Ammonia Production - A Century of Safety, Health & Environmental Improvements

The development of the remarkable iron catalyst by Alwin Mittasch and the technology for the synthesis of ammonia from nitrogen and hydrogen by Fritz Haber and Carl Bosch lead to BASF starting to operate the world’s first ammonia synthesis plant in 1913.

Using a perspective on the history of operations at Billingham, UK and technologies pioneered there, this paper discusses the development of ammonia production over the subsequent years to the present day. Specific references are made to the technical improvements and changes to the process that have contributed to greatly improved safety, health and environmental impacts in the process of ammonia synthesis.

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Introduction

Ammonia is one of the most important chemicals produced globally with approximately 85% being used as fertilizer for food production. Ammonia synthesis from atmospheric nitrogen was made possible in the first part of the 20th century by the development of the Haber-Bosch process. It remains the only chemical breakthrough recognized by two Nobel prizes for chemistry, awarded to Fritz Haber in 1918 and to Carl Bosch in 1931. The development of ammonia synthesis directly addressed “The Wheat Problem” as foretold by Sir William Crookes in 1898 whereby a shortage of available reserves (of wheat) would only allow the world’s population to continue to expand to about two billion, which would be reached around 1930. Thus, in the early 20th Century, the need to increase food production led to the development of the fertilizer industry.

Today, the global value of ammonia production is estimated to be over $100 billion (USD), with individual plants being capable of producing 3300 MTPD (3640 STPD). To achieve this scale, many improvements have been made over the last 100 years in both process and catalyst
technology. This paper aims to review this history with particular reference to Billingham, UK, where commercial ammonia production was established in the 1920’s and where a number of key process innovations have arisen.

**Beginnings**

An ammonia factory being located at Billingham grew out of the needs of World War I - after a shortage of munitions led directly to the failure of the British offensive at Neuve Chapelle in March 1915. The Minister of Munitions at the time (later Prime Minister) Lloyd George called it “the Great Shell Scandal”. Britain was not producing enough nitrate based explosives. At that time natural nitrates imported from Chile were the only source Britain had, and the shipping supply chain was suffering attacks by German U-boats.

As we know, by 1913, BASF had already been synthesizing ammonia on an industrial scale, thus throughout World War I Germany had a local source of the key raw material for explosives.

This problem led to the British Government setting up an organization to develop technology to produce synthetic ammonia, and this organization chose Billingham as the site for the new development. The site was chosen due to the ready availability of key raw materials (coal and water) and skilled labour (shipbuilding and steel industries). By the time the plant (known as the Government Nitrate Factory) was completed, World War I was over and the government was in post-war debt. As a result, the site was put up for sale in 1919 in a wave of privatizations (Figure 1 & Reference 1).

![Figure 1. For Sale “The Times” 19th Nov 1919](image)

A member of a syndicate of interested parties, Johnson Matthey & Co, was a prospective buyer as they were already involved in selling Pt/Ph gauzes for use in the process but they were not successful (it was not until 2002 that Johnson Matthey finally acquired Billingham’s process and catalyst expertise). In April 1920 the Government Nitrate Factory was taken over by Brunner Mond, which became part of Imperial Chemical Industries (ICI) in 1926. By then the factory had been converted to make ammonia-based fertilizers and was renamed the Synthetic Ammonia & Nitrates Division.

**1920-1930’s Technology – Coke Ovens**

Before the first ammonia production plant was built at Billingham, semi-tech plants were developed by Brunner Mond at Runcorn Cheshire at 3 and 5 MTPD outputs. The first Billingham plant was a 24 MTPD (26 STPD) unit that made its first ammonia in December 1924.
The ammonia plants built at Billingham in the 1920’s and 30’s employed the classic Haber-Bosch process based on coke. The original process is shown in Figure 2.

