Woodward, OK Ammonia Converter Revamp: More Efficiency and Reliability through Innovation

With many ammonia plants already stretched to capacities in excess of 150% of their original nameplate, many are contemplating an ammonia converter revamp as part of the next evolution in increasing their production capability. For many, such projects are a once in a career event, and there is much that can be gained from sharing the details of ammonia converter projects that have already been completed successfully. An excellent example of such a project was completed at the CF Industries plant in Woodward, Oklahoma in early 2009. This plant's attention to safety, diligent planning process, and close working relationship with their technology provider and catalyst supplier ensured the safety and success of this project.

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Introduction

With many ammonia plants already stretched to capacities in excess of 150% of their original nameplate, many plants are contemplating or in the nascent planning stages of an ammonia converter retrofit as part of the next evolution in increasing their production capability. For many, such projects are a once in a career event, and there is much that can be gained from sharing the details of ammonia converter projects that have already been completed successfully. An excellent example of such a project was completed at the CF Industries (formerly Terra Industries) plant in Woodward, Oklahoma in early 2009. This plant's attention to safety, diligent planning process and close working relationship with their technology provider and catalyst supplier ensured the safety and success of this project. After nearly two years on stream, operating data verifies the achievements of this project.

In 2009, Terra Industries replaced the internals and catalyst of the ammonia synthesis converter in its Woodward, Oklahoma plant. The new cartridge and catalyst were selected with the goals of improving the efficiency of the synthesis loop and increasing the converter reliability. These two goals were achieved by adopting a better design for the cartridge and by using a high-activity synthesis catalyst. The new cartridge process design is provided by Ammonia Casale and is a well proven one, featuring three catalyst beds with one quench and one interchanger for inter-cooling, in which the latest mechanical design for the catalyst basket walls has been applied.

The catalyst chosen is AmoMax®-10, which is a wustite-based iron oxide catalyst with benefits including higher low temperature activity, superior mechanical strength, lower light-off temperatures, reduced reduction time, and less reduction water make as compared with magnetite-based iron oxide catalysts. These proven benefits have been well demonstrated at CF Industries' Woodward, Oklahoma plant.

In addition to discussing the technology and catalyst utilized, this paper will also discuss the results obtained as well as the project itself. This will include a discussion on the project scope, planning timeline, project milestones and challenges, and safety related topics including specific inspection techniques employed.

Ammonia Converter

The ammonia converter at the Woodward plant has a full-bore opening vessel design, and it was revamped by replacing the old cartridge with a new one. The new cartridge is a 3-bed, axial-radial design by Ammonia Casale. This design offers numerous advantages including:

- higher plant efficiency,
- simplified maintenance,
- simplified catalyst replacement,
- and increased reliability.

Design Overview

The design of the Woodward ammonia converter cartridge consists of three adiabatic, axial-radial beds with intermediate cooling by quench after first bed and by heat exchange after second bed. The cartridge also has inlet-outlet heat exchanger after the third bed. Figure 1 provides 3-D rendering of the new Casale cartridge installed at the Woodward plant.

Figure 1. New Casale cartridge

The catalyst beds used in the current Woodward design are based on the well-known Casale axial-radial technology, which is demonstrated graphically in Figure 2.

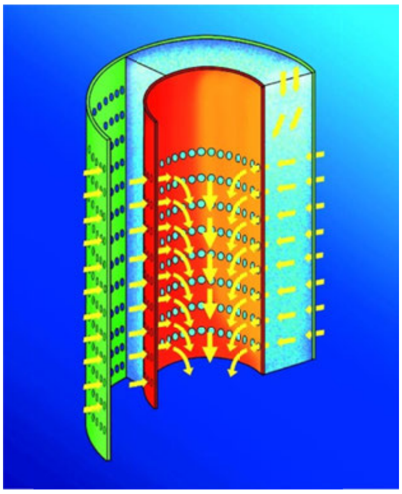

Figure 2. Axial-radial design for catalytic beds

Higher Efficiency

As will be further discussed in later sections of this paper, this cartridge design was selected primarily because it offered higher performances than the old one with an expected energy saving of 0.4 MMBTU/ST (0.465 GJ/MT). The actual energy savings proved to be higher (i.e., 0.7 MMBTU/ST, 0.814 GJ/MT).

