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FIRST APPLICATION OF THE UHDE DUAL PRESSURE AMMONIA PROCESS FOR THE 3300 MTPD AMMONIA PLANT FOR SAFCO IN SAUDI ARABIA.

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ABSTRACT

The most recent process development of Uhde for large scale ammonia plants is the Uhde Dual Pressure Process which reduces the risk for very large capacity single train ammonia plants by utilising proven and referenced equipment. The typical design features of the new process will be presented with examples from the 3,300 mtpd plant being currently constructed for SAFCO in Al Jubail, Saudi Arabia.

I. INTRODUCTION

Ever since the company was established in 1921, Uhde has been engaged in the design and construction of ammonia plants and has played a leading role in the development of ammonia technology. As far back as in 1928, the first ammonia plant using an Uhde proprietary process went on stream, the loop operating at a pressure of 100 bar. In this plant, which was located on the site of the Mont Cenis coal mine at Herne-Sodingen, treated coke oven gas from the existing coking plant was used as the feedstock. The plant had an output of 100 mtpd ammonia and comprised four reactors with a capacity of 25 mtpd each. Since this time the technology has continuously been improved and was setting standards with respect to plant capacity, energy efficiency and reliability throughout the decades.

Over the past 80 years some step changes in ammonia plant capacity can be observed reflecting the development of the process. One of the major steps was M.W. Kellogg´s introduction of the single train concept based on centrifugal syngas compressors in the 1960´s enabling a shift of the capacity to 600 stpd. During the following decades some process variations were introduced, e.g. C.F. Braun´s purifier process or ICI´s AMV and LCA processes, all of these aiming at improved process economics rather than a significant capacity increase.

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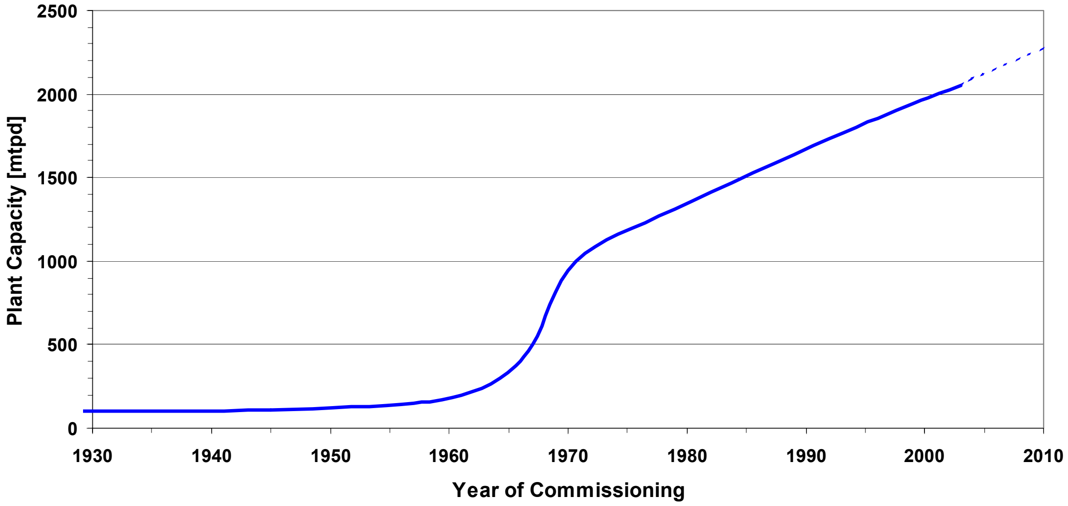

Fig. 1: Capacity Development of new ammonia plants

As early as 1971 Uhde commissioned a 1,400 mtpd plant at a loop pressure of 225 bar. In 1991 the next generation of Uhde ammonia plants started with the BASF Antwerp plant having a nameplate capacity of 1,800 mtpd (now operating at 2,060 mtpd). For this plant design a second ammonia converter was introduced into the loop, the scale up experiences from this project led to design considerations taken into account for the next capacity generation at 3,300 mtpd and beyond.

Since 1998 Uhde joint forces with Johnson Matthey Catalysts, formerly Synetix to further improve the Uhde ammonia process by taking advantage of Johnson Matthey world leading range of catalyst technology. This partnership has proven to be very fruitful, by the close co-operation of an experienced process licensor / engineering contractor and an innovative catalyst developer the process layout could be even more optimised and tailored around the outstanding features of modern catalysts.

Besides the continuous improvement of the conventional Uhde ammonia process Uhde and Johnson Matthey also addressed the demand for very large scale ammonia plants by developing a large-capacity process based on currently available technology and catalysts. The new flowsheet delivers a capacity of 3,300 mtpd using well tried and tested equipment. It also provides the basis for even larger plants. The synthesis loop configuration can deliver a capacity of over 4,000 mtpd using currently proven equipment, while the Uhde reformer can readily be designed for even greater capacities.

