

## Thermodynamics of the Urea Process

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### Summary

As described in the February 2009 Process Paper of UreaKnowHow.com, the large scale manufacture of urea in modern times has been based on synthesis from ammonia and carbon dioxide. This process as originally suggested by Basaroff was first translated into industrial manufacture by German chemists in I. G. Farben in about 1920.

There are two main reactions involved in the synthesis of urea from carbon dioxide and ammonia; the formation of ammonium carbamate from carbon dioxide and ammonia, and the conversion of ammonium carbamate into urea. The reactions involved can be represented by the following equations:

This paper discusses the thermodynamics of the urea process. The thermodynamic models of Frejacques and Lemkowitz, de Cooker and van de Berg will be presented and in the influence of various process parameters like N/C, H/C, temperature and pressure will be discussed.

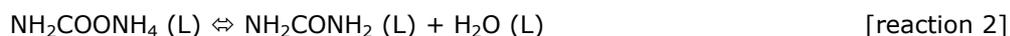
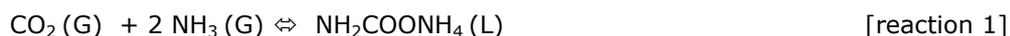
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## 1. Introduction

As described in the February 2009 Process Paper of UreaKnowHow.com, the large scale manufacture of urea in modern times has been based on synthesis from ammonia and carbon dioxide. This process as originally suggested by Basaroff was first translated into industrial manufacture by German chemists in I. G. Farben in about 1920. The development of the process continues to go ahead in different countries and many contributions to the process were made since then.

There are two main reactions involved in the synthesis of urea from carbon dioxide and ammonia; the formation of ammonium carbamate from carbon dioxide and ammonia, and the conversion of ammonium carbamate into urea. The reactions involved can be represented by the following equations:



At the temperature of 135 to 200 °C, the reaction as represented by reaction 1 is almost instantaneous and complete, provided the pressure of the system is greater than the decomposition pressure of the ammonium carbamate at the system temperature. When the system is dry, the only product is ammonium carbamate if the proper relative proportion of the two constituents are used. In the presence of water, carbonates of ammonia are also formed. Water and ammonium carbamate form a meta-stable system which evolves slowly into a complex mixture whose composition depends upon temperature and concentration.

The formation of carbamate is highly exothermic. The huge quantity of heat evolved in the formation of ammonium carbamate from carbon dioxide and ammonia necessitates the continual removal of heat in its preparation. At the point of temperature below the melting point of ammonium carbamate, about 155 °C, the ammonium carbamate forms a compact covering adhering film on the wall of the vessel which conducts heat poorly and thus increases the difficulty of removing the released heat of reaction. Several means have been proposed to circumvent this difficulty.

Above the melting point of ammonium carbamate, the problems resulting from the formation of a bad heat conducting film no longer exist, but they are replaced by serious problem of corrosion.

Since the reaction represented by reaction 1 is an equilibrium reaction, a thorough knowledge for dissociation pressure of ammonium carbamate, equilibrium constants and free energies of ammonium carbamate synthesis is a "must" for the investigation of the process. Heat removal as discussed in the previous paragraph is very important in the process of manufacture. It is necessary to know about the quantity of heat formation of ammonium carbamate. Ammonium carbamate itself is not suitable for fertilizer application because of its volatility and hygroscopic nature and because its application leads to crop "burning".

As to the reaction, represented by reaction 2, the dehydration of carbamate into urea is never completed. The yield of urea involves many factors, such as molar ratio of ammonia to carbon dioxide, effect of water, reactor pressure, time of residence, etc. The reaction is assumed to proceed entirely in the liquid phase. The resulting product is a complex mixture of water, urea, unconverted ammonium carbamate and ammonium carbonates resulting from the action of ammonium carbamate on the water formed. The reaction 2 is an endothermic reaction; however, the quantity of heat absorbed is much smaller than the heat evolved in the formation of ammonium carbamate from carbon dioxide and ammonia.

The rate of the urea formation reaction increases rapidly above 160 °C, as can be seen in Figure 1.

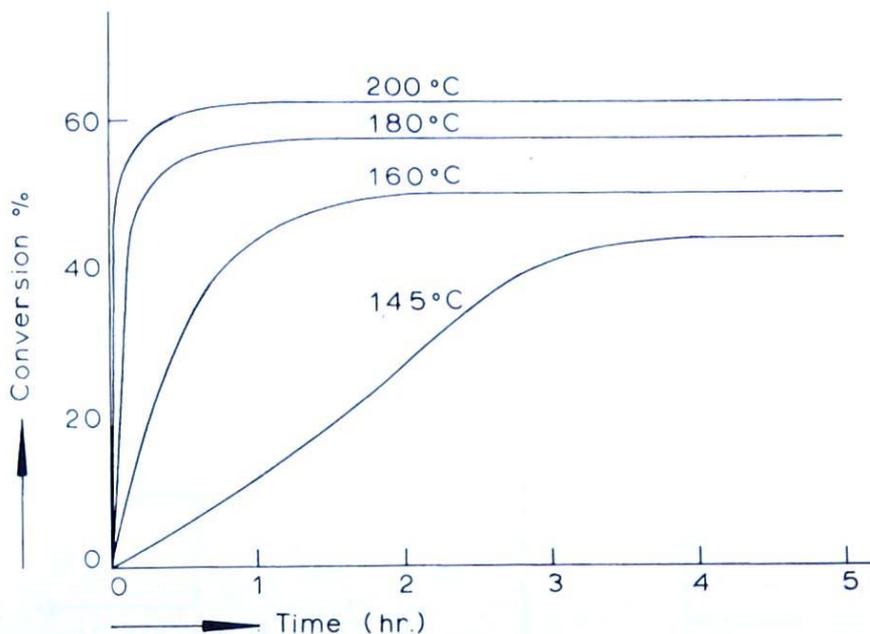


Figure 1: Conversion of ammonium carbamate to urea with time at different temperatures

Since ammonium carbamate is quite volatile at these temperatures it is necessary to carry out the synthesis at elevated pressures.

