

# Capacity Increase of Urea Plants *for*

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<b>1</b>	<b>Revamping in General</b> .....	<b>2</b>
1.1	Targets and Requirements .....	2
1.2	Uhde's Recent Experiences .....	3
<b>2</b>	<b>Revamp concept</b> .....	<b>3</b>
2.1	Basis and Desired Capacities .....	3
2.2	The MP Add-on Concept .....	5
2.3	Revamp Measures of Downstream Sections .....	8
<b>3</b>	<b>More than just the Enhancement of Capacity</b> .....	<b>8</b>
3.1	Stand-by Pump Philosophy .....	8
3.2	Closed Cooling Water Loops .....	9
<b>4</b>	<b>CO<sub>2</sub> Generation</b> .....	<b>11</b>
4.1	Situation .....	11
4.2	Generation of Extra CO <sub>2</sub> .....	12
4.3	CO <sub>2</sub> from the CO <sub>2</sub> Recovery Unit in the Ammonia Plant .....	12
4.4	Recovery of CO <sub>2</sub> from Flue Gas .....	13
<b>5</b>	<b>Conclusion</b> .....	<b>14</b>

# 1 Revamping in General

Starting with an explanation, why a revamp is not just an enhancement of the capacity of a urea plant, two revamps conducted by Uhde are presented. Furthermore two examples showing Uhde's optimization gained through the experience in engineering and construction of urea plants is discussed. Since the restrictions of a capacity increase might be the upstream ammonia plant, ways and opportunities are visualized in order to provide necessary ammonia and carbon dioxide feed in the desired ratio.

## 1.1 Targets and Requirements

Before going deeper into topics like opportunities of increasing the capacity of a urea plant, it first should be stated that a revamp does not only mean increasing the amount of product. Revamping rather has the meaning of renovating since the term "Revamp" etymologically originates from replacing the upper front part of a shoe.

The target of a revamp in terms of a capacity increase shall always use the existing margins to get a maximum possible additional product with the lowest effort necessary. Consequently this target asks inherently for finding the bottlenecks to achieve a certain capacity. Depending on these bottlenecks it sometimes makes sense to think in terms of a step model since each elimination of a bottleneck refers to a certain investment. For instance there is maybe a sharp border at a certain capacity which results in the necessity of an additional piece of HP equipment, if exceeded.

A target may also be the reduction of the energy consumption by heat integration for instance. Reducing the operating costs in a considerable extent will also be a benefit for the plant's owner. Due to experiences gained in the past and due to improvements of technologies, materials and others a target might also be the increase of the reliability and availability of the plant. Environmental improvements might also be a target of a revamp, hence reducing emissions in order to comply with new laws and international standards for instance.

An inherent requirement of such a revamp is to utilize a well proven and reliable technical concept. In addition, one of the most important requirements is to realize a short as possible implementation downtime for modifications and new equipment.

## 1.2 Uhde's Recent Experiences

In the recent past Uhde carried out the basic and detailed engineering for the revamp of two Egyptian urea plants, which have basically the same starting point with a capacity of 1925 MTPD each. The capacities of these plants, which were commissioned by Uhde in the years 2000 and 2006 will be increased by about 17% to a new capacity of 2250 MTPD. Furthermore those two plants mainly differ in their finishing sections since one uses UFT technology for the granulation and the other uses the granulation technology of Stamicarbon.

By finding the general revamp concept only part of the work is done. In order to fulfill all individual requirements of the client a precise investigation of all existing equipment has to be carried out in addition to the newly installed items.

In general for a capacity increase of a urea plant additional reaction volume, stripping, evaporation and condensation capacity needs to be installed depending on how much the capacity will be increased, where the plants bottlenecks are and what the requirements of the clients are, which ends in each small part of the plant. All these factors will always lead up to a very unique revamp concept.

Decisive for the extent of the capacity increase of a urea plant is at first the investigation of opportunities to provide the necessary raw materials and utilities. Remains to point out that for the aforementioned revamp projects which will be discussed in the following chapter more in detail, extra ammonia and carbon dioxide are available through a standalone  $\text{NH}_3$  plant located near to the revamped urea plants.

## 2 Revamp concept

### 2.1 Basis and Desired Capacities

As already mentioned before both urea plants originally designed for a urea capacity of 1925 metric tons per day (MTPD). They are both using the conventional  $\text{CO}_2$  stripping process technology of Stamicarbon for the melt part. The capacity is increased to 2250 MTPD, which is an enhancement of 17%. The granulation section of the first plant using the technology of UFT was originally designed for 2000 MTPD which refers to an increase of 12.5% to achieve an additional production of 250 tons per day.

The granulation section of the second plant uses the technology of Stamicarbon and was their first grass root granulation plant. It was also designed for 2000 metric and will be increased by the same amount.

The figures 1 and 2 show the synthesis sections of these urea plants before and after the revamp. The high pressure synthesis loop of the conventional CO<sub>2</sub> stripping process of Stamicarbon consists of a HP stripper decomposing the carbamate contained in the liquid reactor outlet by means of high pressure carbon dioxide and high pressure steam for the purpose of keeping the raw materials NH<sub>3</sub> and CO<sub>2</sub> in the synthesis loop.