When targeting larger capacities it is not sufficient just to consider what technically can be built or realised, also the risk of the scale up has to be considered for the overall economics of a project, especially when a step change in production capacity is foreseen. At very large capacities the demand for plant reliability is even more important due to the large amount of capital involved and the significant production losses during any shutdown which will be difficult to compensate for with ammonia from the market.

2. THE UHDE AMMONIA PROCESS

A glance on the block diagram (Fig. 2) of an Uhde ammonia plant shows the conventional sequence of process steps that form the basis of most present day ammonia processes. But what appears to be a conventional set-up is in fact a most up-to date ammonia plant concept.

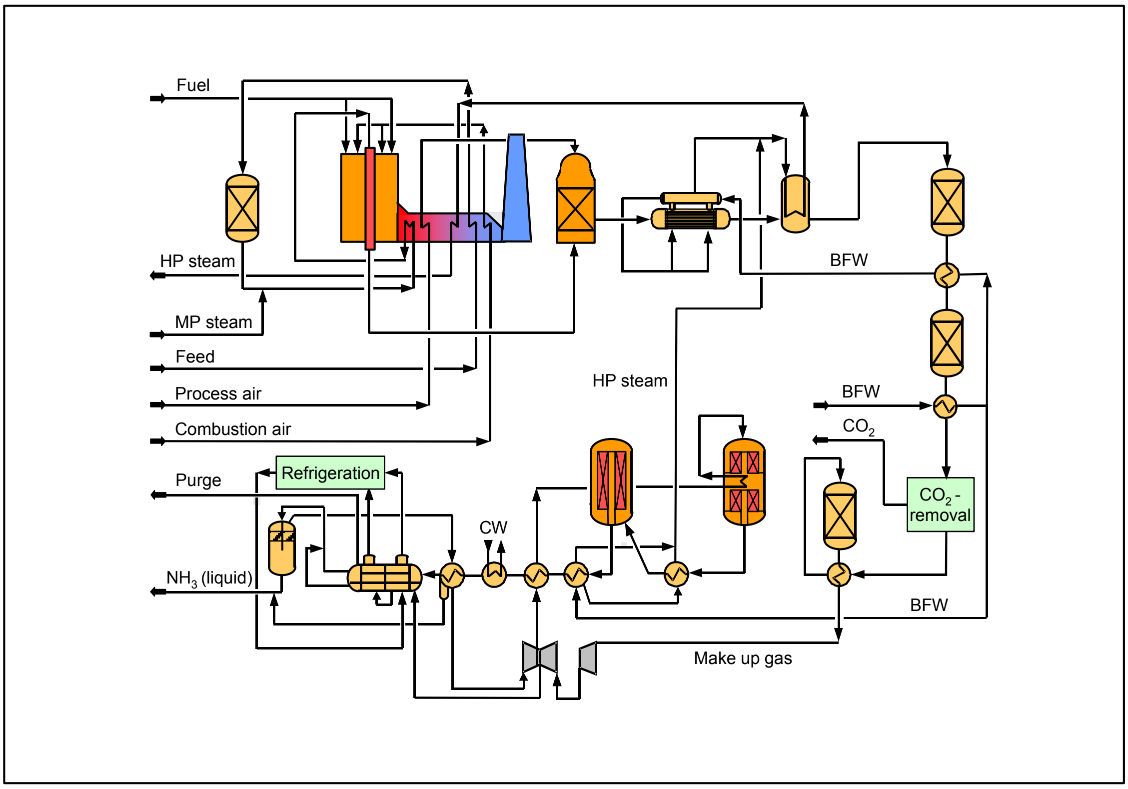

Fig. 2: Uhde Ammonia Process

The total consumption figure (feed + fuel + electric power) per metric ton of ammonia produced is in the range of 6.6 to 7.2 Gcal, depending on local conditions (e.g. cooling water temperature) and project-specific requirements (such as the natural gas price, etc.). This performance has been achieved by continuously improving the plant sections with a major impact on the energy consumption (i.e. reforming section, CO_2 removal and ammonia synthesis).

The typical features of an Uhde ammonia plant comprise a top fired primary reformer with a cold outlet manifold, a secondary reformer with circumferencial vortex burner, HP steam generation and HP steam superheating downstream of the secondary reformer and a two stage CO shift section utilising the heat for boiler feed water preheating. For the removal of CO_2 various chemical and physical absorption systems are available, e. g. MDEA, Benfield and Selexol. Most widely used in nowadays projects is the BASF aMDEA process due to its outstanding low energy requirements and the non corrosive solution. Uhde has a long term experience with the design of large capacity aMDEA systems; already in 1991 an aMDEA wash for a 1800 mtpd ammonia plant was commissioned. The typical Uhde ammonia synthesis consists of three radial magnetite catalyst beds arranged in 2 converters. The recovery of heat downstream of each reactor by generating high pressure steam contributes considerably to the energy efficiency of the process. The synthesis pressure is typically in the range of 190-200 bar, taking the maximum advantage of a two casing synthesis gas compressor and reducing the refrigeration requirements.

Since 1998 all Uhde ammonia projects for new plants and revamps have been based on Johnson Matthey´s advanced KATALCO catalysts for all process steps to ensure optimum plant economics with respect to investment, efficiency and reliability.

