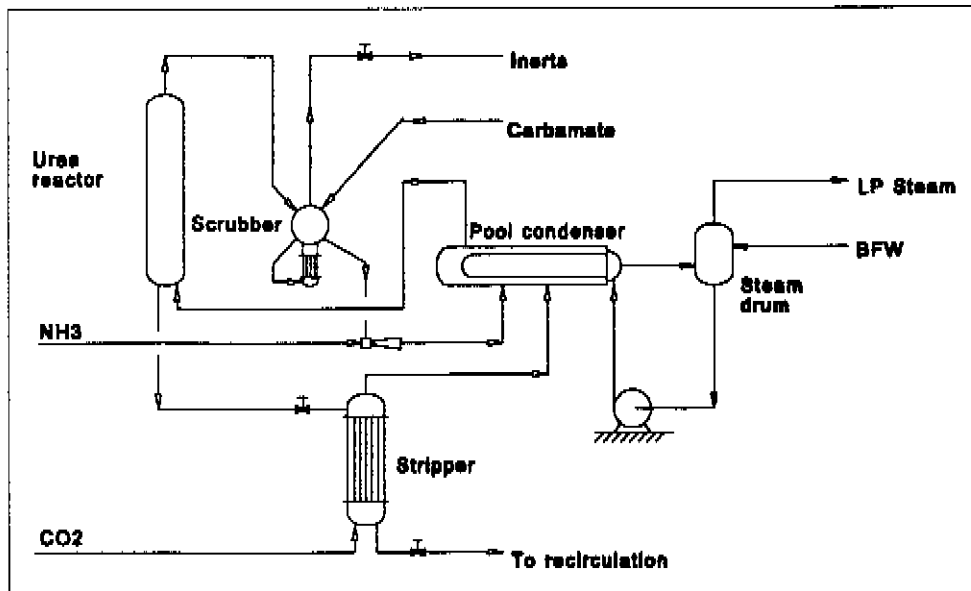
### 3. STAMICARBON UREA 2000plus™

#### 3.1 The Pool condenser - an alternative to the falling film-type HP carbamate condenser

The pool condenser is used in the KAFCO urea plant at Chittagong in Bangladesh. The plant has a design capacity of 1725 mtpd and was constructed by Chiyoda of Japan. It came on stream at the end of 1994.

As described earlier, the pool condenser concept was selected for this plant because of its location in the vicinity of Chittagong Airport. A low skyline was a strict requirement. The pool condenser allowed the reactor to be made considerably shorter because a compensating reactor volume would be available in the shell of the horizontal carbamate condenser (Figure 3).

Figure 3 - Pool condenser synthesis section

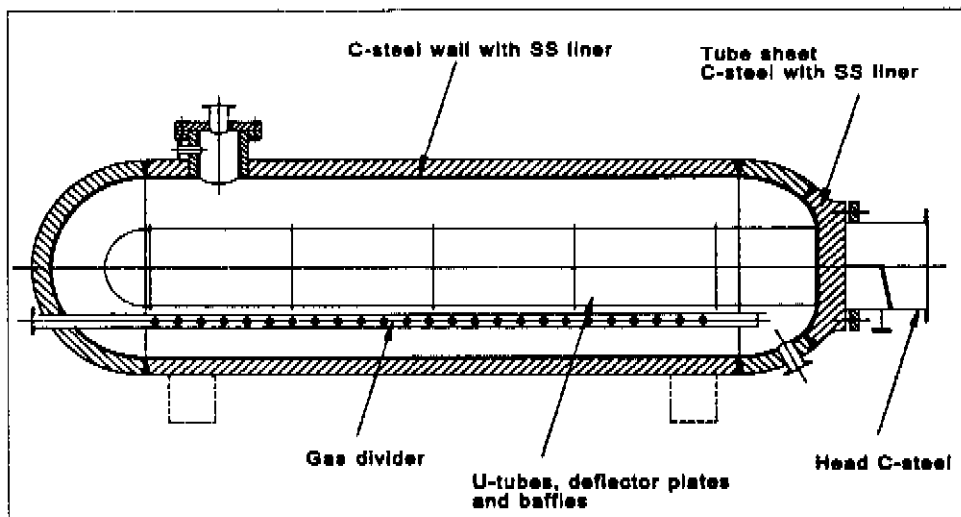


Basically, the pool condenser is a horizontal reactor vessel with a submerged U-tube bundle as shown in Figure 3. It is fabricated from carbon steel with a lining in urea-grade type 316L stainless steel (similar to the standard urea reactor).