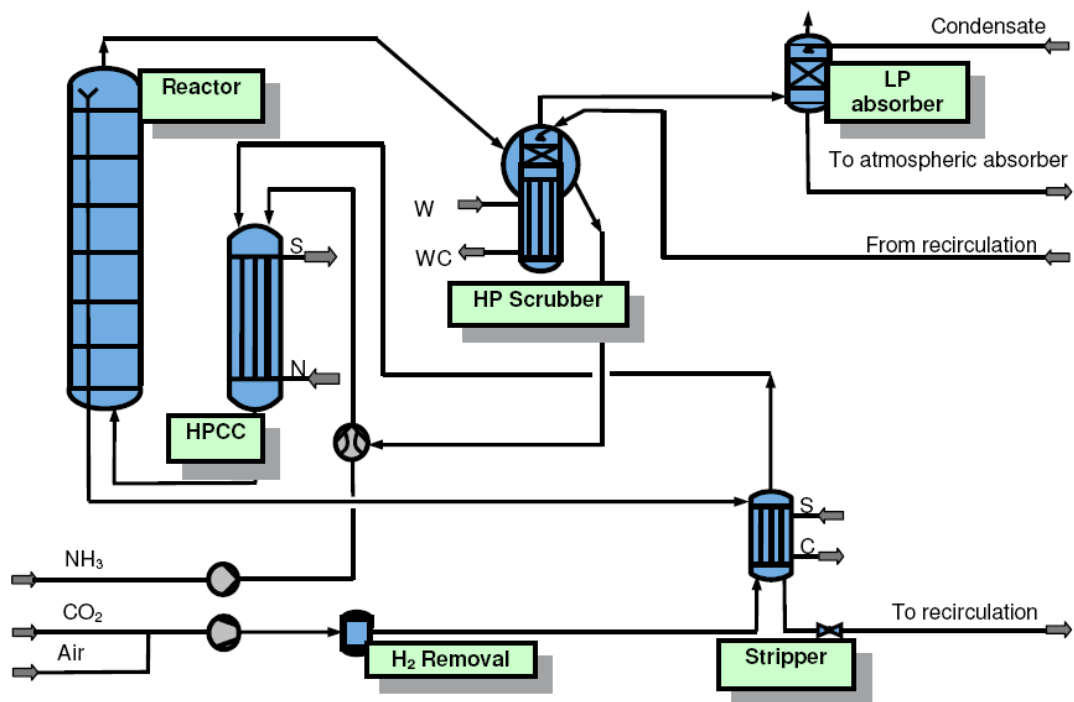


Figure: 1 Conventional Stamicarbon CO<sub>2</sub> stripping process

These strip gases are subsequently condensed together with recycled carbamate and fresh ammonia in the high pressure carbamate condenser (HPCC), while generating LP steam due to the first fast and exothermic reaction to carbamate. The outlet of the HPCC enters the reactor where the second slow and endothermic reaction from carbamate to urea by splitting off a water molecule takes place. Finally the liquid phase is leaving the reactor via the overflow pipe and entering the aforementioned stripper, where the reactor outlet is stripped and routed to the LP recirculation section for further downstream processing. The major bottleneck of this urea synthesis loop is the high pressure stripper since the load of urea solution to the stripper tubes is limited. Exceeding a specific flow will lead to flooding and hence lowering significantly the stripping efficiency.

The only revamp measure for the two Egyptian urea plants in the high pressure section as indicated in figure 2 is the installation of an after reactor, which is basically just like an enlargement of the existing reactor gaining more reaction volume. Furthermore figure 2 shows that the bottleneck of the HP stripper is circumvented by splitting the urea solution coming from the after reactor and sending it partially to a new medium pressure add-on section.

