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UPGRADING A BRAUN 1500 STD SYNLOOP FOR CAPACITY INCREASE AND ENERGY SAVINGS: CASE HISTORY

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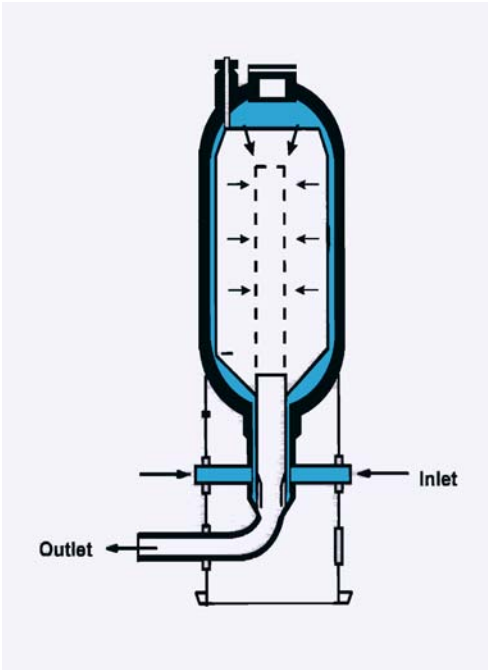

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ABSTRACT

In 1994 a contract was awarded by Arcadian (now PCS) to Ammonia Casale to install axial-radial internals in their multi-vessel ammonia converters. The project was part of an expansion to 2000 short tons/day. The plant, located in Augusta, Georgia, USA was the first to use the Casale concept in Braun ammonia converters. The project was implemented jointly by PCS, Ammonia Casale and Brown & Root. Under PCS management, Ammonia Casale performed the basic engineering for the loop revamping and supplied the technology and materials for the new reactor internals. Brown & Root performed detailed engineering for the whole project, which included other loop modifications plus modifications to the front end of the ammonia plant.

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INTRODUCTION

Background

PCS Nitrogen operates a nitrogen fertilizer complex at Augusta, Georgia, USA. The ammonia unit was commissioned in 1978 with a nameplate capacity of 1500 st/d. Designed by C F Braun & Co, since acquired by Brown & Root, it uses the Braun Purifier Process. The complex became part of Arcadian Corporation in 1989. Arcadian was acquired by the Potash Corporation of Saskatchewan (PCS) in March 1997. PCS Nitrogen is the largest producer of nitrogen-based fertilizer and chemicals in the Western Hemisphere.

In the fall of 1996 the ammonia plant was restarted following the completion of a revamp project. A major part of the project was the installation of Ammonia Casale axial-radial internals in the multi-vessel ammonia converters. The plant in Augusta was the first to use the Casale concept in Brown & Root ammonia converters. The project was part of an expansion to 2000 st/d. Details of the revamp of the balance of the plant are discussed in another paper. [(1)] This paper focuses on the debottleneck of the synthesis loop. It discusses the original design, the revamped design, and presents a comparison of the performance before and after the revamp.

Original Design

Figure 1 shows the original flow scheme for the synloop. Since the loop makeup gas is cryogenically purified, it is dry and following compression is fed directly to the synthesis converters. The synthesis loop uses two adiabatic synthesis converters in series of Brown & Root design. All heat exchange is external to the converters. No quench is used.

Figure 2 shows more detail of the original flow scheme through the converters and associated exchangers, along with typical temperatures and the mode of control. The first converter effluent preheated first converter feed. After passing through the second converter, reaction heat was recovered by producing 100 bar (1500 psi) steam in a forced-circulation boiler.

Figure 3 shows the flow pattern through the original synthesis converters. The converter internals were simple, consisting of a fixed catalyst hopper. There are no removable internals, thus only a manway on the vessel top for access. From the two inlets, gas flowed upward through the annular space between the catalyst hopper and the vessel wall. On reaching the top of the open catalyst bed, gas flowed down axially and exited through a gas collector at the bottom of the bed followed by a concentric outlet pipe. Except for the area around the gas collector, the flow was axial. The two synthesis converters were similar in design, although the second converter held a larger volume of catalyst. The catalyst size was 6-10 mm for the bulk of the beds. Around the gas collector, it was 12-20 mm.