Simplified Design

In addition to increased efficiency, the chosen converter design offers simplified maintenance and catalyst replacement due to the open-top design of the catalyst beds and the easy removability of the beds and interchangers. The latter is attributable to the novel Casale supporting systems of the baskets, which are merely sitting on a ring that is part of the cartridge wall as is depicted in Figure 3. In this way, the baskets can be loaded into the cartridge or lifted out without bolting, welding or cutting, and without the need to even access the supports.

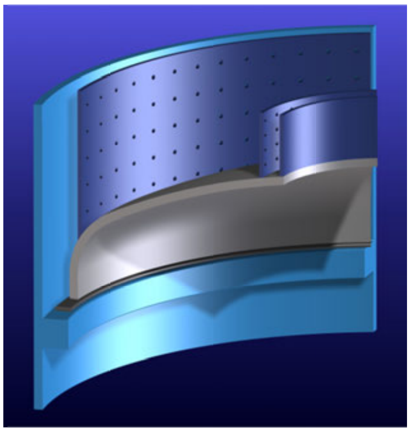

Figure 3. Casale catalytic bed bottom

Increased Reliability

The system described above is complemented by the use of sliding elastic ring joints for all internal connections as is shown in Figure 4. These joints offer superior reliability as they are free of any weak components like bolts, gaskets, or packing rope, and they also enable decoupling of the interchangers without any mechanical operations like unbolting, cutting, etc.

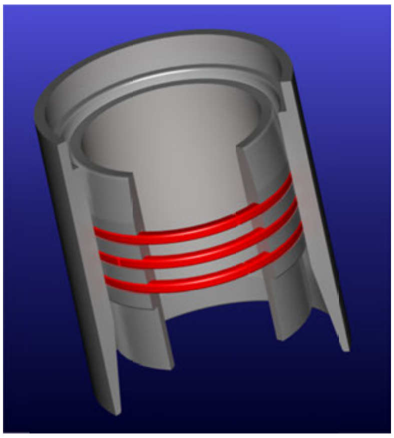

Figure 4. Casale sliding joint

Additionally, the basket walls of this design are fabricated using slotted walls, as described in the AIChE 2009 paper "Safety and Reliability in Ammonia Synthesis Converts" by E.Rizzi and L.Redaelli [1], which ensures a high mechanical reliability. Figure 5 illustrates the slotted wall design. The slotted walls are fabricated in AISI 321, as is the rest of the cartridge, which removes the need for any heterogeneous welding. Using a common material for the walls and cartridge also eliminates the mechanical stresses from differential thermal expansion that are present in cases where Inconel 600 is used for the walls or meshes in contact with the catalyst.

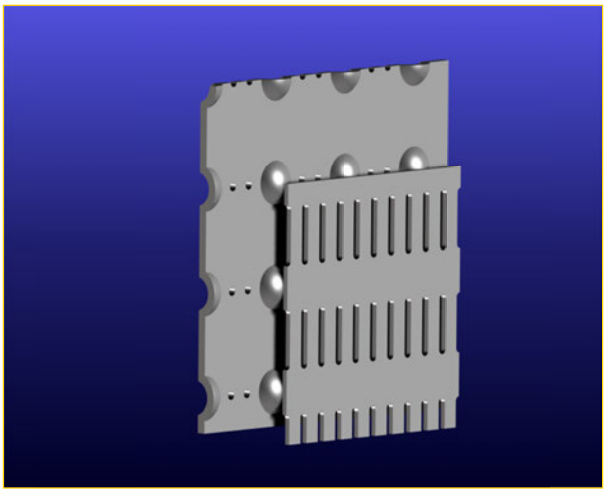

Figure 5. Casale slotted wall

Moreover, the advanced design features applied by Casale are fundamental to avoiding the huge costs and potential safety implications, which can result from options leading to lower reliability or safety.

Converter Catalyst

For the last 100 years, the ammonia industry has relied heavily on magnetite-based ammonia synthesis catalyst to provide millions and millions of tons of ammonia to feed the world. The longevity of magnetite is certainly a testament and great achievement for this circa 1910 discovery, especially considering that magnetite has been continuously challenged throughout its 100 year reign. However, until now, magnetite has always won the battle as the most feasible industrial catalyst in the field of ammonia production. Therefore, AmoMax®-10 represents a long awaited innovation in ammonia synthesis catalyst technology [2].