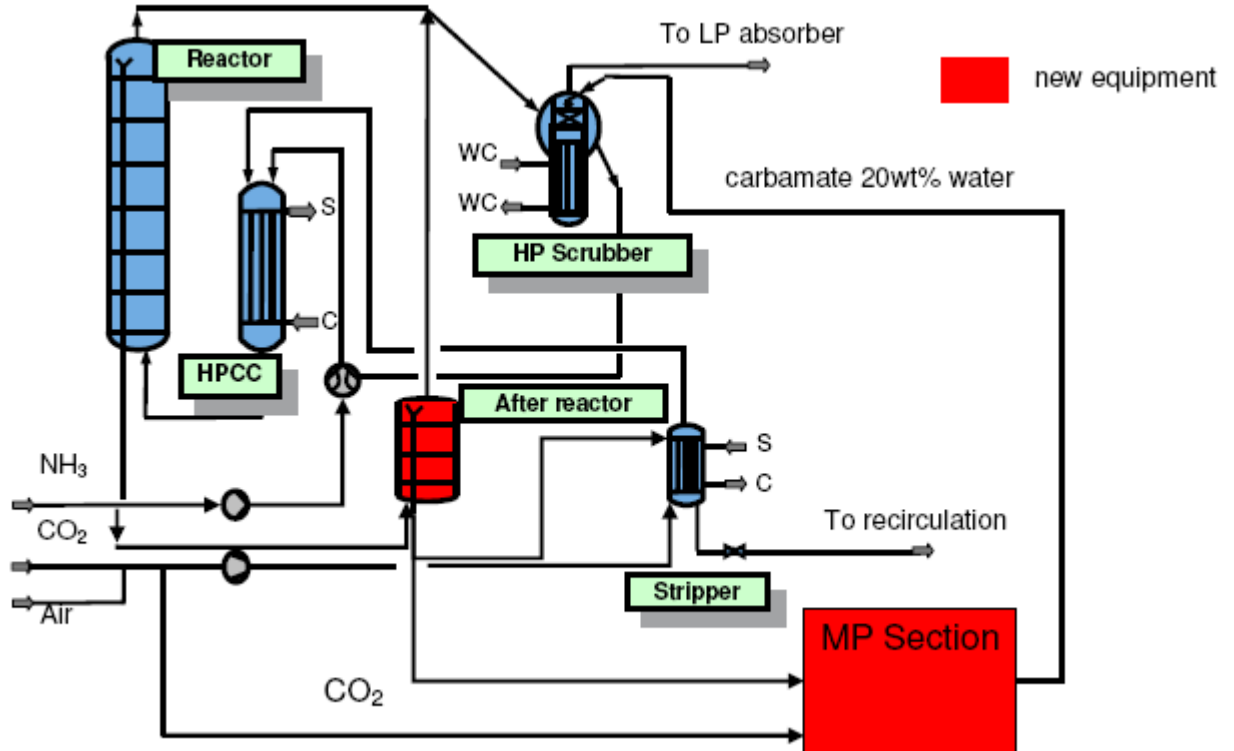


Figure: 2 MP add-on concept applied to conventional CO<sub>2</sub> stripping process

## 2.2 The MP Add-on Concept

The block diagram in figure 3 shows the revamp measures by highlighting the main new units added to the existing plant in light green and gives a general overview of the MP add-on concept applied to both revamps licensed by Stamicarbon and engineered by UHDE. As it is visualized in the block diagram apart from the urea solution, also carbon dioxide and LP carbamate are fed to the medium pressure add-on section.

Two main process streams leave the newly installed MP section. On one hand there is a carbamate stream which replaces the carbamate from the low pressure recirculation section by combining the carbamate streams from the LP and MP section. On the other

hand there is a urea solution stream with a composition comparable to the urea solution leaving the HP synthesis. Furthermore the block diagram in figure 3 shows also that waste heat is exchanged between the medium and the low pressure stages.

According to the aspired capacity a parallel low pressure recirculation part and a parallel desorption section are added to the existing plant.