By 1994, the original charge of synthesis converter catalyst was showing some signs of age. The charge had been in service for 15 years and some pressure drop increase was noted in the first converter, along with some deactivation at the top of the bed. The second converter temperature rise had increased, while the first converter temperature rise had decreased. This showed some shift in conversion from the first to second converters. Overall loop performance was still good. The loop could make up to 1837 tpd, well above its 1500 tpd design. PCS Nitrogen believed the catalyst would continue to perform well through the planned 1995 turnaround, but was concerned about possible operation through the next planned turnaround in 1998.

Scope of Work

PCS Nitrogen approached both Ammonia Casale and Brown & Root about the opportunity to upgrade the synthesis converters while replacing catalyst. The vessels had never been entered before, and with catalyst life being 15-20 years, this was a rare opportunity. The goals were twofold: first, to save energy by increasing conversion, and second, to increase loop capacity to at least 2000 tpd.

In 1994 PCS awarded contracts to, and took out licenses from both Casale and Brown & Root for their respective parts of the revamp project. The project was successfully executed by Casale, Brown & Root and PCS Nitrogen, all under PCS management. Casale provided the process design for the synloop, design and procurement of the converter internals, and supervision of the installation of the internals and catalyst loading. Brown & Root provided the design of a new high pressure steam generator, modifications to the existing interbed exchanger, and detailed design services for the loop including piping and foundations. PCS Nitrogen provided procurement, inspection, construction supervision, and installed the instrumentation.

PROCESS DESIGN FEATURES

In order for PCS to obtain the expected benefits from this synthesis loop revamp, two key process design areas required special attention. These areas were the design of the new internals for the converters and the design of the converter inlet temperature control system. Each of these features and their benefits is discussed in this section of the paper.

Converter Internals

The proposed project called for the converters to be revamped to the Casale axial-radial pattern. There are several advantages that can be obtained from this modification such as:

- lower bed pressure drop as a result of the axial-radial flow pattern
- the use of smaller size, more active catalyst instead of the large size one, leading to an increase in conversion per pass
- better thermodynamic design when quench cooling is replaced with indirect heat exchange

- a higher installed catalyst volume due to the improved mechanical and fluid dynamic design.

All these advantages lead to a considerable energy saving and capacity increase. These advantages range from one million Btu per short ton to allowing for large increases in capacity, or some combination of both. The capacity increase results from the reduction in the circulating flow, about 30 percent, that in turn reduces the load on all loop equipment.

The most important feature of the modification to the converters was the use of the smaller, more active catalyst. Smaller sized catalyst is more active at a lower inlet temperature. With lower converter inlet temperatures an increase of the conversion per pass is possible. This results in a consequent reduction in loop circulating flow rate, which reduces the loop operating pressure and loop pressure drop. This benefit was key to meeting PCS's goals for the revamp.

Converter Temperature Control

In order to obtain full benefit of the low temperature activity of the smaller catalyst, a design was needed to meet the new, lower inlet converter temperatures. The existing process design could not do this. All three companies involved in the revamp recognized this need from the outset of this project. The reasons why the required low inlet temperatures could not be reached are subtle and explained in detail in Section IV of this paper. The lower operating temperature has the consequence that additional heat must be removed from the synthesis loop. This was done by generating high pressure steam in a new boiler. This addition and the better performance of the converters gave as a consequence also a considerable increase in the heat recovered, and therefore in the quantity of steam generated.

Revamped Process Design

As a result of the new axial-radial internals and temperature control requirement, a revised flow scheme was developed for the loop. This scheme is illustrated on Figure 4. The main differences are that inlet temperatures have been reduced by 55 °C and 35 °C to the two converters. A new steam generator has also been installed to cool the feed to the second synthesis converter.

CONVERTER REVAMP

This section of the paper discusses the execution of the revamp project pertaining to the synthesis converters.

History of Revamps

The revamping of the two converters has been done according to the "In Situ" modification technology. This concept was introduced by Ammonia Casale in 1985 to revamp ammonia converters such as the standard Kellogg design for more capacity. Casale's first axial-radial revamp was placed on stream in 1986 for CF Industries.