The first stages of gas production were at atmospheric pressure. Alternate streams of steam and then air were fed into gas generators containing hot coke to make “water-gas” (H₂ rich) and producer gas (N₂ rich). These streams were purified using iron oxides to remove H₂S and a shift converter to convert most of the CO to CO₂ and H₂. The “catalysed gas” was compressed first to 11 bar (160 psi) in rotary compressors and then to 55 bar (810 psi) in reciprocating compressors. CO₂ was removed by counter-current scrubbing with circulating water and the scrubbed gas was further compressed to 250 bar (3670 psi), washed with copper liquor to remove residual CO and CO₂ and then fed as make-up gas to the synthesis loop.

This production of syngas feed by a low-pressure process based on coke was excessively expensive. Cyclic water-gas process are fundamentally inefficient as much heat is lost in blow gas and due to incomplete combustion – the actual use of coke feed was about double the theoretical use of 0.9 tons coke/ton ammonia. The plant was also heavy, voluminous, high in maintenance needs and not kind to the environment. Figure 3 shows the coke ovens and water gas plant.

Using this technology the rise in output from the site is shown in the Table 1.

<table>
<thead>
<tr>
<th>Year</th>
<th>Ammonia</th>
<th>Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1924</td>
<td>24 MTPD</td>
<td>No2 Unit</td>
</tr>
<tr>
<td>1926</td>
<td>52 MTPD</td>
<td>No2 Unit Extension</td>
</tr>
<tr>
<td>1928</td>
<td>170 MTPD</td>
<td>No3 Unit</td>
</tr>
<tr>
<td>1929</td>
<td>373 MTPD</td>
<td>Nos 4 and 5 units</td>
</tr>
<tr>
<td>1932</td>
<td>415 MTPD</td>
<td>Extension</td>
</tr>
<tr>
<td>1941</td>
<td>642 MTPD</td>
<td>Process improvement</td>
</tr>
<tr>
<td>1951</td>
<td>746 MTPD</td>
<td>Converter internals redesign</td>
</tr>
</tbody>
</table>

Table 1. Ammonia output at Billingham from 1924 to 1951

As well as scale improvements there were improvements in effectiveness. In 1929, A.H. Cowap, chief engineer, noted “a striking feature is an ever increasing rapidity of work. The first large unit, No 3 Unit, cost £5,250,000 and was completed in 27 months (of which 7 months was a labour stoppage for a coal strike). No 4 and No 5 units cost £11M and have been completed in 2 months.”

Despite improvements, by the late 1950’s, increasing costs of coal and the intrinsic
inefficiency of syngas generation from coke had made this process uncompetitive.

1950’s Technology – Partial Oxidation Process

In 1954 Texaco (and subsequently Shell in 1956) developed a process for partial oxidation of hydrocarbons which offered improved economics. The partial oxidation process reduced both the capital and operating costs of low pressure gas generation, eliminated the need for low pressure compression and offered greater feedstock flexibility. The principle disadvantage of the process was its requirement for an air separation plant to supply oxygen. In these early days the challenges for safe operation and engineering of these air separation units were significant. Frequent explosions in oxygen plants encouraged engineers to meet and share information with the very first symposium to discuss safety in air and ammonia plants, "Safe Design and Operation of Low Temperature Air Separation Plants" held in 1955 in Boston, USA.

Billingham commissioned a Texaco gasification unit for heavy fuel oil, which was later converted for naphtha feed. Syngas was produced at 30 bar (440 psi) pressure by reaction of the hydrocarbon with steam and a limited supply of oxygen at 1500 °C (2732 °F). The syngas contained a little residual carbon and all the sulphur as H2S. After shift conversion, purification using carbon and CO2 removal with circulating hot potassium carbonate (Benfield) was employed. The partially purified gas was compressed to 250 bar (3670 psi) and added to the existing synthesis plant before CO removal (copper liquor).

Unfortunately a serious explosion occurred during the commissioning of the air separation unit in 1959, which resulted in three fatalities (Figure 4 & Reference 2). This incident resulted in a long delay in the partial oxidation plant achieving beneficial operation, by which time steam reforming technology development had advanced sufficiently to make it a more competitive route for syngas production.