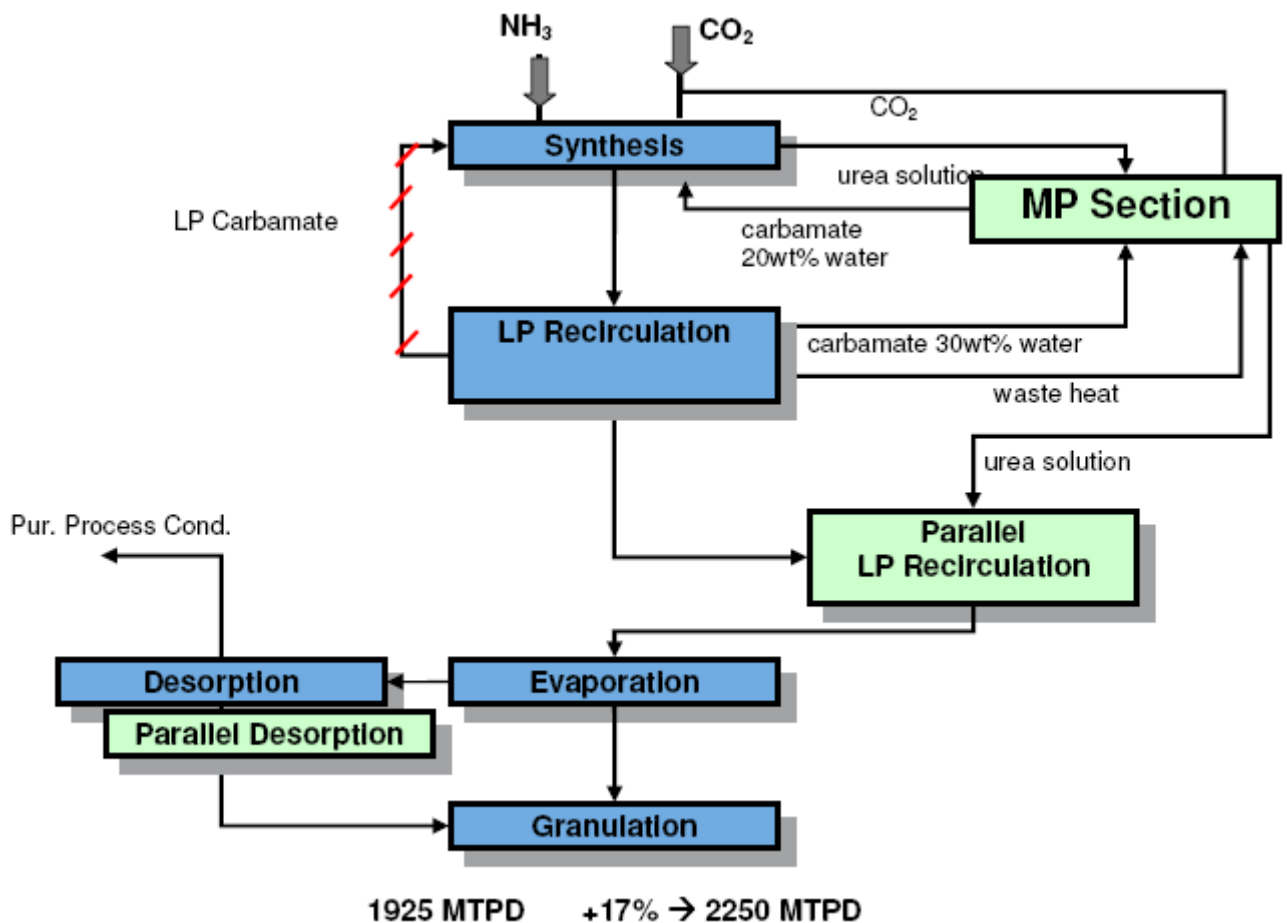


Figure: 3 Block diagram of a urea plant with MP add-on section

As shown in the flow diagram in figure 4 the MP add-on section basically consists of equipments comparable to equipments known from the LP recirculation. The urea solution originating from the urea reactor is first fed to the MP Rectifying Column via a let down valve, enabling the separation of the flashing gas and liquid. Subsequently this liquid is counter currently rectified by means of carbamate gases, which are generated through heating with steam in the lower part.

This rectified urea solution is further sent to the MP Stripper, where it is adiabatically stripped with MP  $\text{CO}_2$  which is provided via a dedicated MP  $\text{CO}_2$  compressor. The urea solution leaves the MP stripper to the LP Recirculation and is processed as usual. The

composition of the urea solution is almost the same as the one coming from the high pressure stripper and sums up to approx. 20% of the total amount of urea solution further processed in the downstream sections.

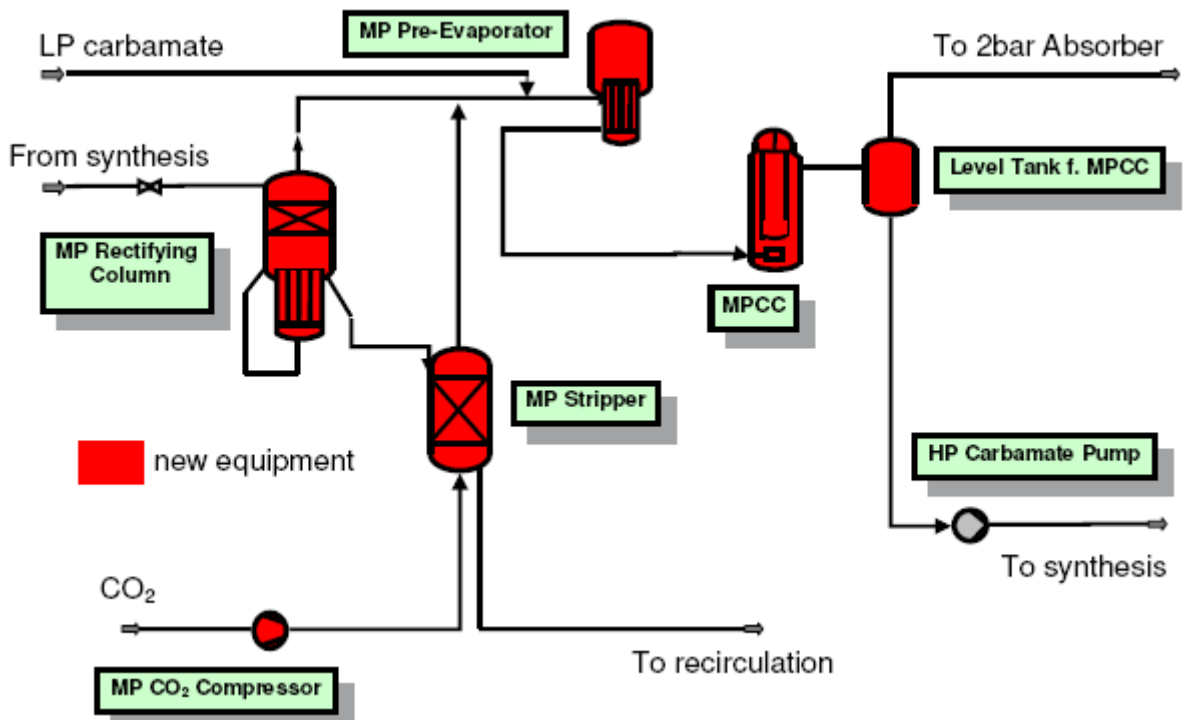


Figure: 4 flow diagram MP section (red box in fig. 2)

The off-gases of both the MP Rectifying column and the adiabatic MP CO<sub>2</sub> strip column are sent to the shell side of the MP Pre-Evaporator, where the MP carbamate gases are pre-condensed together with LP carbamate, which serves as absorption medium for the NH<sub>3</sub> and CO<sub>2</sub> gases since the reaction to carbamate subsequently takes place in the liquid phase. The condensation heat is exchanged with urea solution on the tube side for the purpose of concentrating the solution from 70% to about 79% prior to the evaporation section.