Since this first installation, the Casale concept has been applied to different types of ammonia converters and also to shift and methanol reactors. It consists mainly in modifying the existing cartridge or transforming the existing axial bed into axial-radial beds. In some cases also the existing gas cooling system between beds is modified from quench to indirect heat exchange. The number of beds in the converter may also be modified.

The revamping of Braun-type converters was studied and proposed by Ammonia Casale immediately after the start up of the retrofitted Kellogg converters. It is a logical additional application of the proven Casale in situ retrofitting technology. But its first industrial application took place only in 1996 with the PCS Nitrogen project.

Catalyst Beds

For the PCS revamp, the configuration selected for the catalyst beds is typical of Casale axial-radial designs. With axial-radial distribution, most of the gas passes through the catalyst bed in a radial direction. The balance passes through a top layer of catalyst in an axial direction, thus eliminating the need for a top cover on the catalyst beds. This is illustrated in Figure 5. This feature is an essential factor for an easy and simple design of new converter internals.

To get a uniform gas flow through the bed some pressure drop must be provided across the perforated walls that distribute the incoming and receive the outgoing gas. The design provides for the correct pressure drop along the length of the catalyst bed. This is to ensure that the gas flow pattern is controlled by the design and it is not affected by possible non-uniform catalyst packing density.

A particular feature of the design is its simplicity. The catalyst-containing baskets are easily handled and have a low cost.

The axial-radial bed provides the best possible use of the catalyst volume available with the lowest possible total pressure drop, and is simple and flexible and can match most geometries and process conditions.

Mechanical Aspects

The "In Situ" modification of the two converters in PCS Nitrogen consisted in the removal of most of the existing internals and the installation of a new radial basket in each converter. The original internals that were removed are shown of Figure 3 and include the following.

- the vertical hopper wall containing the catalyst
- the outlet gas collector
- the thermowells
- the large sized catalyst

The bottom pieces of the existing catalyst hopper and the exit nozzle were left in place. The new axial radial bed was then installed by introducing two cylindrical perforated walls. These walls are made in sectors to distribute the gas in the catalyst with the new flow pattern. The two walls consist of one external wall near the pressure shell, welded on the external edge of the existing hopper bottom, and one internal wall close to the converter axis. A sketch of the new radial basket is shown on Figure 6.

The new parts had to be introduced through the existing manhole, without modifying the existing high pressure shell. This meant the perforated outer wall had to be divided in to prefabricated panels to be assembled inside the converter by welding. Both perforated walls are then secured to the existing converter bottom by welding.

Of course no welding was allowed on the existing high pressure parts. The welding between new and old internals was done with a special procedure to take into consideration that the old parts were nitrided and permeated with hydrogen. The technology necessary for these mechanical aspects is the same that was developed and applied successfully for the revamping of the Kellogg-type converters.

MODIFICATIONS TO SYNLOOP HEAT EXCHANGERS

This section of the paper discusses the technical aspects, scope and execution of the detailed engineering part of the synthesis loop revamp project. In particular we discuss the need for the new steam generator for controlling the inlet temperature of the first converter.

Original Heat Exchanger System

Figure 2 depicts the original process scheme for the synthesis loop. There are two adiabatic ammonia converters separated by an interbed heat exchanger. There is also a steam generator downstream of the second ammonia converter followed by the synloop feed/effluent heat exchanger. The inlet temperature to both reactors was designed for about 400 °C. Control of the inlet temperature to the first converter is through bypass of feed around the interbed exchanger. Second converter inlet temperature is controlled through bypassing its effluent around the steam generator.

Ideally the two reactors should be operated at the lowest possible inlet temperature that will still permit an outlet composition close to equilibrium, while maintaining maximum high pressure steam production. By operating this way, ammonia production and heat recovery are maximized while synthesis loop pressure is minimized. These more relaxed synthesis conditions have the disadvantage of requiring more catalyst volume as the kinetics of the synthesis reaction are slower at the lower operating temperatures. But this was not a problem for PCS as their original reactors were conservatively sized. Also, revamping the converter internals to radial flow allows the use of smaller particle size catalyst, which is more active and helps to overcome the slower kinetics at the reduced reactor inlet temperatures. To make the synloop revamp work the converter inlet temperatures needed to be lowered to about 350 °C. As discussed in the paragraphs below, it was not possible to reduce the converter inlet temperatures to this level without sacrificing efficiency. A new exchanger is required.