Steam Reforming of Light Naphthas

Steam reforming of hydrocarbons provides the most economic source of gas for ammonia synthesis. The general reaction is shown below.

\[ C_nH_{2n+2} + nH_2O \rightarrow nCO + (2n+1) H_2 \]

The reaction was known to proceed at 700-800 °C (1292-1470 °F) over a promoted and supported nickel catalyst. ICI were pioneers in methane steam reforming in 1928 with commercial units having been built at Billingham in 1936 to reform propane/butane byproducts of hydrogenation of coal as part of synthetic hydrocarbons production (Oil Works) shown in Figure 5.
In the late 1950’s it became clear that ammonia production based on coal could no longer be economic. At this time natural gas was not available in the UK (discovery and exploitation of North Sea gas was still some 15-20 years distant), however increasing quantities of light distillate hydrocarbons were available at falling prices. Sulphur-free distillate hydrocarbons had been successfully reformed by the catalyst research group at Billingham in 1938 at atmospheric pressure. What was needed was the development of the process to operate at higher pressures to avoid compression costs.

The world’s first pressurized steam reforming process was designed at Billingham and was brought into commercial operation at Heysham in 1962 (Reference 3). The main problems were adequate desulphurization of the feed, and suppression of carbon deposition on the reforming catalyst without the use of excessive steam ratios. Desulphurization of the feed was addressed by development of feed purification technology involving hydrogenation catalysts (Ni-Mo,Co-Mo) along with ZnO absorbents capable of reducing sulphur to very low levels. The problem of carbon formation was solved by the development of new types of alkalized catalysts.

Due to equilibrium considerations, to achieve a low CH₄ slip, a temperature of around 1000 °C (1830 °F) is required, however the metallurgical limit for a 10 year life of the available material, 25:20 Cr-Ni tubes, was a design exit temperature of 800 °C (1470 °F). To overcome this constraint the new steam reforming process adopted two reforming stages, as shown in Figure 6 (Reference 4). Now familiar to us as primary and secondary reformers, these unit operations are still present in nearly all ammonia plants.

The 1960’s steam reforming modernization

Having developed a viable steam reforming process, the ammonia units at Billingham were modernized with four steam reforming units built in 1962-1963 (Figure 7). Each unit included a primary (tubular) reformer with 4 inch (100 mm) ID tubes and a reaction length of 20 ft (6 m). Operating at 14 bar (200 psi), the reformed gas, containing 10-12% CH₄, was collected in headers near the ground and passed to the air injection burner in the secondary reformer. After secondary reforming was waste heat recovery, two stage CO shift, further heat recovery, cooling and CO₂ removal.
The process was rapidly adopted and by the mid-1960’s over 100 steam reforming process licences had been sold from Billingham to the following reputed engineering contractor licensors: Power Gas Corporation (later Davy), Foster Wheeler, Selas, M W Kellogg (later KBR), Friedrich Uhde GmbH (ThyssenKrupp Uhde GmbH) and Humphreys & Glasgow (Jacobs).

**CO₂ Removal Modernization**

Initially the syngas from the new reforming units at Billingham joined the original plants at the intermediate pressure compressors at 55 bar (810 psi) before CO₂ removal. This configuration meant that 13 reciprocating compressors, 28 CO₂ removal towers, 18 water pumps, 13 CO removal towers and 20 synthesis converters were still in use.

The new steam reforming front end occupied an area of 14,160 m² (3.5 acres) – a little less than 10% of the area occupied by the coke-based processes that it replaced. Using space freed up by the reformers, improvements to the gas purification and compression were introduced. As the existing CO₂ removal process employed water washing at 55 bar (810 psi) and consumed 0.75 GJ/tonne (0.78 MMBtu/ton); both capital and operating costs were high. As chemical absorbents with higher capacity for CO₂ removal had become available, both the Benfield process (potassium carbonate) and Vetrocoke (arsenious oxide) were adopted in different Billingham plants in early 1960’s. These processes achieved CO₂ slips of <0.1% dry.

**Early 1960’s - Largest Single Stream Plant**

A “single stream” concept emerged for new ammonia plants and Billingham engineers designed and engineered a 360 MTPD (400 STPD) “single stream” plant. Commissioned at Severnside in 1963, it was, at that time, the largest single stream ammonia plant in the world. The plant used the steam naphtha reforming process, a hot potassium carbonate based CO₂ removal system, a copper liquor CO removal system, and had two HTS beds. Parallel reciprocating compressors driven by electric motors were used for synthesis gas compression.