The partially condensed MP carbamate gases are then finally condensed in the MP carbamate condenser by means of conditioned cooling water and afterwards pumped via the existing HP carbamate pumps back to the urea synthesis. Due to the elevated pressure in the medium pressure section the carbamate contains about 20% water. This is 10% less water than the LP carbamate with about 30%. In general the carbamate flow back to the synthesis will increase to such an extent, that two HP carbamate pumps will be operated in parallel.

Although the medium pressure section is an integrative part between the low pressure recirculation and the high pressure synthesis, provisions are made to run the plant almost with the same configuration as compared to the situation before the revamp.

### **2.3 Revamp Measures of Downstream Sections**

Further downstream processing with respect to the melt plant will not be discussed since it is basically straight forward. Moreover the necessity of parallel or additional equipment in these sections may differ from each and every plant due to the client's requirements, the existing design margins and the sought capacity increase.

For the finishing sections, the granulation part of both urea plants generally require to balance the additional heat input originating from the crystallization heat introduced by the increased load to the granulator. This can be realized in different manners. In order to compensate the additional heat input, the air flow to the fluid beds can be increased, the temperature of the fluidization air may be lowered by means of either evaporating water or by means of chilling with ammonia. For the sake of keeping efforts as low as possible the task for the conceptual engineering is to minimize the modifications to the existing plant, while maximizing the effects on the heat balance, which is finally also unique for each plant.

## **3 More than just the Enhancement of Capacity**

With the completion of the licensor's process design package just a small part of the engineering is done. Especially for a revamp the input and involvement of the contractor might have a severe influence on the success of a revamp project in terms of providing the client a tailor-made solution. In the following two issues are presented exemplarily which show Uhde's input to optimize a revamp concept.

### **3.1 Stand-by Pump Philosophy**

As mentioned in chapter 2 two high pressure carbamate pumps will run in parallel as illustrated on the right-hand side in figure 5. This requirement also applies for the high



pressure ammonia pumps. Consequently if the prevailing philosophy of redundancy for pumps shall be kept, a third high pressure pump suggests itself.

But due to the fact that the stand-by pumps, on one hand the HP ammonia pump and on the other hand the HP carbamate pump are only needed if the new MP add-on section is in operation, the fall back position will be a capacity of 1925 metric tons per day in case of malfunction or maintenance of one pump. Hence the scenario is no longer comparable to the situation before the revamp and a risk-benefit analysis may have completely new results.

Although the high pressure pumps in such a revamp might have a higher cost and time impact compared to other equipment, it is also reasonable discussing the necessity of other items. Uhde is able to assist in solving tasks of this kind for the sake of finding the optimal solution for the benefit of the client. For this specific example two additional high pressure pumps for ammonia and carbamate will be installed based on client's decision.