Heat Exchanger Analysis

To understand why it was not possible to lower the converter inlet temperatures with the original equipment it is helpful to follow the reaction paths shown on Figure 7. This figure shows the equilibrium ammonia concentration at 175 bar-g as a function of temperature. It also shows the "reaction paths" that the synthesis gas follows as it is heated, reacted and cooled in the equipment shown on Figure 2.

Reaction paths for the original design are shown by the solid line. Feed to the interbed exchanger is heated from point 'A' at 280 °C to point 'B' at 400 °C. It then flows through the first converter where ammonia concentration increases from about three to twelve volume percent and the temperature rises adiabatically to about 520 °C. First converter effluent is cooled by exchange with its feed in the interbed exchanger along path CD to 400 °C. A key point is that the amount of this cooling is, of course, necessarily equal to the amount of heating of the feed in the interbed exchanger. In other words, the length of paths AB and CD must be equal. Thus the temperature decrease of the first converter effluent is equal to the temperature increase of the reactor feed. Both are about 120 °C. The syngas then enters the second converter where ammonia concentration rises from twelve to about sixteen percent and the temperature rises adiabatically to about 480 °C.

Now let's see what happens if we open the bypass around the interbed exchanger and close the bypass around the steam generator. This operation is illustrated on the dotted lines on Figure 7. Since the temperature of the saturated steam produced in the steam generator is 314 °C, the lowest syngas outlet temperature we can hope for from this exchanger is 315 °C. In this ideal case, the temperature of the feed to the interbed exchanger would fall to about 265 °C. The temperature rise in the interbed exchanger, represented by path 'ab' will be 85 °C, to give a first converter inlet temperature of 350 °C. But now the cooling of first converter effluent is limited to a temperature range of 85 °C, which will bring it down to only about 425 °C along path 'cd'. The resulting ammonia production from the second converter is limited. The overall ammonia production rises only slightly as can be seen from the difference in ammonia concentration represented by points 'F' and 'f'.

We cannot efficiently reach the low inlet temperature to the second converter required to make the revamp work. This inlet temperature could be lowered at the expense of increased inlet temperature to the first converter. The lowest inlet temperatures attainable simultaneously for both converters are in the range of 380 to 390 °C.

There is another way to lower the inlet temperatures further. The bypass around the synloop feed/effluent exchanger can be opened to further cool the feed to the shell side of the interbed exchanger. But opening this bypass will reduce high pressure steam generation and increase the amount of heat rejected to cooling water. As explained in a patent by Grotz [(2)], an efficient situation cannot be realized with PCS Nitrogen's original scheme. To achieve the capacity goal of the revamp project an additional heat exchanger is needed between the interbed exchanger and the second converter.

Revamped Heat Exchanger System

The benefit provided by the new exchanger can be understood by following the reaction path plotted on Figure 8. Feed to the first converter is heated in the interbed exchanger along path 'AB' from 290 °C to 350 °C. First converter effluent is cooled in the same exchanger along path 'CD' from 500 °C to 440 °C. The new synloop steam generator then cools this effluent further to about 370 °C along path 'DE' shown by the dotted line. In this scheme the second converter can reach nineteen percent ammonia concentration as shown by point 'F'.

Engineering Features

Brown & Root took Casale's process design for the synthesis loop and provided a thermal design for the new high pressure steam generator. This exchanger uses the Brown & Root forced circulation system and is illustrated on Figure 9. Boiler feed water is pumped through the u-tubes where about 20 to 25 percent of it vaporizes. The hot syngas enters on the shell side and is cooled before it reaches the tube sheet. Because of the simplicity of the design a wide variety of vendors can fabricate this exchanger. Accordingly, bids were solicited from about ten vendors. The purchase order was approved and fabrication begun. Unfortunately during the fabrication the vendor misdrilled the tube sheet and had to start over again. This caused a schedule delay in shipping the exchanger.