**1960’s New Shift Duty – Low Temperature**

For coke-based syngas production, the high levels of sulphur present in syngas meant that the copper liquor process was effective in achieving high purity syngas (low levels of CO and CO₂). The iron oxide shift conversion catalysts then in use were operating at >400 °C (>750 °F) giving an equilibrium CO conversion of ~4.5% dry. Although more active copper-based catalysts were known to be able to accomplish the shift reaction at ~250 °C (482 °F), they were very sensitive to poisoning by sulphur and could not be used with syngas made from coke. The virtually sulphur free syngas obtained from steam reforming allowed these copper-based shift catalysts to be used, achieving an equilibrium CO conversion of ~0.2 mol% dry. ICI developed its own robust and reactive Cu catalyst for this application.
Previously the copper liquor scrubbing had reduced carbon oxides to a low enough level for ammonia synthesis. However the combined low level of residual carbon oxides from CO₂ removal and CO shift was now such that they could be made inert by methanation before the synthesis loop, a concept patented by Edward Maxted in England in 1918 (Reference 6).

As a result of all of the improvements considered so far – steam reforming, shift, CO₂ removal and methanation – by the mid-1960’s it was possible to carry out all operations in single stream reactors. The process flowsheet is shown in Figure 8.

![Figure 8. Billingham flowsheet from mid-1960's](image)

**Reciprocating versus Centrifugal Compressors**

Early design memos for the Billingham plants in the 1920’s had discussed the relative economics of reciprocating and centrifugal compression. They showed that the relative efficiency of rotary compressors for the later compression stages would be low except at high throughputs, shown in Figure 9.

![Figure 9. Mid-1960’s final stage compressor efficiencies](image)

As a result of all of the improvements this low efficiency was one of the reasons for excluding centrifugal compressors for all but the LP stages, and this reasoning still prevailed at the beginning of the 1960’s.

**Early 1960’s – a Second Plant for Severnside**

Attention then turned to a second plant for ICI Severnside. This time the capacity would be 600 STPD (544 MTPD). Rather than design it internally, a decision was made to solicit bids from engineering contractors, one of which was M.W. Kellogg. This activity led to what was described as “possibly the most important event in the history of the development” of the single stream ammonia plant (Reference 7). In late 1962, a meeting was held in which Ron Smith, VP of Operations at M.W. Kellogg, opined that the capacity of ammonia plants was bound to increase and queried why the synthesis loop pressure couldn’t be reduced from 325 bar (4700 psi) to 150 bar (2200 psi), thus completely eliminating the need for reciprocating compressors. The resulting bid for Severnside from M.W. Kellogg incorporated a number of important features:

- The steam naphtha reforming process.
- A loop pressure of 150 bar (2200 psi) allowing the use of centrifugal compressors.
• Improved plant efficiency by recovering heat to generate high (for that time) pressure superheated steam for use on steam turbine drives – 62 bar (900 psi) and 450 °C (850 °F) was selected due to a change in specification at 62 bar (900 psi) and 482 °C (900 °F) under ASME code.
• The steam was generated at a higher pressure than that required by the process, so energy was recovered by expanding the steam through turbines to the pressure level required by the process.

At the end of the day, the contract was awarded to a more conventional design from Bechtel. Nevertheless, the basic principles of the M.W. Kellogg ammonia process had been born.

About 2 months later, M.W. Kellogg was invited for further discussions and asked how large a plant could be built. The “1000 STPD” plant had been born. In January 1964, M.W. Kellogg was awarded a contract for two plants to be built at Billingham. Within a few weeks a third plant was announced. With a capacity of 972 STPD (881 MTPD), they would be the largest plants ever built.

Further improvements were made to the design offered for Severnside, and operating information from the early 1970’s shows the Billingham plants with:
• 31 bar (450 psi) reforming pressure
• 103.5 bar (1500 psi) HP steam pressure superheated to 450 °C (842 °F)
• 39 bar (560 psi) MP steam pressure
• 131 bar (1900 psi) loop pressure.