All internals and the overlay welding on the tubesheet are fabricated from type 25-22-2 stainless.

The tubes are welded to the tubesheets by internal bore welding. This welding technique is proven for many years in carbamate service and no difficulties of any significance have ever been encountered.

Figure 4 - Pool condenser



### 3.1.1 Operating principle

This horizontal condenser-reactor is a gas-agitated vessel with a retention time enabling the condensed carbamate to dehydrate partially into urea and water. The gases condense around a bundle of U-tubes, generating low-pressure steam as in any other HPCC.

The stripper off-gas, the carbamate solution from the HP scrubber and ammonia from battery limits are introduced into the condenser. The liquid phase is thoroughly agitated by the gases from the stripper and the heat of condensation is utilized for producing steam in the tube bundle.

The condensation capacity of the condenser is determined by the heat transfer coefficient, the surface area of the tube bundle and the temperature difference between the process side and the steam side.

The temperature difference can be controlled by the pressure of the generated steam. Moreover the process temperature is a function of the rate at which urea is formed, all other parameters, such as the pressure, the  $\text{NH}_3/\text{CO}_2$  ratio and the initial  $\text{H}_2\text{O}$  content, remaining constant.

The rate of formation follows from the installed retention time. Our models accurately describe the temperature as a function of the rate of formation.

The temperature in a falling film condenser, in which almost no urea formation takes place, is about 170°C. With 25% urea, at 60% approach to equilibrium, this temperature is raised to about 175°C.

As is normal, the temperature of the generated saturated steam is dictated by the steam pressure of 4.5 bar required in the downstream sections of the plant.

The amount of heat of condensation is determined by the involved chemical reactions.

The operating principles of the pool condenser can be summarized as follows:

- Strip gases are condensed in a pool of liquid on the shell side, with LP steam being generated on the tube side.
- Adequate residence time allows the reaction of ammonium carbamate to urea and water to proceed to up to 60% of equilibrium.
- The condensation temperature on the shell side is high as a result the formation of high boiling components (urea and water). The formation of gas bubbles ensures a high degree of turbulence and provides a large area for mass and heat transfer.

### 3.1.2 Development of the pool condenser

The pool condenser took several years and a great deal of effort to develop. Use was made of extensive experience gained in urea plants of our licensees in which similar condensers are used.

These condensers are:

- a. The low-pressure carbamate condensers applied in the 4-bar recirculation section of all plants designed since the late 1950s.
- b. The medium-pressure carbamate condensers in revamped conventional total-recycle urea plants operated at 18 to 20 bar. This experience dates back to the early seventies.
- c. The high-pressure scrubbers in the first-generation  $\text{CO}_2$  stripping plants operated at 130 bar.
- d. The bottom section of the HP scrubbers in the  $\text{CO}_2$  stripping urea plants designed in the seventies and the eighties. The operating pressures in these scrubbers range from 140 to 150 bar.

The first three heat exchangers in this list are quite similar. They are installed in vertical position and ammonia, carbon dioxide and water vapour are introduced in the bottom. The resulting condensates go overhead along with minor amounts of non-condensed gases evolving in the top. Heat is removed via cooling water in U-tubes submerged in the solution. The fourth heat exchanger (scrubber) is a vertical shell-and-tube exchanger, with gas and liquid rising concurrently from the bottom to the top. In all these condensers, pool condensation takes place whereby the liquid forms the continuous phase.

A common feature of these condensers and the pool condenser is that there is intensive mixing of the vapour and liquid phases, resulting in a highly turbulent heat transfer to the cooling water tubes. The

difference is that all of the above-mentioned condensers are vertical, whereas the pool condenser is horizontal.

### 3.1.3 Design of the pool condenser

The heat transfer coefficient used in this first pool condenser was conservatively chosen, this ultimately resulted in a higher than anticipated LP steam pressure in the condenser.

