RECONNECT SYMPOSIUM 2022
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Experiences with LAUNCH® MELT™ Flash Design

18 May 2022

Utrecht, The Netherlands

TITLE OF PAPER

Conference name	Stamicarbon Symposium 2022 – Reconnect
Conference date	16th – 19th May 2022
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Classification	Public

TABLE OF CONTENTS

1. ABSTRACT

As energy consumption of urea plants is becoming increasingly important, Stamicarbon introduced two new concepts over the past few years: the Flash Design, (former Adiabatic Flash concept) and the Ultra-Low Energy Design (previously known as 5xx). Both these designs are part of Stamicarbon's LAUNCH MELT™ series.

The Flash Design has been introduced in the market by Stamicarbon several years ago. It makes use of an in-line adiabatic flash stage that is located in between the High Pressure (HP) Stripper in the synthesis section and the Low Pressure (LP) recirculation section.

This adiabatic flash step makes it possible to optimize the HP extraction steam consumption of the plant by reducing the stripping efficiency in the synthesis without overloading the downstream sections. Furthermore, the adiabatic flash step contains a heat integration between the carbamate condensation and the (pre-)evaporation section of the plant.

This heat integration significantly reduces the LP steam demand of the evaporation section. Also, this heat integration makes it possible to achieve urea concentrations in the urea solution tank of over 80% by weight. By now, several plants with this concept are in operation, all reaching their respective design guarantees.

This paper gives some background on the concept of the Flash Design and its comparison to the Pool Condenser & Pool Reactor Designs (former Urea 2000+) and the Stamicarbon latest energy saving concept, the Ultra-Low Energy Design. From this comparison it can be observed that the Flash Design is more energy efficient than the previous standard: the Pool Condenser and Pool Reactor Designs.

However, the Ultra-Low Energy Design has a significantly lower energy consumption than the Flash Design. Based on investment cost, the Flash Design is the most economical concept due to the low amount of HP equipment and the simplicity of its design.

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2. INTRODUCTION

Some time ago, the Flash Design was introduced as a new concept for urea plants. This concept combines several existing technologies in one single concept with the goal to reduce the energy consumption as compared to a traditional CO_2 Stripping Process (also part of the LAUNCH MELT™ series), while having a CAPEX benefit. It is based on the heat integration between a pre-evaporation and a carbamate condensation at Medium Pressure (MP) level, minimizing High Pressure (HP) extraction steam consumption by optimizing the Low Pressure (LP) steam generation and consumption.

Currently, the Flash Design concept is in operation in five plants across the world in different configurations and it has been applied both as grass root (Flash Design) and revamp concept (EVOLVE Energy™).

Several plants are currently under construction with the Flash Design. This concept has become the most offered concept by Stamicarbon due to its balance between CAPEX and OPEX.

The Flash Design can be used as a revamp concept for reducing (specific) steam consumption, debottlenecking the HP Stripper, slight capacity increase and as a replacement for the HP scrubber. When applying the Flash Design in an EVOLVE Energy™ revamp, a thorough investigation of the steam system has to be made, as the HP extraction steam consumption is decreased by minimizing the LP steam export of the plant. This can only be beneficial if the LP steam export is not fully utilized or if the value of the LP export steam is significantly lower than the equivalent value of the HP extraction steam import.

3. FUNDAMENTALS OF THE FLASH DESIGN

In its thermodynamic essence, a urea synthesis consumes High Pressure (HP) steam and produces Low Pressure (LP) steam, where stripping gas is used as an intermediate medium to transfer the heat. As a rule of thumb, 1 ton of HP extraction steam generates approx. 1.2 ton saturated LP steam at a pressure of approximately 4.5 bar absolute.