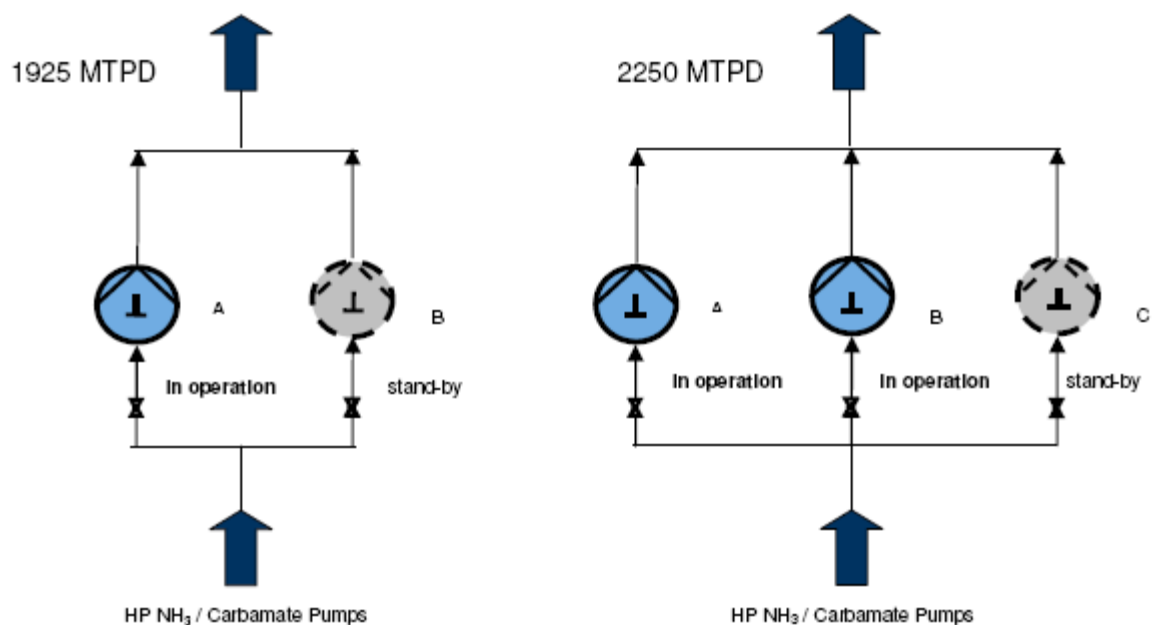


Figure: 5 Redundancy of high pressure pumps

### 3.2 Closed Cooling Water Loops

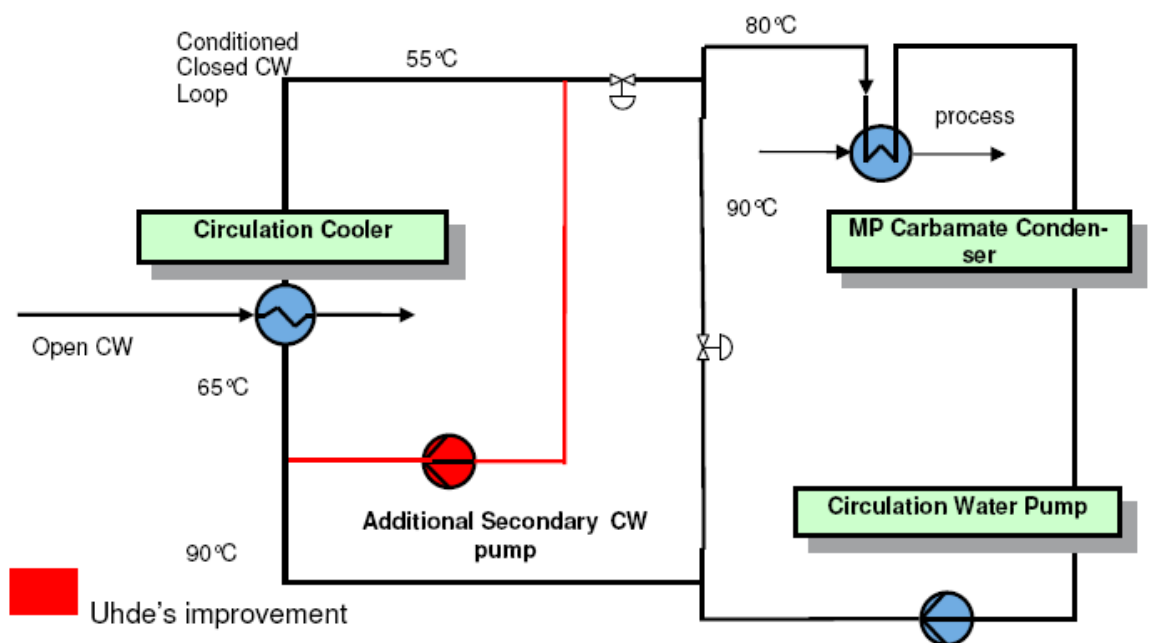
Figure 6 illustrates the conditioned cooling water loop for medium pressure carbamate condenser (MPCC), which has the same configuration as it is the case for high pressure scrubber and the low pressure carbamate condenser.

In this special case for these plants the client faced a fouling problem for the plate heat exchanger tempering the closed cooling water loop according to the correlated carbamate condensation temperature, which lies in the range of the temperature of the HP scrubber.

Due to these high cooling water temperatures and the therefore resulting high wall temperature in the plate heat exchanger the tendency to fouling is increased specially where certain circumstances like an open cooling water loop are present.

Uhde improved this set up by adding an additional pump, which generates a secondary loop circulating around the plate heat exchanger, and reducing the inlet temperature through mixing the hot return water with already tempered water from the outlet of the heat exchanger. Scaling the ratio between both flow rates by choosing the size of the additional pump leads to a certain mixing temperature which will be reduced to such an extent that fouling tendency will be significantly lowered.

Furthermore Uhde applied the concept of a secondary cooling water loop to the existing closed loops of the HP scrubber and the low pressure carbamate condenser and thus gaining a better performance and more availability of the whole plant.



**Figure: 6 Closed cooling water loop**

## 4 CO<sub>2</sub> Generation

### 4.1 Situation

When a capacity increase of a urea plant is discussed, it is a natural question to ask for the source of the additional ammonia and CO<sub>2</sub> needed. A natural-gas based ammonia plant is producing both feedstocks for the urea plant, NH<sub>3</sub> and CO<sub>2</sub>. In an existing ammonia / urea complex, there is often the situation that there is a surplus of ammonia which can not be converted into urea due to a lack of CO<sub>2</sub>. This is due to the fact that normally the production rates of ammonia and CO<sub>2</sub> are not independent of each other. In an idealised process of production of ammonia from pure methane (CH<sub>4</sub>), air and water, the ratio of products CO<sub>2</sub> and NH<sub>3</sub> is 1.14 t/t. In the real process, it can be lower or higher, for example depending on the natural gas composition and losses in the process.

In contrast to that, the urea plant consumes CO<sub>2</sub> and NH<sub>3</sub> in a higher ratio of approx. 1.29 t/t (0.733 t CO<sub>2</sub> / t urea and 0.566 t NH<sub>3</sub> / t urea). Thus, the first bottleneck is the lack of CO<sub>2</sub>. In order to utilise all available ammonia for urea production, extra CO<sub>2</sub> must be sourced as shown in figure 7.