**Mid 1960’s M.W. Kellogg Ammonia Units**

As the M.W. Kellogg plants incorporated the steam naphtha reforming process, Billingham engineers worked closely with their counterparts from M.W. Kellogg in the design of the reformers, shown in Figure 10.

![Figure 10. Three M.W. Kellogg reformers](image_url)

When commissioned, the three plants suffered from a variety of problems and initially were very unreliable. This low reliability was attributed to a variety of reasons including the following:
• The novel use of equipment such as high speed condensing turbine drives for process machinery.
• UK taxation laws which discouraged steam generation other than from coal, which meant that the plants did not have an auxiliary boiler.
• A change in mind-set was required. If you have a multi-stream plant with say ten units in parallel, and you lose one of them you still make 90% of what you intend to make, so the upstream and downstream parts of the plant stay online. If you only have three single stream plants, and you lose a piece of equipment in the middle of one of them, you can lose the entire plant and 33% of your production.

Catalyst technology and knowhow continued to develop and it was noted that “It is important to keep a constant level of mobile potash on the surface of the catalyst to prevent carbon formation. The alkali must be released from the support in a controlled way to maintain the appropriate level of potash on the catalyst surface. A fine balance is required, since too rapid removal of potash leads to short life,
whilst too slow a rate would lead to carbon laydown” (Reference 8). The practice of installing different types of catalyst in a single reformer tube – more heavily alkalized at the top, lightly or un-alkalized at the bottom (double-decker) helped control potash migration as the potash was only present where it was needed and could be captured before being eluted from the tube.

In the early 1970’s, the plants were converted to run off a natural gas feed, with a propane backup facility later being added. An on-going problem with hot band formation led to the development of more specialized catalysts, suitable both for natural gases which contain heavier hydrocarbons and for dual feed applications.

1960’s Kanpur Ammonia Plants

In keeping with its status as an operator, designer, technology licensor, and catalyst manufacturer, ICI continued to develop its own technology. Two Billingham designed ammonia plants, constructed in Kanpur in 1969 featured the first application of ICI’s single nozzle secondary burner (Figure 11); the forerunner of a design used in many ICI (and subsequently Johnson Matthey) designed plants.

The 1970’s at Billingham

The experiences of the 1960’s led to a more conservative approach to plant design. This conservatism is illustrated by the fact that, although designed for 1100 STPD (998 MTPD), Ammonia IV, commissioned in 1978 and shown in Figure 12, was able to achieve a throughput of about 1350 STPD (1225 MTPD) without substantive modification.

Figure 12. Ammonia IV (Ammonia 4)

The 1970’s – Process Safety

Developments continued, especially in the field of process safety. A major milestone was the introduction of the Hazard and Operability Study. Before its introduction, safe operation was often learned the hard way, by experiencing fires, explosions and toxic releases, and learning how to prevent them. The breakthrough was in the recognition the answer to preventing process accidents lay in the hands of the designer. Only by critically examining and questioning the design in detail could plants be made safer.

An ICI procedure, issued in 1972, required the use of quantified risk assessment techniques both to confirm the adequacy of trip systems and to calculate the frequency with which they
needed to be proof tested in order to maintain their integrity (Reference 9).

Arrangements were also made to allow the plants to remain online whilst the trip systems were being proof-tested. Although there are some differences in terminology, the technique is similar to a SIL assessment, which only started to gain wide acceptance in the ammonia industry in the 2000s (Figure 13).

The 1970’s – Guard Catalysts

Before the effects of chlorine were recognized, sulphur was thought to be the major cause of LTS deactivation. Some companies tried to address this by installing guard vessels or beds filled with zinc oxide. In some plants, however, deactivation continued even after major improvements to feedstock desulfurization (Reference 10).