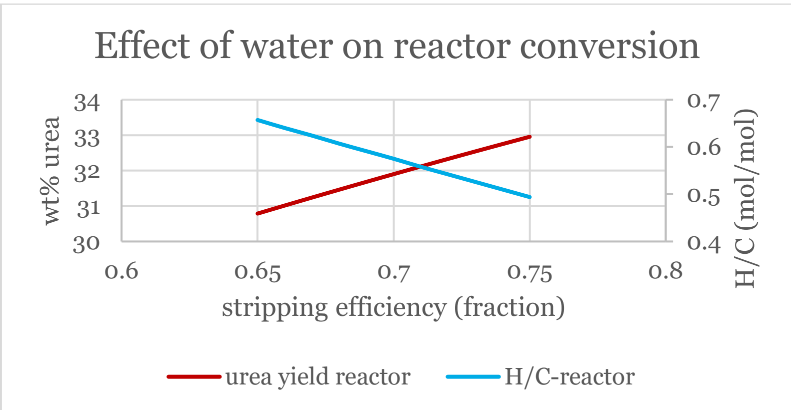
This LP steam is used in the downstream sections in the process, mainly for purification and concentration of the urea product. Excess of LP steam is typically used for:
- Admission steam for the turbine (low efficiency; condensation heat not utilized but dissipated in cooling water).
- Exported to other plants (sites with multiple plants).
- Blown-off.

The table below shows the impact on the key variables of the HP synthesis by implementation of the Flash Design in a CO_2 Stripping Process Design plant.

Reactor	**Pool Condenser Designs**	**Flash Design**	**Unit**
Fraction approach to equilibrium (FAE)	95	95	%
N/C-ratio	3.1	3.1	mol/mol
H/C	0.51	**0.61**	mol/mol
Inert pressure top reactor	7.5	7.5	vol %
Total pressure	144	144	kg/cm2
Temperature outlet reactor	182.4	182.8	ºC
Urea yield	32.9	**31.3**	wt %
Stripper			
stripping efficiency	78	**68**	%
solution temperature	173	171.5	ºC
urea yield	54	**47**	wt%

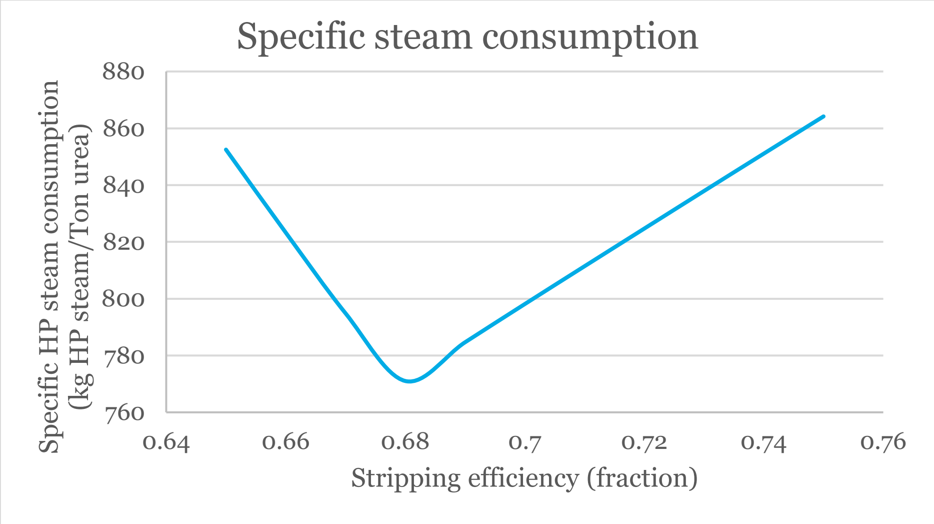
Table 1: Impact on the key variables of the HP synthesis by implementation of Flash Design in a Pool Condenser Design.

Stripping efficiency is the ammonia conversion downstream the stripper. It is calculated by considering the amount of ammonia that is converted to urea or biuret, divided by the total amount of nitrogen (all on a molar base). By decreasing the stripping efficiency from 78% to approx. 68% more carbamate is recycled back to the reactor. However, Graph. 1 below shows the detrimental effect of excess water on urea yield in the reactor.