Figure 1 also shows that the conversion of ammonium carbamate to urea does not go completely, leading to the necessity of a dissociation and a recycle process step.

All processes follow the same general principle: The raw materials carbon dioxide and ammonia enter the autoclave or reactor, sometimes as carbamate already, in which they

(further) react and form urea. The reacted mixture then flows out from the reactor into a decomposer or stripper, in which the non converted materials are decomposed and separated from the urea product in the solution. The urea solution is in a condition to recover the final product urea. The unconverted ammonia and carbon dioxide recovered from the decomposer or stripper are typically recycled back to the reactor to reach a complete conversion into urea; this is the principle of the so called total-recycle process.

The corrosion working of carbamate in the liquid phase, like the kinetic rate of the urea formation reaction and the vapour pressure of the synthesis solution, are roughly an exponential function of the temperature. The conditions in a urea reactor are therefore a compromise of high reaction rate and degree of conversion and low corrosion rate and reactor pressure. Normal operating conditions lie in the area of 170-200 °C and 130-300 bars.

All of the above mentioned factors such as removal (and optimum use) of the large reaction heat of the carbamate formation reaction, the high pressures involved, the necessity of substantial recirculation and the severe corrosiveness of the liquid carbamate have necessitated a much more sophisticated technology for the production of urea than for the production of other nitrogenous fertilizers.

## 2. Thermodynamic models

### 2.1 Frejacques model

The first and still most widely used thermodynamic model for the ammonia-water-carbon dioxide system at urea synthesis conditions was presented in 1948 by M. Frejacques in *Chimie et Industrie* 60, 2211.

In this model the liquid phase is described by one overall reaction:



$$K_1 = \frac{X_{\text{urea}}(\text{L}) * X_{\text{H}_2\text{O}}(\text{L})}{(\text{XNH}_3(\text{L}))^2 * \text{XCO}_2(\text{L})} \quad [\text{reaction 4}]$$

$\text{XNH}_3(\text{L})$  and  $\text{XCO}_2(\text{L})$  refer to  $\text{NH}_3$  and  $\text{CO}_2$  in the liquid phase not existing as urea.

Frejacques assumed, for his model, that the urea synthesis solution did not contain any ammonium carbamate. Later Ivo Mavrovic claimed to have improved the  $K_1$  values, derived by Frejacques, so that the conversions can be calculated accurately up to 190-200 °C.

Although Frejacques model is strong due to its simplicity, it also cannot explain some observations such as for example the fact that the conversion of carbamate into urea ( $K_1$ ) increases with temperature at least to (190-200 °C), while the reaction 3 is strong exothermic (about -22 kCal/mol). However an equilibrium constant ( $K_1$ ) which increases with temperature for an exothermic reaction is in contradiction with the rule of Van 't Hoff.

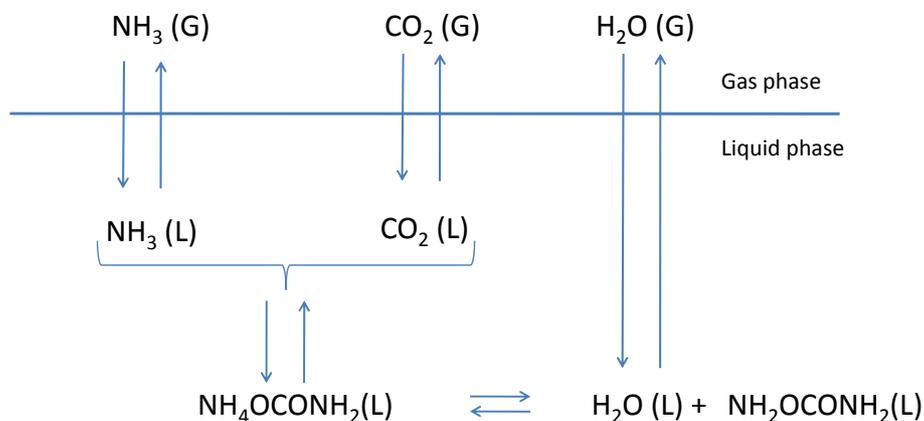
The rule of Van 't Hoff in chemical thermodynamics relates the change in temperature (T) to the change in the equilibrium constant (K) given the standard enthalpy change ( $\Delta H^\ominus$ ) for the process. The equation was first derived by Jacobus Henricus van 't Hoff.

$$\frac{d \ln K}{dT} = \frac{\Delta H^\ominus}{RT^2}$$

So if the reaction is exothermic,  $\Delta H^\ominus$  is negative and K should decrease with an increase in temperature.