Further design criteria are presented here below:

- Process design
  - shell side 140 bar synthesis pressure 175°C
  - tube side 4.5 bar steam/BFW
  - gas dividing system with flow deflector plates
- Mechanical design
  - stainless steel
  - U-tube bundle
  - internal bore welding
  - tube supports

### 3.1.4 Advantages of the pool condenser over a falling-film condenser

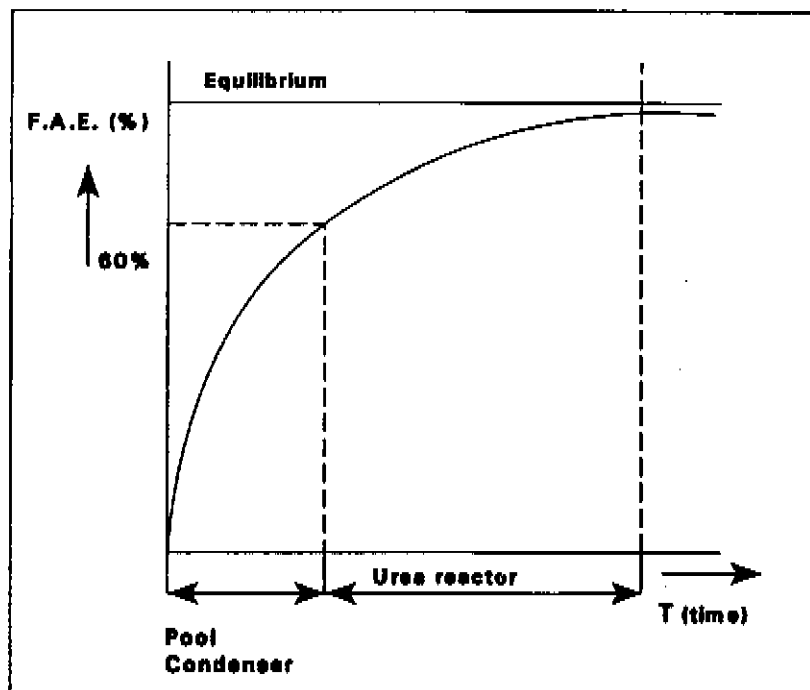
The technological advantages of the pool condenser are as follows:

**Table 1 - Technological advantages**

	Pool condenser	Falling film condenser
Heat/mass transfer	<ul style="list-style-type: none"> <li>- high turbulence</li> <li>- large transfer area (bubbles)</li> <li>- large LMTD due to urea reaction <math>T_{\text{process}} = 175^{\circ}\text{C}</math></li> </ul>	<ul style="list-style-type: none"> <li>- restricted by laminar layer between gas and liquid film</li> <li>- limited area (tubes)</li> <li>- small LMTD <math>T_{\text{process}} = 170^{\circ}\text{C}</math></li> </ul>

Another advantage of a urea synthesis equipped with a pool condenser is that a smaller reactor can be used. Many calculations done through the years indicate that the optimum approach to equilibrium in the urea reaction is 95%. This is illustrated in Figure 5.

**Figure 5 - Optimum reactor design**



As can be seen from this curve, about 60% of the approach to equilibrium is reached already within the pool condenser whose capacity is only 30 to 40% of the required reaction volume. As a direct consequence, the actual reactor volume can be considerably reduced. The improved heat transfer in the pool condenser in combination with the reduced reactor volume results in different equipment dimensions in the synthesis section.

Both the heat exchange area in the condenser and the reactor volume will be smaller (Table 2). A smaller reactor volume obviously gives weight savings, making transportation to the site and site handling a lot easier.