Graph 1: effect of stripping efficiency on urea yield and H/C ratio in the reactor

Although the Flash Design reduces the overall synthesis efficiency (lower reactor yield, lower stripping efficiency), the final result on energy intake (read HP extraction steam to the HP Stripper) reduces compared to the traditional CO_2-stripping process concepts. That is what Flash Design is about: compromising synthesis efficiency in favor of minimizing net energy intake. The overall result is plotted in Graph 2 below:



Graph 2: specific steam consumption as function of stripping efficiency for a typical Pool Condenser & Pool Reactor Designs

As the optimum stripping efficiency in the Flash Design is significantly lower than in the CO2 Stripping Process Designs, a lower steam pressure on the HP Stripper shell in the Flash Design, resulting in a lower shell temperature (by some 10°C). This lower shell temperature will reduce passive corrosion in the HP Stripper, leading to a significant increase of lifetime for the HP Stripper.

4. ANALYSIS OF LOW PRESSURE (LP) STEAM BALANCE IN THE FLASH DESIGN

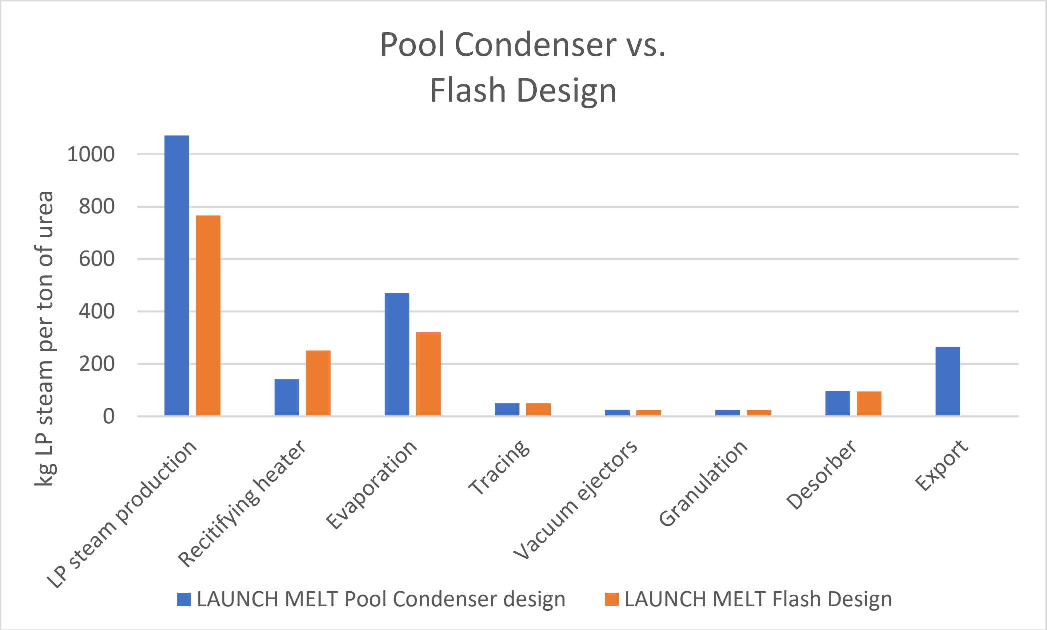
It is clear from the previous section that the Flash Design is based on optimization of Low Pressure (LP) steam production and consumption. In case the production of LP steam exceeds the demand of the plant, LP steam will be discharged from the plant. This is the case for traditional CO_2 stripping plant designs.

The exported LP steam can be used for several purposes but in practice it is often vented. In case the value of the LP steam export is significantly lower than the equivalent value of High Pressure (HP) steam, it is beneficial to decrease the HP steam consumption by decreasing the LP steam export.

In traditional CO_2 stripping plant designs there are two High Pressure (HP) extraction steam consumers from which the HP Stripper is by far the largest one. HP extraction steam consumption of the HP Stripper can be reduced by lowering the stripping efficiency. A decreased stripping efficiency means that less carbamate is dissociated in the HP Stripper and consequently less stripped vapor is generated.

Thus, the required heat duty in the HP pool condenser/reactor in the HP synthesis section is decreased resulting in a smaller tube bundle size and a smaller LP steam generation. As a consequence, the reduced stripping efficiency will lead to an increased load to the downstream sections that increases the LP steam consumption in the rectifying heater despite the introduction of the adiabatic flash step in between the HP Stripper and the LP section.

However, the increase of LP steam demand on the LP recirculation heater is compensated by using the condensation heat from flashed vapor from the adiabatic flash step to pre-concentrate the urea solution. As a consequence, less LP steam is needed to concentrate the urea solution to its desired concentration, which is key to save LP steam.