AmoMax®-10 is based on $Fe_{(1-x)}O$ (wustite) versus Fe_3O_4 (magnetite) and offers the following advantages relative to all other iron-based ammonia synthesis catalysts, including those containing cobalt:

- outstanding mechanical stability,
- higher low-temperature activity,
- enhanced thermal stability,
- higher resistance to poisoning,
- lower light-off temperature,
- and quicker & easier start-ups.

For reference, AmoMax®-10 is the commercial name for the oxide form of this catalyst, and AmoMax®-10RS is the pre-reduced and stabilized form.

Mechanical Strength and Stability

The mechanical strength of ammonia synthesis catalyst is not only important during transportation and loading, but also during operation. Superior mechanical strength of an ammonia synthesis catalyst in operation ensures low pressure drop and only a marginal pressure drop increase over its long and entire lifetime. AmoMax®-10RS is mechanically stronger by more than 400% compared to commercial magnetite catalysts options, as shown in Figure 6. Since during upsets the ammonia catalyst could be subjected to quick changes in temperature and pressure, the mechanical strength is also very important during such process upsets.

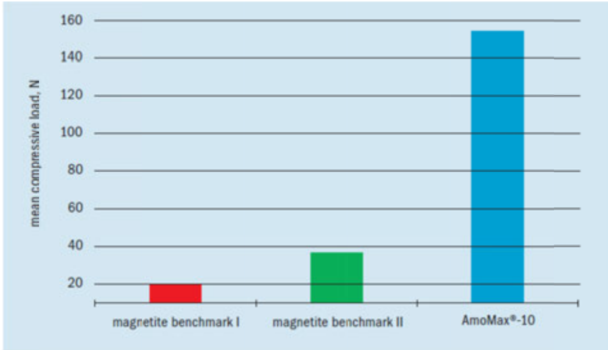

Figure 6. Superior mechanical stability of AmoMax®-10

Activity

As shown in the Arrhenius plot in Figure 7, AmoMax®-10RS is not only more active than traditional magnetite catalyst, but it also provides a much higher activity at lower temperatures. This allows operation at lower inlet temperatures while providing more conversion per pass because of a more favorable thermodynamic equilibrium at the lower temperature.

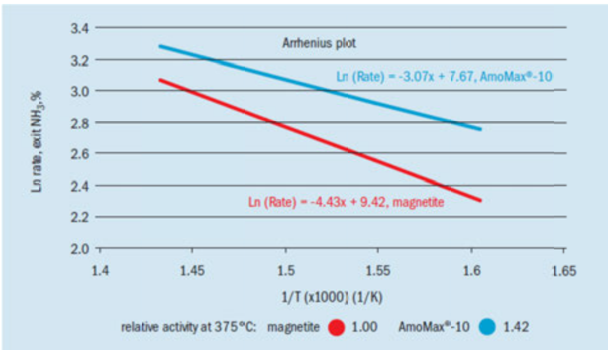

Figure 7. Superior activity of AmoMax®-10 vs. magnetite-based catalysts

Thermal Stability

Thermal stability is very important to ensure the long life of an ammonia synthesis catalyst in the elevated temperature and pressure conditions of commercial ammonia converters. Lab tests were conducted, at temperatures exceeding normal operating conditions (i.e., 550°C, 1022°F), comparing the performance of commercially available magnetite catalysts with AmoMax®-10. As shown in the life test in Figure 8, AmoMax®-10 not only provides higher initial activity but it also undergoes less deactivation with time on stream. By comparison, the thermal stability of AmoMax®-10 exceeds that of magnetite-2 and magnetite-3 and behaves comparably to magnetite-1. This has also been confirmed by stable commercial operation at several references that have been on-stream for more than seven years.

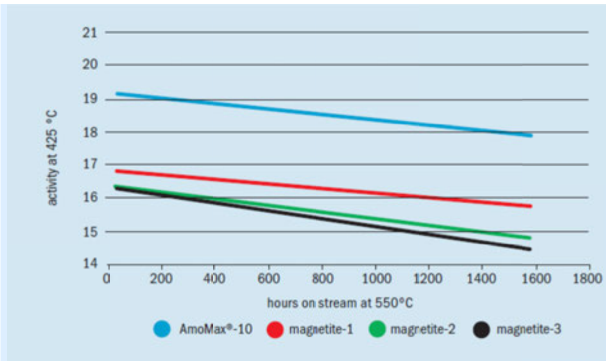

Figure 8. Superior thermal stability of AmoMax®-10 vs. magnetite catalysts

Resistance to Poisoning

Oxygenates in the ammonia synthesis gas such as CO, CO_2, and H_2O affect catalyst activity and are considered temporary poisons to ammonia synthesis catalysts by oxidizing the active α-Fe sites. The data shown in Figure 9 illustrate the outstanding resistance of AmoMax®-10RS against poisoning by oxygenates compared to magnetite with CO_2 used as the model molecule.