In the 1970’s, it was recognized that appropriately formulated LTS catalysts could be self-guarding not only in regard to sulphur, but also towards chloride. It was also recognized that the benefits in terms of shift activity and bed life accruing from the use of fresh LTS catalyst outweighed the cost savings realized by reusing discharged LTS catalyst. All LTS catalysts subsequently developed by ICI and Johnson Matthey were therefore optimized to maximize their self-guarding capability.

Early 1980’s – The AMV Process

Ammonia technology continued to develop and Billingham based engineers were tasked with the design of a fifth ammonia plant for Billingham (Ammonia V). Economic considerations meant that capital cost had to be reduced whilst improving plant efficiency. Although market conditions in the early 1980’s meant that the plant was never built at Billingham, the designs for Ammonia V evolved into the AMV process. The first AMV design was commissioned at Courtright, Canada in August 1985 (Figure 14). Ammonia production was achieved 43 hours after feed gas introduction – believed to be a record at that time (Reference 11).

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**Figure 13. Simplified analysis of high temperature trip on air feed to a reformer**

Following an explosion at Flixborough in 1974, ICI’s HAZOP process (developed in the 1960’s) was “donated” and rapidly became accepted by the process industries as a best practice.
Features of the AMV process at the time included the following:

- ICI process design combined with Uhde mechanical design
- Electrically driven single casing syngas compressor
- Separate ammonia circulator
- Low pressure loop operating at about 85 bar (1230 psi) and featuring a new low pressure ammonia synthesis catalyst (KATALCOJM™ 74-1) which had been developed specially for this project
- Cryogenic hydrogen recovery unit recovering hydrogen to the circulator suction
- A real-time dynamic operator training simulator
- Dynamic simulation of the plant steam system conducted during the design process.

Operating with a low steam ratio, the plant was one of the first to suffer from by-product formation and pressure drop increase due to HTS over reduction. Copper was added to the HTS catalyst formulation to create an over reduction resistant formulation, which was first installed in 1987.

Mid-1980’s – The Leading Concept Ammonia (LCA) Process

By the mid-1980’s, the two ammonia plants at Severnside were becoming uncompetitive and a decision had to be made – improve their efficiency, replace them, or close the site. Improving the efficiency wasn’t really an option. New technology was developed at Billingham to solve the problem.

The LCA process implemented at Severnside, shown in Figure 15, used a combination of new equipment, new catalysts, and improved construction and procurement techniques, some of which are as follows:

- First low temperature HDS (Hydro-desulphurization) KATALCOJM 61-2
- First low temperature sulphur removal absorbent PURASPECJM™ 2020
- First application of a process gas heated reformer
- Isothermal shift catalyst – Catalyst 83-1 specifically developed to resist the high operating temperature
- Pressure Swing Absorption (PSA) for CO₂ and nitrogen removal
- First low temperature methanation catalyst (KATALCOJM 11-4)
- Low pressure ammonia synthesis using KATALCOJM 74-1 – 80 bar (1160 psi), which is even less than at Courtright
- Modularized and prefabricated construction
- Segregation of ammonia plant from utilities enabling “off the shelf” utilities to be purchased
- Use of Slamshut valves and instrumented protection to reduce the size of the relief system
- Low ammonia inventory
- Automated start up sequences, the most automated ammonia plant ever built
- Easy to start up – the second plant at Severnside made ammonia only 19 hours after natural gas was first introduced.
1990’s – Process Safety Revisited

With the advent of HAZOP and other process safety techniques during the 1970’s and 1980’s, process accidents became less and less frequent within the company. However, there was still some concern that many older plants had not been properly studied using HAZOP. Then, in 1987 and 1989 two significant incidents took place. First, the process conditions which occurred during start up led to a failure, a brittle fracture, and a fire at the base of the flare stack of the largest plant in the company. Second, an ammonia injector in the Billingham urea plant ruptured, releasing liquid ammonia which killed two people in the machine house (Reference 12). These events gave urgency to a process which had already started - the systematic review of process hazards on all ICI's plants.

Legislation already required detailed safety reports to be submitted to the Government Health & Safety Executive by July 1989. These reports were required to detail and assess both the potential major hazards and the prevention and protection measures on certain specified plants. The scope and extent of these reports was however limited, so they were not very helpful in meeting the requirements for safety assurance. On many older plants a concise listing of potential hazards did not exist because no previous formal hazard study had been carried out. The potential sources of, or consequences of, loss of containment had not been fully considered.