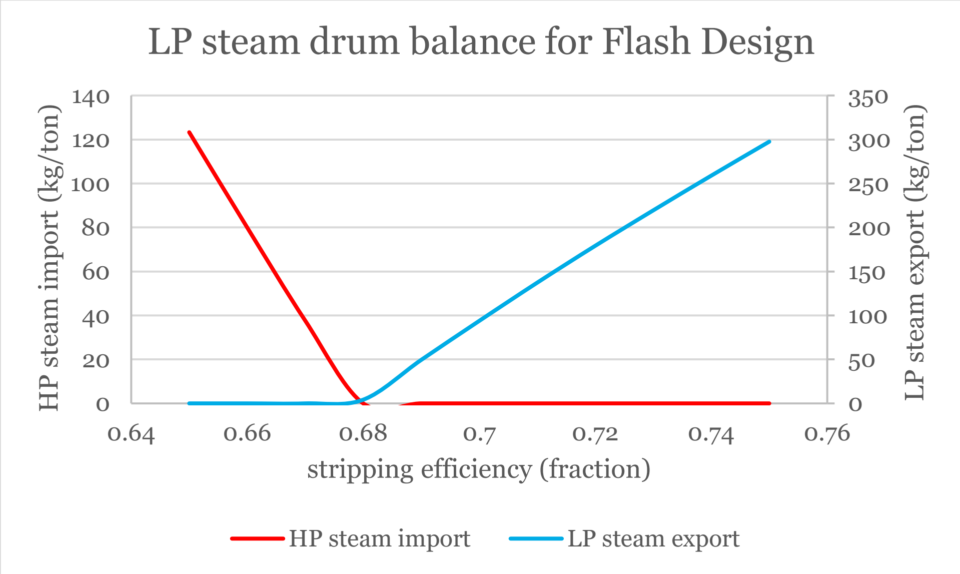
Graph 3. Overview of steam consumers in a urea plant

In the graph 3 above, a comparison of the specific LP steam production or consumption (depending on the equipment considered) between the Flash Design and the Pool Condenser is illustrated.

In the Flash Design, the specific LP steam consumption of the evaporation is lower, due to the heat integration with the pre-evaporator. The specific LP steam consumption of the rectifying heater has increased compared to the Pool Condenser Design caused by a lower stripping efficiency.

The overall result of the Flash Design is that less LP steam is produced in the HP pool condenser/ reactor and thus a minimum amount of LP steam is exported in favor of a reduction in the HP extraction steam import. This is especially interesting in case LP steam consumers are limited or venting is restricted.

When the LP steam export becomes negative and the stripping efficiency is further reduced, HP steam shall be imported to the LP steam drum in order to satisfy the demand on all LP steam users in the urea plant itself. This is not a desired operation. Therefore the optimum stripping efficiency to be applied for a Flash Design is a minimum LP steam export, as can be seen in graph 4 on the next page.



Graph 4. LP steam export vs HP extraction steam import on LP steam drum

In case the Flash Design is used to revamp an existing CO_2 stripping plant, the steam balance has to be assessed. If the produced LP steam export is utilized, it has to be considered to which extent the LP steam export can be reduced. In case the LP steam is used in the turbine of the CO_2 compressor or if the LP steam export is discharged to a site network, reducing the LP steam export to a minimum will reduce the steam consumption of the urea plant itself, but the optimal stripping efficiency might be higher considering the steam balance of the complete plant site.

5. VARIATIONS IN THE FLASH DESIGN

There are two possible basic variations of the Flash Design: The Adiabatic flash step can be designed either with or without using the off gases from the High Pressure (HP) synthesis. In practice, when the off gases from the HP reactor are discharged to the Adiabatic flash step, the usually applied HP scrubber is no longer required in the HP synthesis section. This makes the Flash Design an attractive revamp alternative when the HP scrubber of an existing plant is at its end of life.