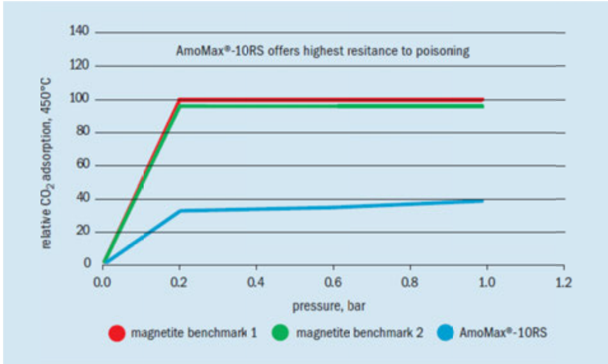

Figure 9. Superior resistance to poisoning by oxygenates of AmoMax®-10RS

Light-Off Temperature

The considerably lower light-off temperature of AmoMax®-10RS, as shown in Figure 10, allows for faster start-up of the loop, saving time and energy. Once in operation, this same characteristic results in less potential for loss of reaction during process upsets when operating with AmoMax®-10, which adds a safety margin to ammonia plant operation.

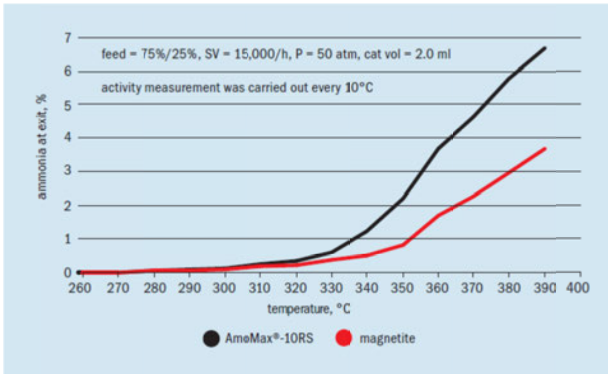

Figure 10. Lower light-off temperature of AmoMax®-10RS vs. magnetite catalysts

Woodward Project

The planning process for this ammonia converter revamping project began many years before the project execution. Indeed, planning and completing an ammonia converter revamp is no small undertaking. However, with the right design, planning process, and execution, the success and safety of the project can be ensured, and the results offer a sustained increase in profitability and reliability for many years. The project at the Woodward plant is offered as an example of such a project for others considering similar projects to gain a sense of the timeline and scope of an ammonia converter revamp.

Planning Timeline

Planning for Woodward's ammonia converter revamping project began in 2004. Initially, management wanted to only change out the catalyst without replacing the converter internals. However, after consultation with an industry expert, concerns about nitriding of the internal components of the then 20 year old converter prevailed, and the planning process for replacing the converter internals began.

A radioactive isotope leak test performed on the old converter in 2006 provided further confirmation of the need to replace the converter internals. The radioactive isotope Argon-41, which has a short half life, was injected at the feed inlet of the converter and radiation detectors were placed at the inlet and outlet piping of the converter. The test detected a sizable packing gland leak at the cold shot inlet. Additionally, it showed bypassing occurring at the internal heat exchangers. The leak detection test showed that, in total, approximately 14 to 16% of the gas was bypassing, which equates to approximately 0.056 MMBTU/ST (0.065 GJ/MT) in excess compression energy. Therefore, performing this test aided in the economic justification for replacing the converter internals. At this point, the selection process for a state-of-the-art technology provider was initiated.

This process began by gathering bid proposals from Ammonia Casale and another industry leading ammonia process technology provider. In spring 2007, after thoughtful consideration of each bid, Ammonia Casale was selected based on the fact that the Casale design offered more attractive energy savings as well as the flexibility of being able to choose from all of the Casale approved catalyst suppliers.

In June 2008, a request for bid was issued to Süd-Chemie and several other catalyst suppliers. In September 2008, Süd-Chemie was selected as the preferred catalyst supplier based on the characteristics described previously. These characteristics reduced the payback period on the investment required for this project and provided a sustained increase in profitability thereafter.