The reduced duty for the interbed exchanger caused a minor surprise during the engineering effort. When the final process conditions were established, we discovered that the amount of flow required through the exchanger was very low. The majority of the flow had to be bypassed around the cold side to control first converter inlet temperature at 350 °C, and as a result the temperature rise of the syngas flowing through the exchanger was too high. It would have exceeded the design temperature. The existing tube bundle was modified to reduce the heat transfer in the interbed exchanger.

Other engineering features were rather routine. The control valve in the bypass line around the original steam generator was replaced with a manual valve. It is used during startup to speed heat up of the synloop. New piping was designed for the runs between the new steam generator and the interbed exchanger and second converter. An external bypass is provided around the new steam generator to control the inlet temperature to the second converter. The existing control valve was reused in this new line. A foundation was designed for the new steam generator.

OTHER SYNTHESIS SECTION MODIFICATIONS

In addition to the converter revamp and new high pressure steam generator described in the previous sections, two other modifications were made to the synloop and refrigeration system. These were the following.

High Pressure Separator

The vanes in the high pressure ammonia separator were changed to add capacity. Although the vapor flow to the separator would be less than 10% above original 1500 stpd design, the lower loop pressure would result in higher velocities in the separator. Also the design liquid flow of ammonia would increase by about 33 percent over the original design rate. The vanes were replaced to add about 50 percent more area. The high pressure shell was not modified.

Refrigeration Condenser

A shell was added to the ammonia refrigeration condenser. The existing condenser consisted of two shells in parallel. A third shell was added with provision to take one out of service at a time for cleaning. This allows for cleaning without having to wait for a maintenance turnaround. The reason we made this modification was that experience had shown that at high capacity on hot summer days, the ammonia refrigeration condenser was a bottleneck.

PERFORMANCE RESULTS

The ammonia unit was restarted after the outage in early October 1996. Pre-reduced catalyst was used in the first converter, so the catalyst reduction went quickly. As soon as the first converter catalyst was reduced, the plant was able to make original nameplate capacity of 1500 st/d. As the reduction of the second converter proceeded, the synloop settled out at a very low pressure. This was evidence of the improved conversion in the reactors.

As the front end of the plant was lined out, rates were gradually increased. The unit averaged over 2000 st/d for the month of November 1996. Cold weather allowed the plant to reach 2100 st/d for brief periods. In February 1997, a set of plant data was taken to evaluate the performance of the entire plant. The production rate was 2085 st/d. Table 1 compares before and after plant data with the 2000 st/d design.

The synloop performance was excellent. At rates above design, conversion was near design at pressures below design. The synconverters met all performance guarantees, and operating conditions suggest the converters and loop can handle additional capacity without further modification.

REFERENCES

1. Keith Wilson, Michael Crowley and Mukund Bhakta, "Maximizing Ammonia Production", presented at the 1998 AIChE Ammonia Safety Symposium, Charleston, SC

2. U S Patent Number 4,867,959, "Process for synthesizing Ammonia", Bernard J. Grotz, assigned to Santa Fe Braun Inc, Alhambra, CA

Table 1: Comparison of Synthesis Loop Parameters of Before and After Revamp with Revamp Design.

Parameter	Before Revamp	After Revamp	Design
Date	22 Sept 1993	19 Feb 1997	1994
Ammonia Capacity	1482 mtd (1634 std)	1891 mtd (2085 std)	1814 mtd (2000 std)
Recycle Discharge pressure	190 bar (2770 psig)	168 bar (2443psig)	176 bar (2550 psig)
First Converter inlet inerts	4.1 %	4.0 %	4.3 %
First Converter inlet ammonia	3.3 %	2.8 %	3.2 %
First Converter inlet temperature	397 C (747 F)	346 C (655 F)	353 C (668 F)
First Converter temperature rise	100 C (180 F)	155 C (279 F)	155 C (278 F)
Second Converter inlet ammonia	9.4 %	12.6%	13.1%
Second converter inlet temp.	390 C (734 F)	364 C (687F)	370 C (698 F)
Second converter temperature rise	93 C (167 F)	91 C (163F)	85 C (153 F)
Second Converter outlet ammonia	15.7 %	19.1%	19.3%
Loop pressure drop	15.2 bar (220 psi)	11.1 bar (161 psi)	10.3 bar (149 psi)