Apart from the benefit of reduced steam consumption, this will also bring down the number of pieces of HP equipment of the HP synthesis section as both the HP scrubber and the HP ejector become obsolete. Moreover, the amount of required HP piping is consequently reduced.
Another advantage of having the off gas of the HP reactor in the synthesis section going to the Adiabatic flash stage is the fact that the NH_3/CO_2 molar ratio of the released off gas is relatively high. The off gas from the Adiabatic flash itself is relatively rich in CO_2, leading to a very low NH_3/CO_2 ratio.

In case the ammonia rich off vapor of the HP reactor in the synthesis is discharged to the Adiabatic flash step, this vapor corrects the NH_3/CO_2 ratio favoring the carbamate condensation in the shell side of the pre-evaporator possible resulting in a high carbamate temperature. Such high carbamate temperature allows to concentrate the urea solution in the pre-evaporator up to 80 % by weight without the appearance of pinching symptoms.

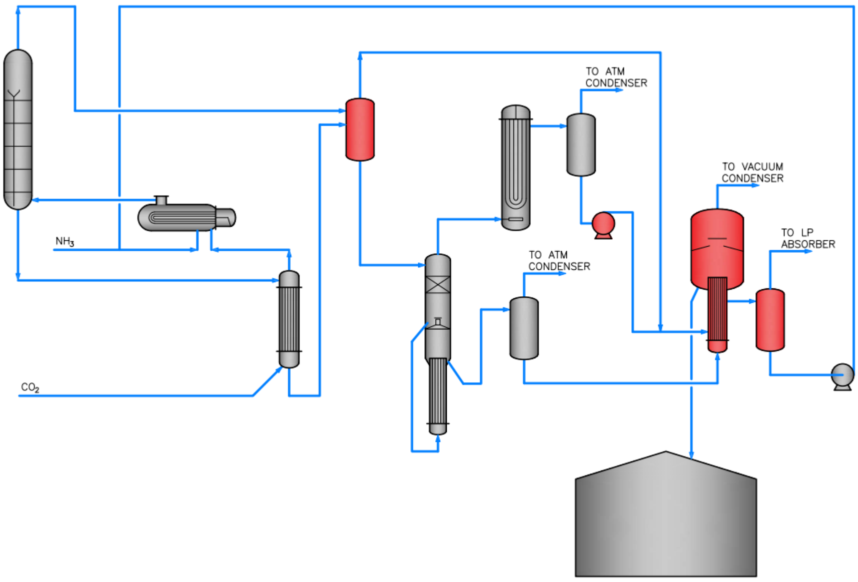


Figure 1: Flash Design scheme without HP scrubber.

It is also possible to design the Flash Design including a HP scrubber in the HP synthesis. In that case, the inert off gas leaving the synthesis is further purified as per the current Stamicarbon standard in a LP absorber before it is released into the atmosphere.

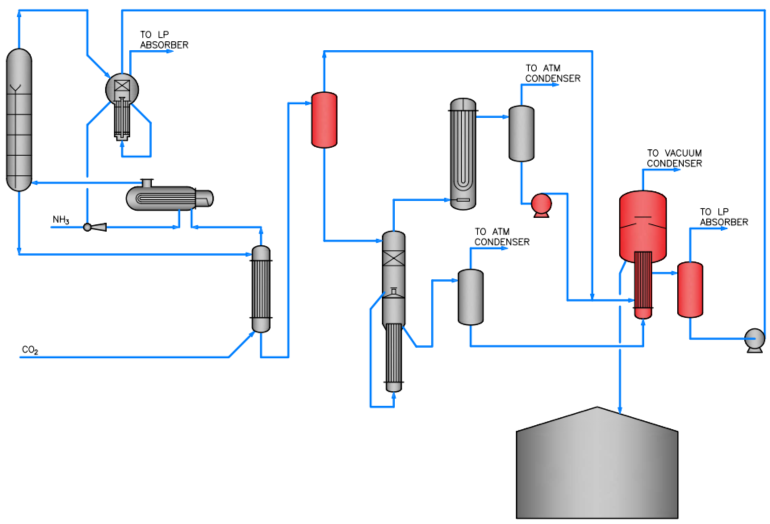


Figure 2: The Flash Design scheme with HP scrubber

In certain cases when the Flash Design is applied in a revamp in which the synthesis section is equipped with a HP scrubber, the off gas from the adiabatic flash step contains a relative low amount of ammonia.