Initially, the converter retrofit project was schedule to correspond to a planned turnaround in May 2009. The other major activity planned for that turnaround was a revamp of the high pressure syngas compressor. When the converter internals arrived in November 2008 and the plant experienced a market-driven outage shortly after, an ambitious pursuit began to implement the converter retrofit as soon as possible. Since the converter internals and major component needed for the syngas compressor revamp had already arrived, the challenge was to ensure that the catalyst could be delivered earlier and that the catalyst handler, Süd-Chemie and Casale technical support personnel, the welding services provider, and the crane could all be available on such short notice. Luckily, each of the selected service, product, and technology providers were able to act with extreme responsiveness, and the converter and syngas compressor revamp were able to be completed during the same market-driven outage. The only residual portion of this project that had to be completed during the May 2009 turnaround was the replacement of the converter outlet piping for reasons described in the safety section below.

Table 1 provides a list of these and other project milestones from this converter revamp project as well as the dates by which these milestones where reached for this project as compared with a list of typical timing.

Planning Milestones	Woodward Actual	Typical Timing
Initial decision to replace converter internals	2004	T- 30 months
RFQ issued to ammonia technology suppliers	Jan-05	T - 24 months
Technology business awarded to Ammoina Casale	Mar -07	T - 20 months
Converter internal fabrication begins	May-07	T - 16 months
RFQ issued to ammonia synthesis catalyst suppliers	Jun-08	T - 7 months
Catalyst business awarded to Süd-Chemie	Sep-08	T - 6 months
RFQ issued to catalyst handling companies	Sep-08	T - 4 months
Catalyst handling business awarded	Dec-08	T - 1.5 months
Construction of converter internals finished	Sep-08	T - 3 months
Converter internals arrive on site	Nov-08	T - 2 months
Retrofit project begins	17-Jan-09	T = 0
Catalyst loading begins	27-Jan-09	T + 10 days
Catalyst loading complete	30-Jan-09	T + 14 days
Converter is bolted shut	2-Feb-09	T + 18 days
Inspections complete	5-Feb-09	T + 20 days
Catalyst reduction begins	9-Feb-09	T + 27 days
Catalyst reduction complete and converter online	13-Feb-09	T + 31 days

Table 1. Actual vs. typical planning timeline

Budgeting

In late 2006, the original budget was set for this project at $4MM. The budget included:

- a new converter cartridge,
- removing the old converter cartridge,
- installing the new converter cartridge,
- labor for the piping changes required to add another temperature control valve for the second bed,
- crane rental plus crane operators,
- import taxes and freight insurance,
- and replacement of the old nuts on the bolts of the converter head to super-nuts.

Because the proposal from Casale was not in USD, changes in the foreign exchange rate could have affected the project cost. Furthermore, it was difficult to predict the exchange rate over the time frame of this project. Figure 11 graphically represents the volatility of the exchange rate over the course of this project [3].

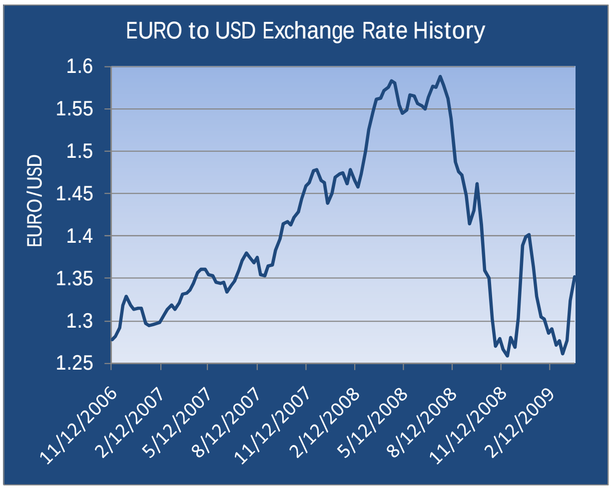

Figure 11. Euro to USD exchange rate history

Due to the variability of exchange rates and the long duration of this type of project, one can consider purchasing futures contracts to exchange currencies at a specified date in the future and at a fixed rate. This is a relatively inexpensive way to hedge the risk of currency inflation and simplify the project budgeting process.

Of course, as the project became more well-defined and drew nearer to the actual time of execution, there were also other changes to the initial budget.