**Table 2 - Investment advantages**

Equipment dimensions in urea synthesis, base case 2000 mtd plant capacity		
	Pool condenser	Falling film condenser
Cylindrical reactor volume	150 m <sup>3</sup>	230 m <sup>3</sup>
Cylindrical pool condenser volume	80 m <sup>3</sup>	
Condenser heat exchange area	55%	100%

### 3.1.5 Operational experience with the pool condenser

Basic observations:

- From the very first start-up of the synthesis it became clear that the fundamental design aspects of the pool condenser were correct.
- The LP steam pressure achieved in the condenser is about 1 bar higher than anticipated due to better heat transfer as compared to the design.
- The space around the tube bundle, forming the reactor volume in the pool condenser, was anticipated to be equal to one continuously stirred tank reactor (CSTR) which has a mixed temperature of 175°C. However, the large increase in temperature along the shell indicates that the pool condenser behaves more or less like a plug flow reactor, resulting in a higher urea concentration in the top of the following reactor as a bonus. The observed temperature increase (from 174°C to about 180°C), at a pressure of 138 bar in the synthesis is a definite advantage if compared to 170°C at 140 bar in a conventional HPCC.
- The final temperature in the top of the urea reactor is about 186°C at a pressure of 138 bar. We have never experienced this before in any of our plants, but we can completely reproduce it in our computational models.

The design of the reactor which comes after the pool condenser is comparable with all other reactors, except, of course, for its volume. Its feed, however, has already covered 60% of the approach to the equilibrium composition. Channelling of almost finished product will hardly affect the composition in the top of the reactor.

- Experience indicates that the pool condenser is much less sensitive to variations in the N/C ratio. This is quite understandable, since condensing off-spec gas alone is more difficult than condensing the same off-spec gas in a pool providing ample amounts of one or other failing component in the gas phase.

The « inverse response », occurring in all our stripping plants has disappeared here, so that the level control valve can now be put on automatic. Until now, on slightly opening the level control valve, the level in the reactor always increased a bit before it went down. This is due to increased gas generation in the stripper part. Initially, the gas is not completely condensed and returns to the reactor. This phenomenon is called inverse response. In the pool condenser, however, all of the gas condenses straight away and the inverse response has disappeared.

### Operational experience at KAFCO (Bangladesh) since December 1994

- Fundamental concept of the pool condenser is correct.
- The heat transfer is even better than anticipated resulting in 5.5 bar steam (goal was 4.5 bar)

- The pool reactor acts as a bank of CSTRs rather than as a single CSTR. This was evidenced by a temperature increase to 180°C from 174°C rather than a uniform temperature of abt. 175°C. (unexpected benefit)
- The inverse response in the synthesis loop has vanished (unexpected benefit).
- Deviating N/C ratio's do not affect condensation in the pool condenser and thus the synthesis pressure (unexpected benefit).
- The pool condenser has a positive effect on the reactor temperature and pressure. It is now 186°C at 138 bar (unexpected benefit).
- An inspection of the pool condenser after one year of operation did not show any abnormal corrosion to vessel wall or internals.

### 3.1.6 Future developments

A major development resulting from the successful performance of the pool condenser in Bangladesh is the incorporation of all the required retention time for the urea reaction in one and the same vessel, so creating the pool reactor. Furthermore the introduction of the pool condenser is a step closer to the N=3 low-energy process, in which stripping steam is used three times, so reducing the energy demand of the CO<sub>2</sub> stripping process.

Table 3 summarizes further potential improvements. The first pool reactor, for DSM in Geleen, is now being fabricated for a plant capacity of 1150 mtpd. This new plant is slated to come on stream in 1997.

**Table 3 - Future developments**

1. Further development of low-level arrangement <ul style="list-style-type: none"> <li>- Reactor bottom at ground level</li> <li>- 2000 mtpd urea plant with total elevation of max. 30 m</li> <li>- Considerable investment savings</li> </ul>
2. Application in N=3 low-energy process <ul style="list-style-type: none"> <li>- Energy supplied to HP stripper to be used three times using multiple effect heat exchange</li> </ul>
3. Further refinement of the pool reactor <ul style="list-style-type: none"> <li>- Substantial investment savings</li> </ul>

### 3.1.7 Conclusions concerning pool condenser

Summarizing the main features of the pool condenser, the following conclusions can be drawn:

1. The pool condenser reduces the urea reactor volume by some 40%.
2. The pool condenser requires some 45% less heat exchange area.
3. The pool condenser reduces height of steel structure by some 10 m.
4. No stress corrosion can take place in pool condenser.
5. The pool condenser is commercially proven and is operationally a success.
6. The pool condenser paves the road to further improvements such as the following:
  - Further reduction of the height of the steel structure
  - Further energy savings
  - Development of the pool reactor

## 3.2 Pool reactor

After the successful commissioning of the pool condenser at KAFCO, with its process and operational advantages and high temperature at the outlet, it became obvious that the step to the pool reactor was only a small one. Installing some more volume in the pool condenser, but without spoiling the reactants, which are almost in equilibrium, with fresh condensed carbamate, the idea of the pool reactor was born and patent applications were filed.