In order to prevent the NH_3/CO_2 ratio of this gas becoming too low and thus the NH_3/CO_2 ratio in the shell side of the pre-evaporator, urea solution from the HP reactor can be partly by-passing the HP Stripper and can be directly added to the adiabatic flash step. This will provide for additional ammonia in the flashed vapor leaving the adiabatic flash step and it will unload the HP Stripper.

Since the tube load in the HP stripper is a typical bottleneck in a CO_2 stripping plant, installing a bypass over it will allow for a higher plant load. In case the tube load of the HP Stripper is limiting the plant capacity, installing a bypass increases the plant capacity by around 5-10%.

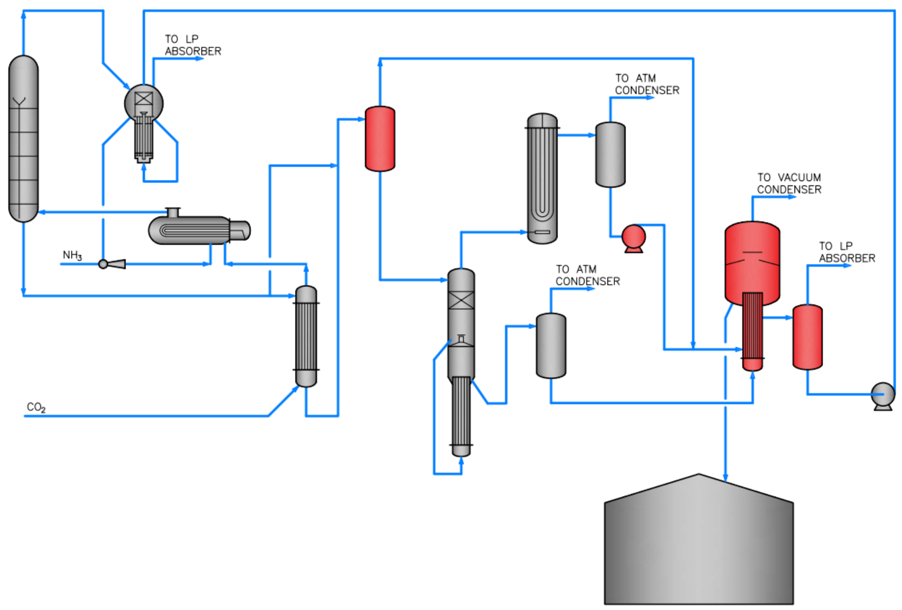


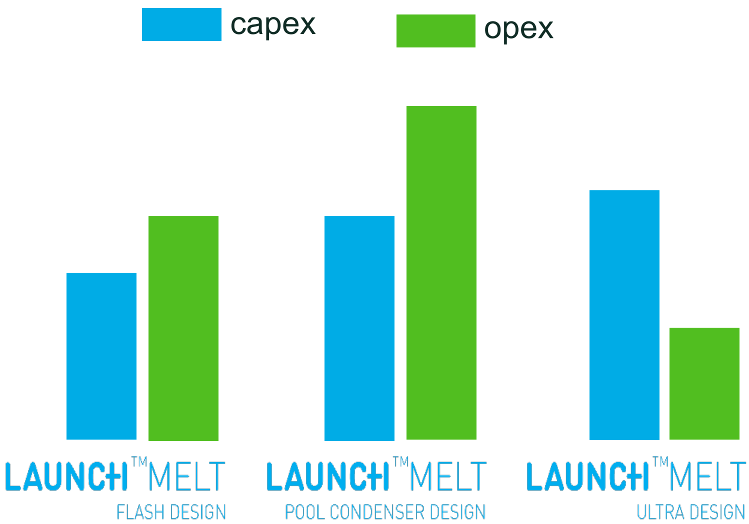
Figure 3: The Flash Design scheme with HP scrubber and partly by-passing the HP Stripper

6. CAPEX AND OPEX COMPARISON

Apart of the Flash Design, there are other commonly used concepts by Stamicarbon: the Pool Condenser and Pool Reactor Designs (former Urea 2000+ concept) and the Ultra-Low Energy Design (former 5xx concept). When making a comparison between these process concepts at the same design capacity, it is obvious that the OPEX (expressed in High Pressure (HP) extraction steam consumption) of the Flash Design is significantly lower as compared to the Pool Condenser and Pool Reactor Designs (typically about 870 kg/ton[1)]). The Ultra-Low Energy Design however makes use of further heat integration and has therefore a lower OPEX expressed as HP extraction steam as compared to the Flash Design (typically some 560 kg/ton[1)]).