Later others developed a more sophisticated model such as Effremova and Leontieva in 1962 and Nilsen in 1969. Here we like to discuss the model of S.M. Lemkowitz, M.G.R.T de Cooker and P.J. van den Berg (for short called here the Lemkowitz model) developed presented in 1972 at The Fertiliser Society in London.

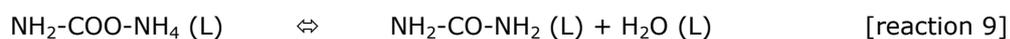
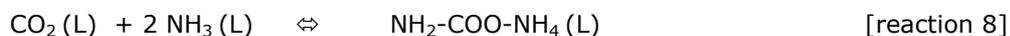
2.2 Lemkowitz model



This model assumes the following:

- The liquid phase is an ideal mixture of ammonium carbamate, urea, water and free (unreacted) ammonia and carbon dioxide. The presence of carbonates, bicarbonates, biuret etc is neglected. Ideal mixture means that the activities of the constituents are assumed to be equal to their mol fractions.
- The gas phase is ideal and a mixture of ammonia, carbon dioxide and water. The presence of urea and isocyanic acid is neglected.
- $K_1$  of Reaction 4 are taken the values, measured by Mt. Ivo Mavrovic.

The model consists of the following five reactions:



$\text{CO}_2 (\text{L})$  and  $\text{NH}_3 (\text{L})$  refer to free  $\text{CO}_2$  and  $\text{NH}_3$  in the solution, not the  $\text{CO}_2$  and  $\text{NH}_3$  originally added or existing as urea or ammonium carbamate.

For calculation purposes it is useful to combine reaction 8 and 9:



$$K_2 = \frac{X_{\text{urea}}(\text{L}) * X_{\text{H}_2\text{O}}(\text{L})}{(X_{\text{NH}_3}(\text{L}))^2 * X_{\text{CO}_2}(\text{L})} \quad [\text{reaction 11}]$$

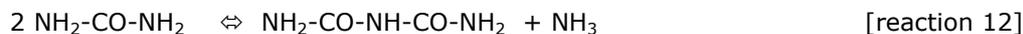
Please note that in this model there is made a difference between:

- Initial CO<sub>2</sub>, NH<sub>3</sub> or H<sub>2</sub>O. The initial mixture is the hypothetical mixture consisting only of NH<sub>3</sub>, CO<sub>2</sub> and H<sub>2</sub>O, if all reactions are shifted completely to the left, so the carbamate formation reaction, the urea formation reaction (and also the biuret formation reaction).
- Free CO<sub>2</sub> or NH<sub>3</sub> is the amount of CO<sub>2</sub> or NH<sub>3</sub> in the liquid phase not existing as urea, carbamate (or biuret).
- Bound CO<sub>2</sub> or NH<sub>3</sub> is the amount of CO<sub>2</sub> or NH<sub>3</sub> in the liquid phase existing as urea, carbamate (or biuret).
- Gaseous CO<sub>2</sub> and NH<sub>3</sub>

### 2.3 Urea process indicators

Before we go further lets first discuss some indicators often used in urea industry. In this paragraph biuret formation is assumed to be zero. In urea plant biuret is however typically analysed.

Biuret forms via the reaction:



So for one biuret molecule two CO<sub>2</sub> and three NH<sub>3</sub> molecules are needed and with this one is able to extend the formula here below. As an example this is done for the N/C ratio.

Some process indicators are related to defining in composition of the mixture of the liquid phase, such as:

*N/C ratio (or also sometimes defined as m or L)*

The N/C ratio or NH<sub>3</sub>/CO<sub>2</sub> ratio is the Ammonia / Carbon dioxide molar ratio of the liquid composition of the so-called initial mixture. This parameter can be typically chosen freely when designing a urea process.

$$\text{N/C ratio} = \frac{(2 * \text{wt\% urea} / 60) + (\text{wt\% NH}_3 / 17) + 3 * \text{wt\% biuret} / 103}{(\text{wt\% urea} / 60) + (\text{wt\% CO}_2 / 44) + 2 * \text{wt\% biuret} / 103}$$

*H/C ratio (or also sometimes defined as W)*

The H/C ratio or H<sub>2</sub>O/CO<sub>2</sub> ratio is the Water / Carbon dioxide molar ratio of the liquid composition of the so-called initial mixture. This parameter gives an indication of the amount of extra water introduced in the synthesis, typically via the recycle carbamate flow.

$$\text{H/C ratio} = \frac{\text{wt\% H}_2\text{O} / 18}{(\text{wt\% urea} / 60) + (\text{wt\% CO}_2 / 44)}$$

*H/U ratio (or also sometimes defined as h)*

Sometimes one also uses the H/U ratio or H<sub>2</sub>O/urea ratio is the Water / Urea ratio of the liquid composition. As the formation of one mole of urea leads at the same time to one mole of water the H/U ratio should be minimum 1. The H/U ratio gives a little more easy an indication of the amount of extra water introduced to the synthesis, typically via the recycle carbamate flow.

$$\text{H/U ratio} = \frac{\text{wt\% H}_2\text{O} / 18}{\text{wt\% urea} / 60}$$

Other process indicators are related to defining how far the urea formation reaction did or could progress, such as:

*CO<sub>2</sub> conversion (or also sometimes defined as etha  $\eta$  or Y)*

The CO<sub>2</sub> conversion gives the amount of CO<sub>2</sub> converted into urea divided by the total amount of CO<sub>2</sub>, both expressed in moles.