- By fall 2008, the labor cost estimates for the ammonia converter retrofit had increased by approximately twice the original estimate due to the fact that labor and mobilization costs had escalated significantly during that two year time frame.
- There was a need for some temperature element connection modifications on the reactor head that were not part of the original scope.
- The cost of the crane rental had also increased. When the costs estimates were gathered for the crane rental, historical data indicated that a 300 ton crane was used for the installation of the previous converter. As it turned out, a knock-out drum was not in place the last time a crane was used for the previous cartridge and catalyst charge. The knock-out drum placement created a need for a longer load radius to accommodate the tail swing of the crane. Therefore, the crane equipment manager determined that a 500 ton crane would actually be needed.
- Additionally, the original budget did not include the cost of catalyst, the catalyst handling for removing and loading the catalyst and the nitrogen needed during these services, or the cost of the natural gas required for reduction of the catalyst.

With these added costs, the total budgeted rose to just under $6.5MM. Based on the anticipated energy savings from less pressure drop, less refrigeration energy, and additional heat recovery alone, the payback for the capital portion of this investment using the then current ammonia economics was approximately 5.5 years. The higher than expected efficiency improvement alone, i.e., 0.7 MMBTU/ST (0.814 GJ/MT) vs. 0.4 MMBTU/ST (0.465 GJ/MT), reduced the length of this payback period to just over 3 years, which does not take into account the additional payback from increased ammonia production and improved ammonia economics.

Safety

Completing this ammonia converter revamp project safely was the single most important metric in evaluating the success of the project. The Woodward site's diligent planning process, safety focus of the Terra organization, and close working relationship between the site, Casale, Süd-Chemie, and other onsite contractors helped to ensured the safety and success of this project.

The following describe some of the specific inspections and steps that were taken to ensure the safety of this project.

- As already mentioned, co-current with this converter revamp project, the site also revamped their high pressure syngas compressor. This revamp resulted in the potential for increased flow to the converter at a lower energy input. Therefore, all of the pressure safety valves had to be evaluated to ensure that they were adequate for the potential increase in flow.
- For every piping change, a pipe stress analysis was performed to verify the integrity of the modification.

Additionally, the converter vessel itself required an internal inspection. For background, the vessel was manufactured by Krupp Apparatebau of Germany and is a full-bore multi-layer wall construction with a flat flange top and single-wall bottom hemi-head. The maximum allowable working pressure (MAWP) of the vessel is 3600 PSI (24821 kPa). As it had been over 20 years since the last internal inspection of this converter vessel, an internal inspection was required. The internal inspection included:

- a thorough visual inspection,
- wet fluorescent magnetic particle testing on all welds,
- and a phased array ultrasonic non-destructive evaluation (NDE) to inspect an old repair on the bottom head that was originally performed in the fabrication shop while the vessel was being manufactured.

The bottom head of the vessel contains internal refractory, and the refractory was still in very good condition, so it was left in place and not removed.

Additionally, while the old converter cartridge was being removed, there were several areas on the inside wall that were mechanically scraped by the cartridge's outer layer of metal sheeting, which had failed. These areas were smoothed by removing the rough edges via grinding and buffing. Therefore, these areas were also evaluated using wet fluorescent magnetic particle testing.

None of the above mentioned inspections resulted in any repairs. However, during the retrofit, positive material identification (PMI) technology was employed to determine the alloy chemistry and grade identification information of the weld on the outlet of the converter to the piping in order to ensure the proper welding rod was used, and the same technology was applied to the piping itself. This lead to the discovery that the outlet piping metallurgy was only 1¼% Cr , ½% Mo. This piping was supposed to be 2¼% Cr, ½% Mo. Review of API 941's Nelson curves revealed operation on the edge of the safe operating environment for the current piping with regards to risk of hydrogen attack. Therefore, a plan was made to replace the outlet piping during the May 2009 turnaround.

In addition to these steps, various measures were also taken by Casale and Süd-Chemie to ensure a safe and successful startup.

To help ensure the safety of the cartridge installation, catalyst loading, and reduction, Casale:

- provided an engineering design package inclusive of procedures for all the site activities from installation to start-up together with a list of the required manpower and tools to enable the site to become familiar with the operations to be performed,
- reviewed and thoroughly discussed the detailed cartridge installation procedure with the site in advance of their turnaround,
- Casale field engineers were present during all phases of cartridge installation and catalyst loading,
- and Casale start-up engineers were present during the catalyst reduction and converter start-up.