As chance would have it the DSM Melamine business unit was planning to scrap its 40-year old urea plant at Geleen and replace it by a new one.

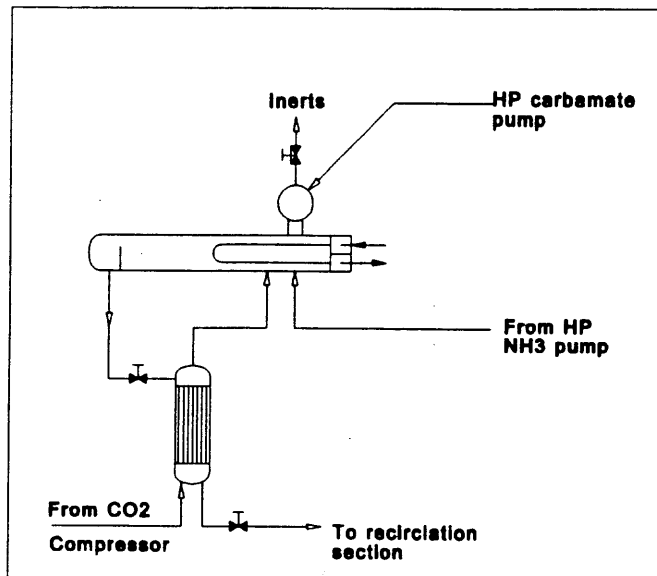
Following a thorough evaluation process, in which all aspects of the pool reactor, the process and commercial risks were considered, Melamine, in cooperation with Stamicarbon decided to opt for the pool reactor for this new 1150 mtpd urea synthesis plant.



### 3.2.1 The synthesis configuration

The principle of the pool reactor synthesis section is shown in Figure 6.

**Figure 6 - CO<sub>2</sub> stripping synthesis (pool reactor)**



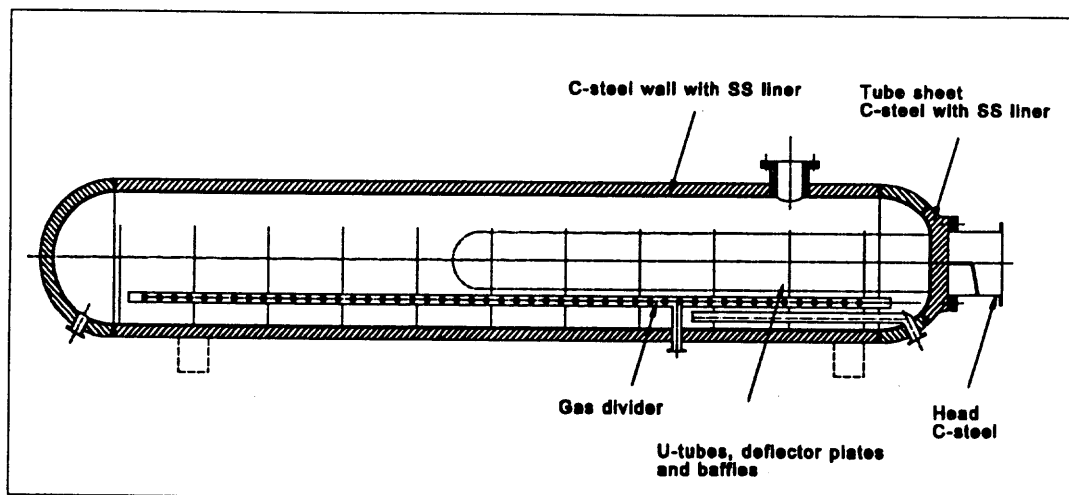
The urea synthesis section shown in this flowsheet no longer includes the vertical reactor and basically comprises a CO<sub>2</sub> stripper, an elongated pool condenser, now called the pool reactor, and the safety features of the HP scrubber. The heat exchanger in the HP scrubber is omitted also.