Following the fatal accident on the urea plant, a small team met for five full days to review the process safety in detail. A large number of items, unrelated to the cause of the accident, were raised by the study team.

This small multi-disciplinary working team approach provided the pattern for developing a streamlined technique - the Process Hazard Review. This became the sixth stage of the ICI 6 stage Hazard Review Process and is similar in concept to PHA promulgated under OSHA 1910.119, which came into force in 1992 (Reference 13).

1990’s – Catalyst Developments

Catalyst developments continued; Figure 16 illustrates the dramatic improvement in the activity of one particular catalyst, which resulted from a combination of on-going development and the incorporation of learning from the development of the LCA ITS catalyst.

Environmental issues came more to the fore resulting in developments to reduce methanol formation across LTS catalyst. Until 1997, progress had been modest. The step change that occurred in 1997 was due to the acquisition of the BASF syngas catalyst business. This acquisition allowed the knowledge of two great companies to be combined.
In some cases the best of both companies was combined to create a new product – as happened in the case of LTS catalyst. BASF had previously had low methanol products, K3-110 and K3-111, which suffered from some issues relating to strength and poison resistance. ICI had LTS products with good strength characteristics, but could not mimic the BASF low methanol recipe due to patent protection. The combination meant that a low methanol, high strength product could be developed. The results were KATALCOJM 83-3K, launched in 1997, and KATALCOJM 83-3X, which was launched in 1998, which has the lowest level of methanol byproduct formation (Figure 17).

1990’s – Computer Aided Design Tools

Until the 1970’s, furnaces were being designed manually. In the 1970’s, reformer design tools including reforming kinetics were developed on mainframe computers. By the 1980’s mini-computers were used for process engineering simulation; and REFORM was developed. REFORM is the proprietary reformer modelling tool that has since been further developed and is still used by Johnson Matthey today. With the introduction of PC-based design modelling, the use of computerized techniques for both plant and catalyst design accelerated in

CFD was also used to investigate abnormally high pressure drops which were seen in both high and low temperature shift converters. The result was the development of STREAMLINE™ technology, which utilized a special high voidage support media to reduce the pressure drop at the base of vessels. Figures 18a and 18b show the CFD results of a STREAMLINE™ application.

Figure 17. LTS by-product reduction.

Figure 18a. Before STREAMLINE - collector pressure drop of 7 psi (0.48 bar)

Figure 18b. After STREAMLINE improvements pressure drop reduced to 0.14 psi (0.01 bar)
The 2000’s

Although the beneficial effect of shape on reforming catalysts was recognized by the launch of a 4 hole shape in 1986, the 2000’s saw the use of design tools such as finite element analysis to assist with the design and optimization of catalyst shape. This effort facilitated the significant improvements in activity, pressure drop, and breakage characteristics realized by KATALCOJM QUADRALOBE™ reforming catalysts launched in 2001.

In 1998, ICI and Uhde formed an alliance in the field of ammonia technology resulting in a variety of new developments, the most public of which was the Dual Pressure Ammonia process, which combined Uhde’s design and engineering expertise with Johnson Matthey (then ICI) catalyst, operational and design know-how. Launched to the world in 2001 (Reference 14), and optimized around the performance of Johnson Matthey’s catalysts, the first plant was commissioned at SAFCO in 2006 (Figure 19). It remains the largest proven design available today.

In 2002, ICI Catalysts was acquired by Johnson Matthey. It is now part of a company with a much more diverse range of catalyst and technology interests than had been the case with ICI. This diversity has reinvigorated ambition to create better catalysts and technology, through a combination of incremental improvements and cutting edge research. Describing these more recent innovations is however outside the scope of this paper.

Conclusion

Over the last century, scientists and engineers based at Billingham have made a significant contribution to the nitrogen industry. Their heritage now resides with Johnson Matthey and the challenge is to continue this legacy and make an equally significant contribution to the future of this vital industry.

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