To help ensure the safety of the catalyst loading and reduction, Süd-Chemie:

- conducted a pre-planning meeting with the site, Casale, and the selected catalyst handler,
- provided an on-site Süd-Chemie technical service engineer during the catalyst loading,
- conducted a thorough review of the site's reduction procedure, including operator training and laboratory training/review for water analyses, to verify alignment with our guidelines and ensure maximum catalyst performance and longevity,
- prior to beginning the reduction, developed contingency plans with the site for specific actions to be taken in response to various events that could cause an upset during the catalyst reduction (e.g., compressor trips, power outages, loss of forward flow through the converter, etc.),
- performed a thorough on-site walkthrough of the system prior to starting the initial heat up for reduction to again make certain that proper measures were taken to ensure proper reduction of the catalyst and avoid any temperature excursions and other situations that would be harmful to the project or startup,
- and provided 24-hour on-site Süd-Chemie technical service engineer presence during the entire catalyst reduction.

Results

The primary driver for this project was to increase the plant's efficiency in terms of the amount of natural gas required to produce ammonia. Originally, the combination of upgrading the converter to an Ammonia Casale, 3-bed, slotted wall design was expected to garner an energy savings of 0.4 MMBTU/ST (0.465 GJ/MT). The actual outcome of this upgrade combined with the installation of AmoMax®-10 actually far exceeded this goal with a realized energy savings of 0.7 MMBTU/ST (0.814 GJ/MT). In addition to the converter retrofit and catalyst upgrade, the syngas compressor was also upgraded, and this 0.7 MMBTU/ST figure is not inclusive of the savings realize from the compressor project. The energy savings achieved from the compressor revamp were 0.206 MMBTU/ST (0.24 GJ/MT). Therefore, the combined energy savings from the syngas compressor upgrade, installation of AmoMax®-10, and converter revamp resulted in a total energy savings of 0.906 MMBTU/ST (1.05 GJ/MT).

Table 2 below summarizes the results of the converter revamping project.

Woodward Ammonia Converter	Before Revamping	Test Run
Capacity	1350 STPD	1384 STPD
NH_3 increase across converter	10.74 mol%	12.78 mol%
Converter outlet pressure	3002 PSIG	2827 PSIG
Converter pressure drop	69 PSI	27 PSI

Table 2. Revamping results summary

As this table demonstrates, in addition to the energy savings listed above, the converter revamp and catalyst upgrade resulted in appreciably more ammonia production (i.e., 34 STPD, 31 MTPD), significantly more ammonia conversion per pass at a much lower operating pressure (i.e., 175 PSI, 1207 kPa), and drastically reduced the pressure drop across the converter (i.e., 42 PSI, 290 kPa). In fact, the site has since increased ammonia production to more than 1,500 STPD (1,361 MTPD).

Conclusions

Clearly, planning and completing an ammonia converter revamp is a highly involved and lengthy process. However, it is also clear that with the right planning process, design, and execution, the results of such a project offer an attractive payback period with a sustained increase in profitability and reliability thereafter, which make the undertaking very worthwhile. In the example of the Woodward plant, the plant's diligent planning process and strong attention to safety and related inspections, as well as close cooperation with their selected technology provider and catalyst supplier, ensured the safety and success of this project.

Additionally, the careful planning and responsiveness of all parties involved in this project enabled the implementation of this revamping project six months in advance of the original schedule, which is remarkable accomplishment. This not only allowed the site to experience the benefits of improved plant performance earlier than expected, but it also allowed the site to reduce the lost opportunity cost associated with the require shutdown by timing it with the site's marketing outage.

Furthermore, the example of the Woodward plant's ammonia converter revamp provides a good demonstration of how significant innovations in converter and catalyst technology have increased the economic feasibility of these projects and provide the potential to simultaneously, significantly, and sustainably improve ammonia plant efficiency, reliability, and production.

References

[1] Enrico Rizzi, Luca Redaelle, Ammonia Casale, AIChE Ammonia Safety Meeting 2009, Paper 5b.

[2] Kisnaduth Kesore, Norbert Ringer, Stefan Gebert & David Rice, Süd-Chemie, Nitrogen + Syngas 300, July-August 2009.

[3] www.oanda.com/currency/historical-rates