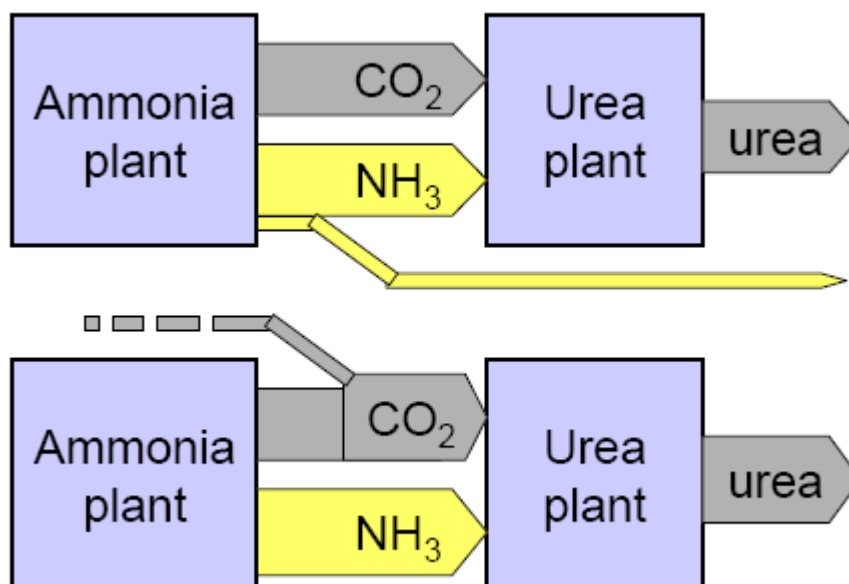


Figure: 7 NH<sub>3</sub>/CO<sub>2</sub> ratio in an ammonia / urea complex

## 4.2 Generation of Extra CO<sub>2</sub>

For the urea plant revamp discussed in the previous sections, there is an ammonia plant located nearby, which can provide additional CO<sub>2</sub>. Not every producer is in such a comfortable position, and thus must take care of its own extra CO<sub>2</sub> production.

Several possibilities exist for the generation of this extra CO<sub>2</sub>. One is an increased production in the CO<sub>2</sub> removal unit of the ammonia plant, the normal source of all CO<sub>2</sub> consumed by the urea plant. The other is to use a separate unit for collection of CO<sub>2</sub> from other CO<sub>2</sub> containing streams like flue gas.

## 4.3 CO<sub>2</sub> from the CO<sub>2</sub> Recovery Unit in the Ammonia Plant

CO<sub>2</sub> for urea production is normally generated by separation from synthesis gas in the CO<sub>2</sub> removal unit. The amount of CO<sub>2</sub> can be increased by passing more synthesis gas through this unit. Downstream of the CO<sub>2</sub> removal unit, the excess synthesis gas not needed for ammonia production is withdrawn and is sent to the reformer where it is used as fuel gas. This scheme increases the feed gas consumption of the plant and leads to a higher throughput and consequently higher duties in the front end units of desulphurisation, reforming, waste heat recovery, CO shift and CO<sub>2</sub> removal. On the other hand, the synthesis gas which is returned to the reformer as fuel reduces the natural gas used as fuel. However, there is of course a net increase of natural gas consumption. This is illustrated in figure 8.

If the additionally needed amount of CO<sub>2</sub> is small, and there is still margin in the front end units, the modifications are really small and of low cost as only a let-down for a small syngas stream to the reformer fuel gas system is needed, as shown in Figure 8. For higher amounts of CO<sub>2</sub>, additional modifications must be made in a revamp of the plant to allow for the higher duties of the said process units.