### 3.2.2 Pool reactor

Construction of the pool reactor is similar to that of the pool condenser, and the same materials can be used. The construction, the materials and leak detection system are based on Stamicarbon's experience with the fabrication of urea reactors. The only difference is that the pool reactor is in horizontal position whilst its predecessor was placed in vertical position.

As in the pool condenser, the tubes are welded to the lined tubesheet using an accurately well controlled internal bore welding procedure. A sectional drawing of the pool reactor is given in Figure 7.

**Figure 7**



### 3.2.3 The advantages of the pool reactor

The expected advantages of the pool reactor configuration are as follows:

- The amount of transferred heat through the condenser bundle in the reactor will be the same as in the pool condenser configuration (So, far better than in the falling film condensers).
- The baffles in the reactor positively prevent backmixing, so affording the highest approach to equilibrium in the urea reaction and consequently the highest conversion and most economic downstream equipment sizing.
- The same operational flexibility as with the pool condenser, namely:
  - a. synthesis less sensitive to deviating N/C ratios
  - b. no inverse response in the synthesis loop.
- Considerably lower investment because of:
  - a. omission of an expensive HP vessel
  - b. omission of HP ejector
  - c. far less HP piping in the synthesis section
  - d. lower steel or concrete structure.

### 3.2.4 Proprietary equipment

Stamicarbon/DSM have developed the pool condenser and reactor through extensive research efforts, covering both the process aspects and fabrication. Internal bore welding is a specific feature of fabrication. Stamicarbon has extensive experience in HP equipment fabrication, from which customers can benefit. In the interest of our customers, the new vessels will be fabricated as proprietary equipment by selected manufacturers only. Selection of these manufacturers is underway.

### 3.2.5 Availability for licensing

The UREA 2000plus™ technology is ready for licensing by Stamicarbon through its licensed contractors. The pool condenser plant in Bangladesh has now operated for more than 20 months and the pool reactor plant of DSM will be on stream well before a third plant can be commissioned. Consequently, any teething troubles, if any, in the pool reactor plant at DSM will have been resolved in time. The UREA 2000plus™ technology can also be used in plant revamps and debottlenecking projects in order to improve profitability.

## 4. PROCESS DATA

### Consumption Figures

<i>Finishing technique:</i>	<i>Prilling</i>	<i>Granulation</i>	<i>Unit</i>
<b>Raw materials</b>			
NH <sub>3</sub> (100%)	568	564	kg
CO <sub>2</sub> (100%)	733	730	kg
<b>Utilities</b>			
MP steam (22 bar, 330°C)	855	805	kg
Electricity	14	50	kWh
Cooling water ( $\Delta = 10^\circ\text{C}$ )	58	50	ton
UF 85	-	7.5	kg
<b>Utilities production</b>			
LP steam (4 bar sat.)	370	415	kg
Steam condensate export	235	280	kg
Process condensate export	570	245	kg

All figures are per metric tonne of final product and are given by way of example only. Local conditions may have a great impact on the optimum consumptions.

### Scope of Performance Figures

The figures include:

- ammonia compression
- synthesis section
- recirculation section
- evaporation section
- waste-water treatment section
- finishing section (either prilling or granulation).

The above figures exclude:

- CO<sub>2</sub> compression
- storage and bagging facilities.

### Product Characteristics

nitrogen (N) content, wt. %	46.4
normal biuret content, wt. %	0.85
low biuret content, wt. %	0.25
moisture content, wt. %	0.25

### Waste-Water Characteristics

Urea concentration	1 ppm wt
Ammonia concentration	1 ppm wt

SI units are used.

In this system 1 tonne equals 1,000 kg.

## 5. CONCLUSION

Technology can always be improved upon. Stamicarbon has again proven that mature technology can be innovated, while retaining all process advantages of the CO<sub>2</sub> stripping process at the same time substantially reducing the investment cost of the synthesis section. With its UREA 2000plus technology, Stamicarbon can license state-of-the-art urea plants with capacities far above 2000 mtpd for dependable service well beyond the year 2000.