This parameter is the mostly used parameter to express how much urea has been formed, thus is an indication of the chemical equilibrium of the overall reaction.

$$\text{CO}_2 \text{ conversion} = \frac{\text{wt\% urea} / 60}{(\text{wt\% urea} / 60) + (\text{wt\% CO}_2 / 44)}$$

*NH<sub>3</sub> conversion*

The NH<sub>3</sub> conversion gives the amount of NH<sub>3</sub> converted into urea divided by the total amount of NH<sub>3</sub>, both expressed in moles.

Also this parameter indicates how much urea has been formed and thus is also an indication of the chemical equilibrium of the overall reaction, but is less widely used.

$$\text{NH}_3 \text{ conversion} = \frac{2 * \text{wt\% urea} / 60}{(2 * \text{wt\% urea} / 60) + (\text{wt\% NH}_3 / 17)}$$

When talking about CO<sub>2</sub> and NH<sub>3</sub> conversion one should also define if one talks about the CO<sub>2</sub> and NH<sub>3</sub> conversion at equilibrium conditions or at actual conditions. As the reaction from carbamate into urea is a slow reaction, in a real urea reactor one will never reach equilibrium conditions (please refer to Figure 1). The actual CO<sub>2</sub> conversion divided by the CO<sub>2</sub> conversion at equilibrium is typically defined as Fraction Approach to Equilibrium or FAE.

$$\text{FAE} = \frac{\text{actual CO}_2 \text{ conversion}}{\text{CO}_2 \text{ conversion at equilibrium}}$$

A similar equation can be made for the NH<sub>3</sub> conversion.

And again other process indicators are related to define the efficiency of a stripper or decomposer such as:

*Alfa (a)*

Efficiency of a stripper or decomposer (heat exchanger) is defined as is the ammonia converted to urea (and biuret) divided by the total amount of ammonia, typically measured at the liquid outlet of the heat exchanger. In fact this is same definition as the NH<sub>3</sub> conversion.

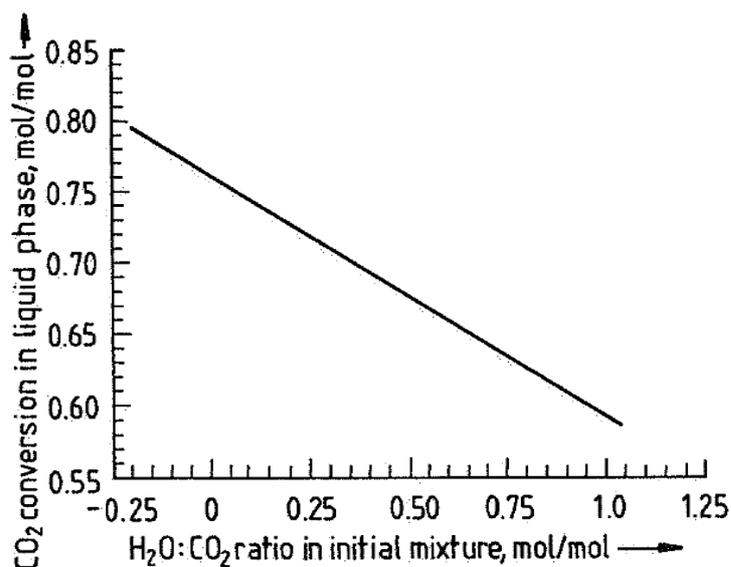
$$\text{Alfa} = \frac{2 * \text{wt\% urea} / 60}{(2 * \text{wt\% urea} / 60) + (\text{wt\% NH}_3 / 17)}$$

### 3. Influence of various process parameters

#### 3.1 Influence of H/C ratio

The influence of the composition of the initial mixture on the chemical equilibrium can be explained qualitatively by the law of mass action on the overall urea formation reaction.

For example a larger amount of water in the initial mixture (increasing the H<sub>2</sub>O/CO<sub>2</sub> ratio) results in a decrease in both CO<sub>2</sub> and NH<sub>3</sub> conversion. Obviously because water "pushes" the chemical equilibrium of the overall reaction is pushed to the left side. Figure 2 shows the influence of the H/C ratio on the CO<sub>2</sub> conversion and the NH<sub>3</sub> conversion.



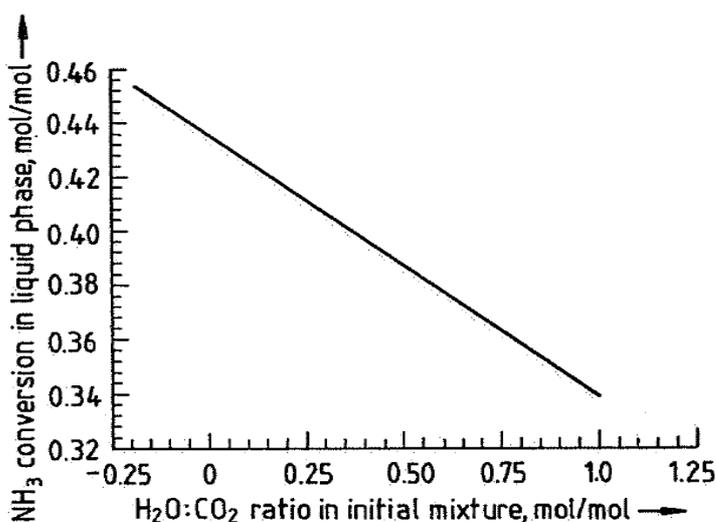


Figure 2: The influence of the H/C ratio on the CO<sub>2</sub> conversion and the NH<sub>3</sub> conversion.