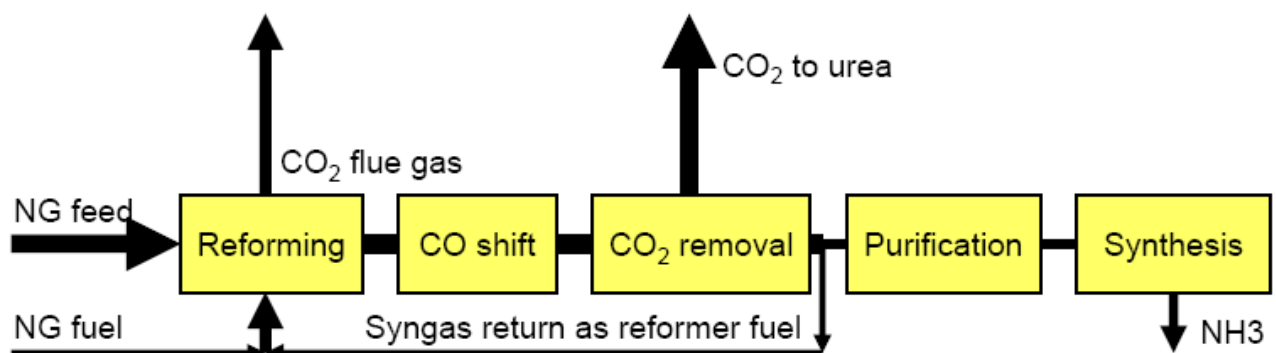


Figure: 8 Increased CO<sub>2</sub> production by increased front end flow

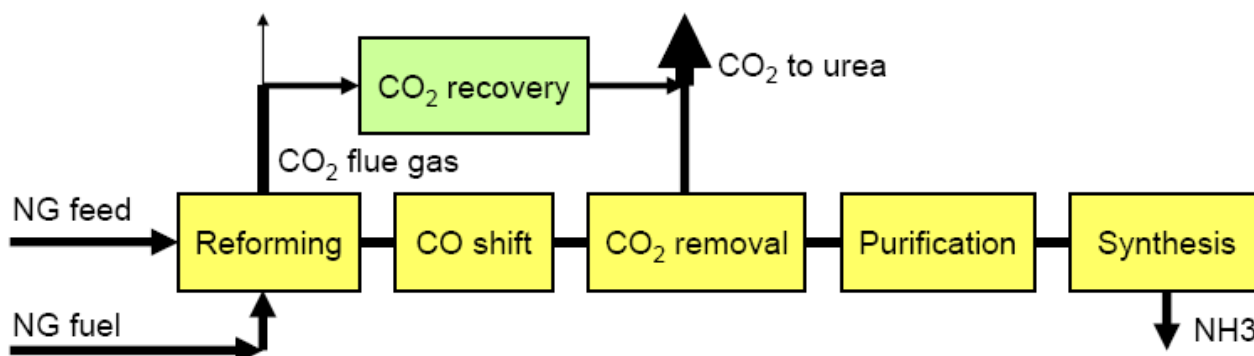


Figure: 9 Increased CO<sub>2</sub> production by recovery of CO<sub>2</sub> from flue gas

#### 4.4 Recovery of CO<sub>2</sub> from Flue Gas

High amounts of CO<sub>2</sub> are present in the flue gas from the reformer and the package boiler which make them another possible source of CO<sub>2</sub> for urea production. Several technologies exist to recover it from the flue gas stream. Same as the CO<sub>2</sub> removal from synthesis gas, also the processes applied to flue gas are based on the same principle of absorption and desorption. The recovered CO<sub>2</sub> is of good quality (no hydrogen content) and is mixed to the existing CO<sub>2</sub> stream upstream of the CO<sub>2</sub> compressor. Often amines are used as solvents here as well, but they are different in order to cope with challenges by the side components O<sub>2</sub>, NO<sub>x</sub> and SO<sub>2</sub> in the flue gas. These processes are also under investigation for separation of CO<sub>2</sub> from fossil power stations for later sequestration.

A CO<sub>2</sub> recovery unit is a separate and additional unit. It is connected to the flue gas outlet of the reformer or boiler, as shown in figure 9, but does not have many other interconnections with the rest of the plant. That makes installation of such a unit as a re-vamp an easy task.

On the other hand, the investment cost is the relatively high. Operating cost occur for steam for solvent regeneration and electric power for pumps and flue gas fans. In addition to that, there is a constant need to balance the solvent losses by addition of fresh chemicals.

	Increased ammonia plant front end	CO <sub>2</sub> recovery from flue gas
Revamp scope	Higher throughput through front end up to outlet of CO <sub>2</sub> removal unit, relatively simple plant modifications	Additional unit connected to flue gas outlet of reformer or boiler
Investment	Relatively low	Relatively high
Operation	High load in front end might bring the plant to its capacity limit	No change in existing units
Operating cost	Increase due to higher natural gas consumption	Increase due to consumption of steam, electrical power and chemicals

**Table: 1: Comparison of the two CO<sub>2</sub> generation schemes**

Table 1 lists the main characteristics of the two CO<sub>2</sub> generation processes. Both ways of CO<sub>2</sub> production have their advantages and disadvantages. The economical optimum mostly depends on the amount of CO<sub>2</sub> needed and the cost of energy, namely natural gas. For a high amount of CO<sub>2</sub> or for a site with high gas cost, the solution with the CO<sub>2</sub> recovery from flue gas is the better choice. If only a small amount of CO<sub>2</sub> is needed, or the energy price is not so critical (as it is typically the case in Arabian countries), the increased production of the front end might be favoured. Another factor which can be taken into account for the decision can be the CO<sub>2</sub> emission to the atmosphere, the “carbon footprint”. The overall CO<sub>2</sub> emission of the plant per ton of urea produced is less for the version with CO<sub>2</sub> recovery from flue gas. While this paper is on revamps of plants, it should however be noted that for a new plant also an ammonia process using autothermal reforming (ATR) is an interesting option as its syngas usually contains more CO<sub>2</sub> which is separated from it in the standard CO<sub>2</sub> removal unit, being available for urea production.

## 5 Conclusion

Concluding it can be stated that there are a lot of ways to conduct a revamp for a urea plant. An often chosen strategy for revamping is the selection of a determined process concept like the above presented MP section, which is capable to gain a certain extra capacity. This results finally in defined demands on raw materials, upstream plants and utilities such as boiler or the cooling water system.

Considering the fact that changes in one place always lead to changes in another place, makes it important to select a competent contractor, who is familiar with the up-

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stream ammonia plant, is living the cooperation with the urea licensor Stamicarbon and is very experienced in issues concerning offsites and utilities, like Uhde.

Moreover it is essential that plant owner and contractor work together in good partnership. Different from a new plant for a revamp there are many constraints set by the existing periphery.

Finally it is the contractor's obligation to complete and optimize the process design package of the licensor, which is just a part of the whole in order to provide the client a tailor-made solution.