Considering the ISBL CAPEX however, the Flash Design is lower than both the Pool Condenser and Pool Reactor Designs, due to the fact that less HP equipment is involved; and that the Ultra-Low Energy Design since less Medium Pressure (MP) equipment is used.

1) *Mentioned steam consumption figures consider HP extraction steam of 330°C and 23 kg/cm2-a)*



Graph 5. CAPEX and OPEX comparison

7. OPERATIONAL EXPERIENCES WITH THE FLASH DESIGN

There are currently five plants in operation that apply the Flash Design from which two are revamped.

CLIENT	YEAR IN OPERATION	DESIGN CAPACITY [MTPD]	GRASS ROOT / REVAMP	SCRUBBER YES/NO	STEAM CONSUMPTION
Linggu, PR China	2015	2700	Grass root	Yes	710 kg/ton
Nutrien, TX, USA	2017	1800	Grass root	No	760 kg/ton
KOCH, OK, USA	2017	2200	Grass root	No	
XLX, PR China	2017	2*1530	Revamp	Yes	-76 kg/ton (saving)
OCI, the Netherlands	2019		Revamp	Yes	

Table 2: overview of Flash Design plants in operation (HP steam consumption normalized at 330°C and 23 kg/cm²-a)

As it can be seen in table 2 above, the Flash Design is applied in both grass root plants and as a revamp concept. In a grass root, the concept gives the benefit of a lower High Pressure (HP) steam consumption and thus a lower OPEX in combination with a reduced number of HP equipment and thus a lower CAPEX. In a grass root plant design, the HP steam saving potential can be fully utilized as the LP steam export is minimized as a design parameter. This results in a proven specific HP steam consumption figure as low as 710 kg HP steam/ton urea for grassroots, while in revamp cases a 10-15% reduction of specific HP steam can be expected.

The plants in operation all show the same operational benefits as compared to typical CO_2 stripping plants, being that disturbances in the synthesis are partly mitigated before impacting the LP section due to the presence of the Adiabatic Flash vessel. In the Adiabatic Flash vessel, vapor from the flash is sent to the pre-evaporator condenser, leaving the disturbance on the downstream LP section to a minimum. Therefore, changes in reactor N/C ratio, stripping efficiency, plant load etc. have a reduced impact on the LP section.

In case the Flash Design is applied without the presence of a HP Scrubber, the operational benefit of the lower number of HP equipment is noticeable. Operation of a synthesis without HP Scrubber reduces the number of variables to be controlled, therefore increasing the ease of operation.

8. CONCLUSIONS

The Flash Design as introduced by Stamicarbon some years ago is now successfully in operation in several plants across the world, both grass roots and revamps, and proved its potential to optimize urea plant operations. In both cases, the operation of the plant has become more simple due to the dampening effect of the adiabatic flash step, mitigating upsets from the synthesis section. In case the design without HP scrubber is applied, the operability of the plant is improved due to the lower amount of variables to be controlled in the synthesis. The specific High Pressure (HP) extraction steam consumption has proved to be as low as 710 kg HP steam/ton urea; while the typical reference value for the Pool Condenser and Pool Reactor Designs is around 870 kg HP steam/ton urea. The HP steam saving demonstrated in revamp projects is around 75 kg HP steam/ton urea.

Regarding the OPEX expressed in HP extraction steam consumption, the Flash Design comes in between the standard Pool Condenser and Pool Reactor Designs and the Ultra-Low Energy Design. When taking investment cost into consideration, the Flash Design is the most economical concept available. The Flash Design is therefore considered as the optimum balance between CAPEX and OPEX.

Another benefit of the Flash Design is the lower shell temperature of the HP Stripper, which reduces the passive corrosion and therefore increases the lifetime of the Stripper.

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