However a full quantitative description cannot be derived simply from the law of mass action. Other, not yet fully understood reaction mechanisms probably contribute to the chemical equilibria to a minor extent.

### 3.2 Influence of N/C ratio

A higher NH<sub>3</sub>/CO<sub>2</sub> ratio (increasing the NH<sub>3</sub> concentration) increases the CO<sub>2</sub> conversion. The most simple explanation was made by Frejacques, who explained it by the laws of mass action (the chemical equilibrium of the overall reaction is pushed to the right side by NH<sub>3</sub>).

Later Otsuka explained it by assuming that an excess of NH<sub>3</sub> lowered the activity of water present in the reaction mixture. Here with activity is meant the measure of the "effective concentration" of water in the liquid solution. Activity depends on temperature, pressure and composition of the mixture, among other things. The difference between activity and mole fraction arises because molecules in non-ideal solutions interact with each other, either to attract or to repel each other. The activity of an ion is particularly influenced by its surroundings.

temperatures below 190-200 °C the concentration of free CO<sub>2</sub> is very small relative to the concentrations of the remaining constituents, i.e., the dissociation of carbamate may be neglected. At these conditions, the conversion to urea is controlled by reaction 9. In this reaction however, NH<sub>3</sub> does not occur explicitly, so how to explain the influence of the higher N/C ratio?

Lemkowitz states that the effect of the excess NH<sub>3</sub> must be seen primarily as that of an essentially diluent and a general rule of thermodynamic states that a diluent increases the conversion of a reaction in which the number of moles increases, so the urea formation reaction is shifted to the right side.

Figure 3 shows the relation of CO<sub>2</sub> and NH<sub>3</sub> conversion at different N/C ratios.

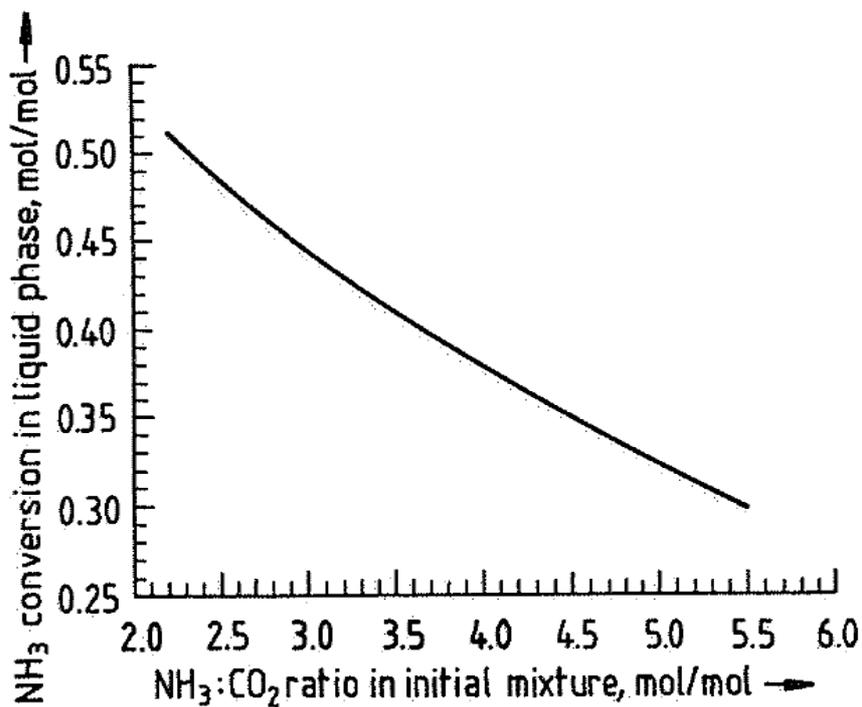
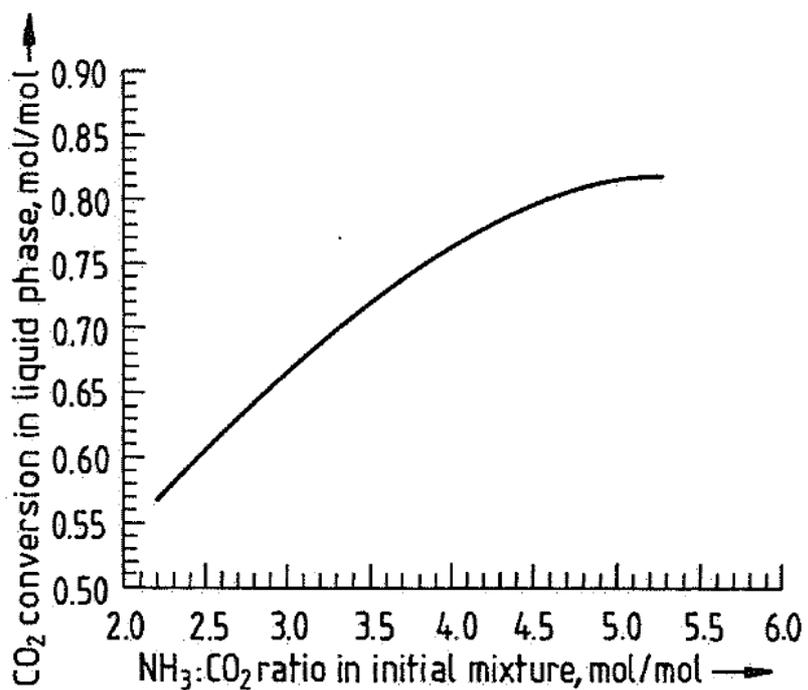


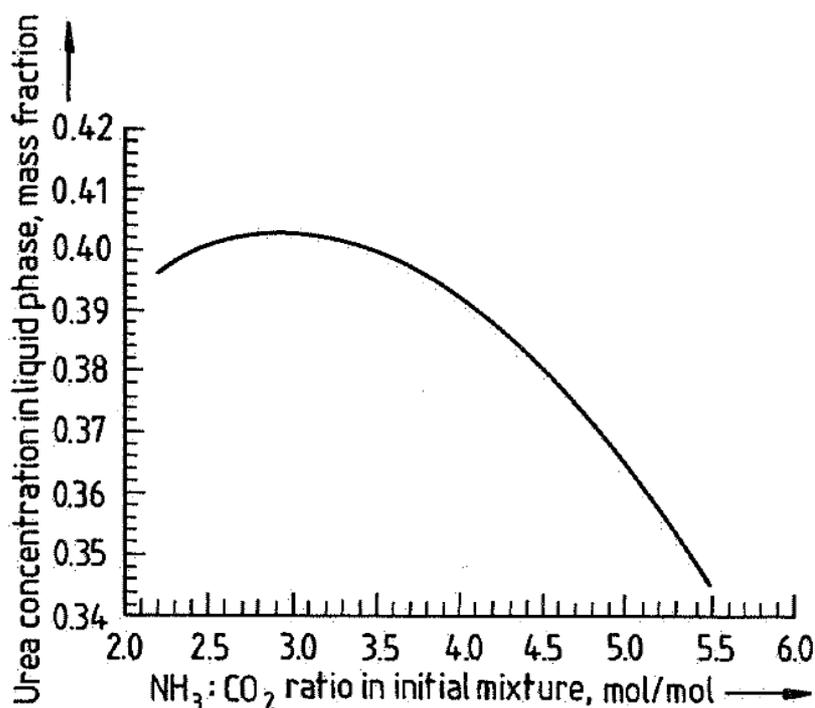
Figure 3: The influence of the N/C ratio on the  $\text{CO}_2$  conversion and the  $\text{NH}_3$  conversion.

Figure 3 shows that although the  $\text{CO}_2$  conversion increases with a higher N/C ratio, the  $\text{NH}_3$  conversion decreases. The fact that the  $\text{NH}_3$  conversion decreases can be simply explained by the fact that there is more initial  $\text{NH}_3$  at a higher N/C ratio.

*Why we talk about  $\text{CO}_2$  conversion and  $\text{NH}_3$  conversion ?*

In the traditional urea literature, typically the urea conversion is expressed as  $\text{CO}_2$  conversion. This is based on the arbitrary choice of  $\text{CO}_2$  as the key component. Historically, this may be justified by the fact that early in the urea processes,  $\text{CO}_2$  conversion was more important than  $\text{NH}_3$  conversion. For example in conventional urea plants  $\text{NH}_3$  conversion is not so important as these plants have a pure ammonia recycle so unconverted ammonia will be recycled back to the synthesis without additional water. As indicated in paragraph 3.1, water reduces the  $\text{CO}_2$  as well as the  $\text{NH}_3$  conversion, so the water content should be minimized. This means in urea plants with a pure ammonia recycle,  $\text{CO}_2$  conversion is more important than  $\text{NH}_3$  conversion. Typically these processes operate therefore at higher N/C ratio's.

However for example for a Stamicarbon  $\text{CO}_2$  stripping process, giving a higher value to  $\text{CO}_2$  conversion is not justified. Both  $\text{NH}_3$  as well as  $\text{CO}_2$  will recycle together with additional water in the form of carbamate to the synthesis, so both conversions need to be maximum. Certainly here the urea yield (i.e. the concentration of urea in the liquid phase) is a better tool to determine the optimum process parameters than  $\text{CO}_2$  or  $\text{NH}_3$  conversion. Figure 4 shows the urea yield at different N/C and H/C ratios.



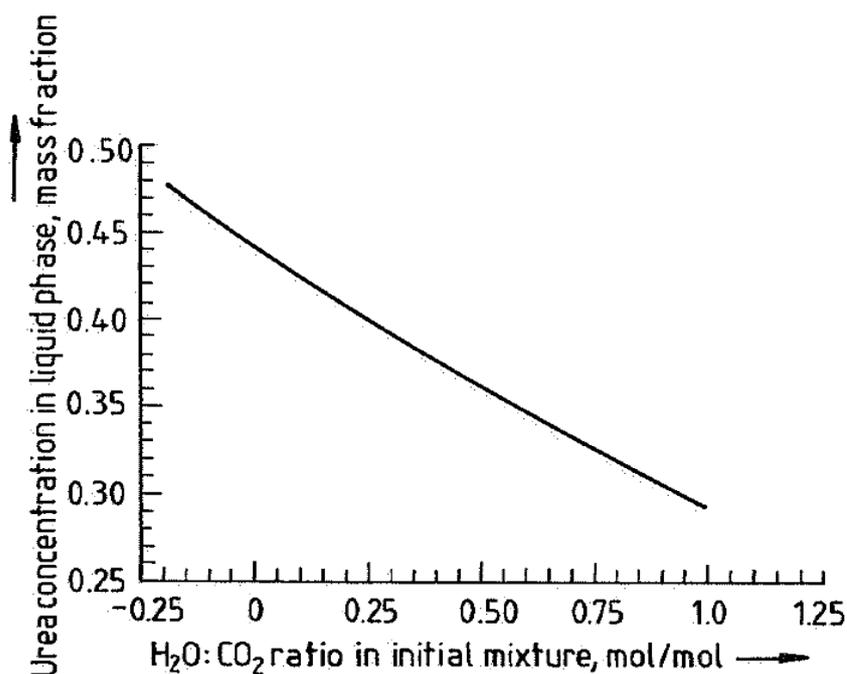
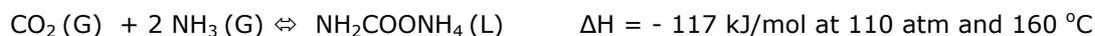


Figure 4: The influence of the N/C and H/C ratio on the Urea yield.

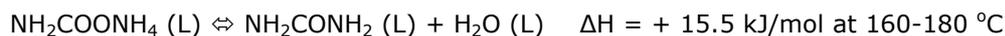
Figure 4 illustrates that urea yield as function of NH<sub>3</sub>/CO<sub>2</sub> ratio goes through a maximum: The urea yield as function of NH<sub>3</sub>/CO<sub>2</sub> ratio reaches its maximum around a value of 3/1. Another important parameter, which determines the optimum process conditions can be found from the physical phase equilibria (phase diagrams) in the NH<sub>3</sub>-CO<sub>2</sub>-H<sub>2</sub>O-urea system. This will be covered in a future paper. The figure right shows again the detrimental effect of excess water on urea yield; thus it is clear that one of the targets in designing a recycle system must be to minimize water recycle.

### 3.3 Influence of temperature

As indicated earlier the formation of urea from ammonia and carbon dioxide can be described as a two step process. First ammonia and carbon dioxide form ammonium carbamate, which reaction is fast and exothermic.



The second reaction is the conversion of ammonium carbamate into urea and water. This conversion is slow and slightly endothermic.



Since more heat is produced in the first reaction than consumed in the second, the overall reaction is exothermic. The achievable conversion per pass, dictated by the chemical equilibrium, as a function of temperature goes through a maximum. This is shown in Figure 5.

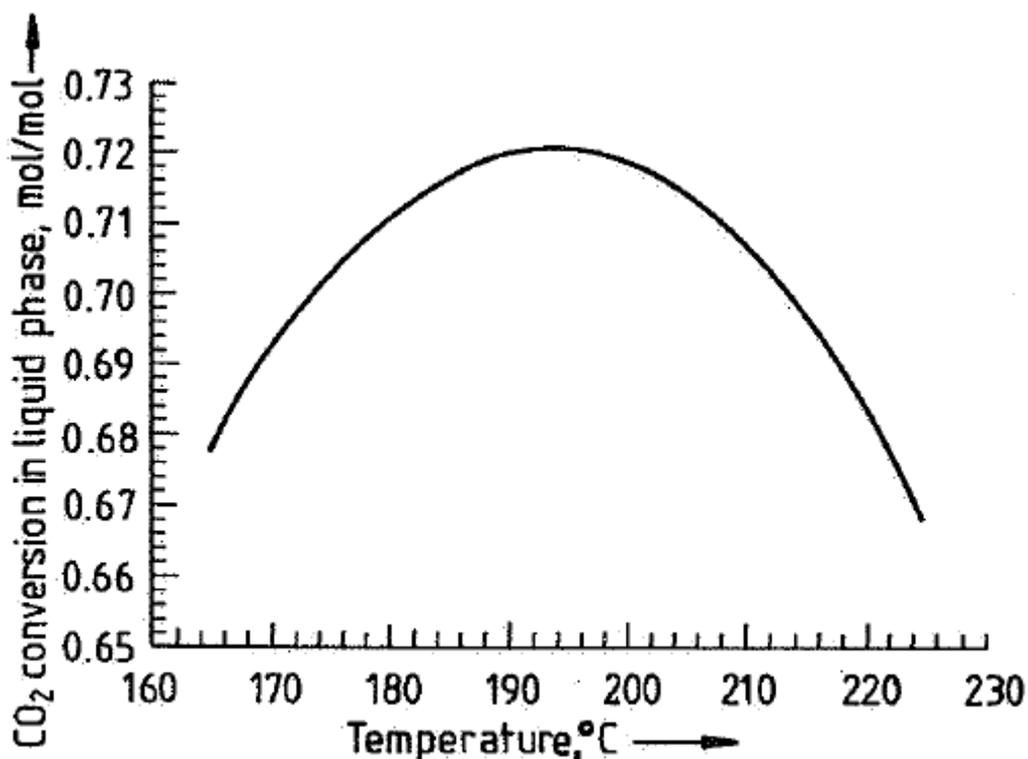


Figure 5: CO<sub>2</sub> conversion at chemical equilibrium versus temperature (N/C = 3.5 and H/C = 0.25)

This effect is usually explained by the fact that the ammonium carbamate concentration as a function of temperature goes through a maximum. This maximum in the ammonium carbamate concentration can be explained, at least qualitatively, by the respective heat effects of the carbamate and urea formation reactions. At higher temperatures the dissociation reaction of carbamate becomes controlling and a further increase in temperature leads to a decrease in the conversion.

This mechanism cannot however explain the observed conversion maximum fully and quantitatively; other contributing mechanisms have been suggested. Lemkowitz believed that also the fact that one approaches critical conditions at higher temperatures is a secondary factor. As the temperatures increase the concentration of free ammonia and carbon dioxide in the liquid phase increase also due to the carbamate dissociation reaction. The liquid phase becomes more and more "gas like". The critical line in the NH<sub>3</sub>-CO<sub>2</sub> system occurs at lower temperatures and pressures a higher N/C ratio. This explains why the maximum in Figure 5 occurs at lower temperatures when the N/C ratio is higher.

With the temperature here above is meant the maximum reachable temperature in a reactor. There are some reasons that this temperature is never reached in real conditions. One reason is because there are inerts present in the reactor, this will be elaborated in the next paragraph. Another reason is that the urea formation reaction is very slow. The maximum temperature is the temperature at equilibrium, but equilibrium is never reached in a real reactor.

The temperatures measured in a real reactor is the boiling temperature of the liquid. It increases from inlet to the outlet due to the fact that urea (and water) are formed and the light boiling components NH<sub>3</sub> and CO<sub>2</sub> are converted into heavy boiling components urea and water. Typically the temperature difference of the reactor is therefore a good indication for the urea conversion.

As the boiling liquid flows from inlet to the outlet of the reactor the urea formation reaction takes place. This reaction is endothermic and needs some heat to be able to proceed. Typically the condensation of gasses takes care of this heat requirement. A reactor is this typically a bubble column with a liquid at boiling point. Therefore temperature and pressure are obviously related to each other.

The higher the temperature the faster the urea formation reaction will proceed. This will be according to the Arrhenius relation. The Arrhenius equation gives the dependence of the rate constant  $K$  of a chemical reaction on the temperature  $T$  and activation energy  $E_a$ :

$$k = Ae^{-E_a/RT}$$

Figure 1 shows the relation of conversion versus the temperature.

### 3.4 Influence of pressure

As indicated in paragraph 3.3, a higher temperature in the reactor will increase the reaction speeds and is beneficial for the approach to equilibrium and the position of the urea equilibrium.

However a higher temperature is also related to a higher pressure (boiling curve). And in case of a stripping process a higher pressure results however in a reduced stripping efficiency. Thus the choice of reactor temperature (or the corresponding reactor pressure) in a stripping process is in general an optimization between high reactor conversion on one hand and high stripping efficiency on the other.

Further please realize that with the feeds ammonia and carbon dioxide also inerts are introduced in the urea synthesis section. Partly these inerts originate from the ammonia process and partly from passivation air and air needed for the hydrogenation reactor (if present). Ammonia and carbon dioxide convert via carbamate into urea. At the outlet of the reactor a major part of the reactants are condensed and the percentage of inerts increases.

The total pressure can be divided up into an inert pressure (determined by the amount of inerts, i.e. hydrogen, oxygen, nitrogen, Argon, methane and methanol) and a system pressure (determined by the reactive components mainly ammonia, carbon dioxide and water). A higher inert pressure at constant overall pressure means a lower system pressure. This means the reactor temperature will be higher (better conversion) in case less inerts are present.

As explained in paragraph 3.3 a reactor is a bubble column consisting of a boiling liquid. The measured temperature is in fact the boiling temperature of the liquid at the system pressure and not at the total pressure which one actually measures.

When talking about boiling points of mixtures physical equilibria (phase diagrams) are of importance and especially in the urea process phase equilibria are rather complicated but of major importance to understand better what happens in a urea plant. This will be the topic of a future paper.

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Mark Brouwer was born on July 6, 1966 in Groningen, The Netherlands. He graduated in 1988 at the Technical University of Eindhoven at the faculty of Chemical Engineering. His thesis was about the production of ethylene by partial oxidation of natural gas.

After University Mark joined Military Services, Dutch Royal Navy where he was working at the Prins Maurits Laboratory of TNO in Rijswijk. In this period he was involved in Process simulation studies on the absorption of poisonous gasses on active carbon.

In 1990 he joined DSM, working for the Ethylene Plant No.4 as a Process Engineer. In these seven years he was involved in the Basic Engineering of a debottlenecking project at Stone & Webster in London and in the implementation of the DSM Extraction Styrene project (from Conceptual Engineering up to the successful start up) .

In 1997 he joined Stamicarbon, the Licensing subsidiary of DSM as Licensing Manager Urea Revamps. Later he became Manager Stamicarbon Services responsible for all Stamicarbon's activities in existing urea plants, such as After Sales, Plant Inspections, Debottlenecking Projects, Reselling projects etc. In these nearly twelve years he did visit nearly one hundred urea plants worldwide and was involved in numerous revamp, relocation, debottlenecking and grass root projects.

Since January 1, 2009, Mark Brouwer left Stamicarbon and started up UreaKnowHow.com. UreaKnowHow.com is an independent group of urea specialists with an impressive number of years experience in designing, maintaining and operating urea plants. UreaKnowHow.com's mission is to support, facilitate and promote the exchange of technical information in the urea industry with the target to improve the performance and safety of urea plants.

Please feel welcome at UreaKnowHow.com, the website where the urea industry meets.