2.1 Scale up Considerations

When thinking of scaling up an ammonia plant the first focus will be on the critical equipment, which is typically the reforming section and the machinery, especially the synthesis gas compressor. A closer look on the reforming section reveals that a box type furnace design represents no limits even for very large capacities. The largest top fired Uhde reformer with 960 tubes is in operation in a methanol plant since 1999. A 3,300 mtpd ammonia plant would require only 408 tubes, so enough margin is left with this design even for very high capacity plants.

There are of course alternative ways to produce synthesis gas for the synthesis loop and they have advantages in some area but also disadvantages in other areas. Few of the alternative processes have been used for ammonia production and one should therefore carefully evaluate the process risk before abandoning the conventional process.

Compared to the conventional process, a process which utilises extra load on the secondary reformer by either oxygen enrichment or excess air to the secondary reformer and consequently a smaller or no primary reformer will in the frontend have a larger carbon dioxide wash. Furthermore when adding oxygen to the secondary or auto thermal reformer, the potential for over-reduction of the high temperature shift increases. From an economic point of view the application of autothermal reforming in ammonia plant syngas generation could not be justified due to the considerable costs of the air separation unit.

Since from a technology point of view there is no need to leave the proven primary/secondary reforming concept in ammonia plant syngas generation it can not be expected, that commercial plants in the range of 2,000 – 4,000 mtpd will be based on autothermal reforming in the near future.

The next area of concern when scaling up ammonia plants would be the CO_2 removal section. Manufacturing of the large columns is not such an issue as transport to site and erection. These problems will be more severe with processes which are based on reduced primary reforming. The semi-lean solution pumps have to be configured already as 3 x 50% below 3,000 mtpd. The CO_2 removal unit will require very large piping, especially in the LP-flash vessel overhead section.

Even more important is the piping issue in the synthesis loop since standard piping in the required 1500# rating is only available up to 24". Everything beyond this limit would have to be specially manufactured and would drive plant cost up significantly. Besides the availability also the increased nozzle loads for the equipment due to the increased stiffness of the larger piping represent a problem. This stiffness is increased especially for the high pressure piping due to its high wall thickness. While larger static equipment can also take larger nozzle loads this is not the case for the machinery, where special care has to be taken for the piping connection.

The synthesis gas compressor is by far the most critical piece of equipment in the ammonia plant, it accounts for about 20% of all shutdowns.

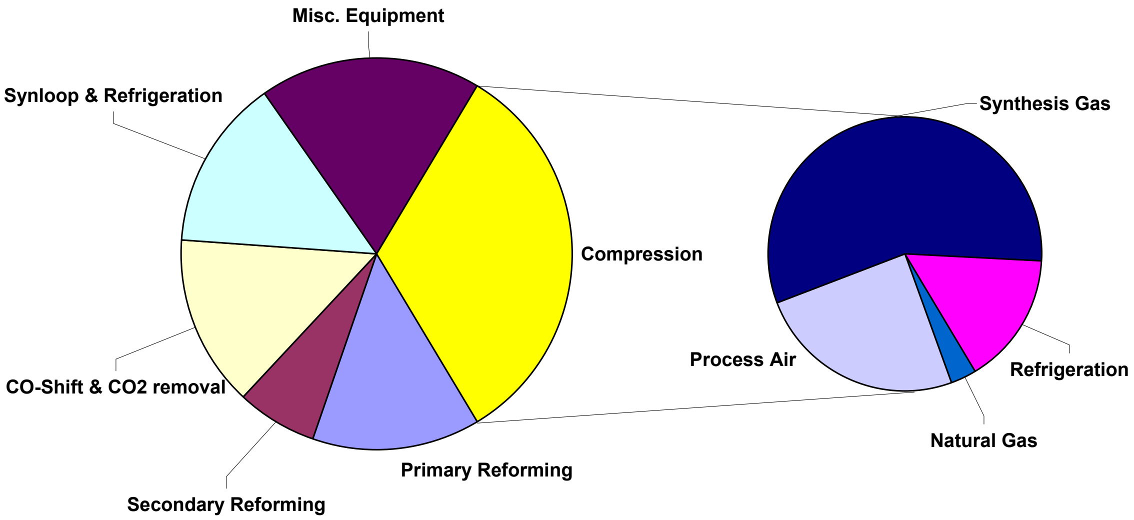

Fig. 3: Distribution of plant sections causing shutdowns

Therefore the reference situation of this compressor is more and more important in new projects and design changes at this equipment are seen very critical. The largest low pressure casing in operation today has been used in plants from 1,100 mtpd up to 2,000 mtpd. At 3,000 mtpd it will be necessary to move to the next casing size if the process is simply scaled up. Alternatively, the process can be modified slightly and an existing machine can be used.

The circulation in the synthesis loop is a function of the conversion per pass across the ammonia converter. A high conversion per pass can be obtained by reducing the ammonia separator temperature, by reducing the inerts level and by increasing the catalyst volume. However, there is only limited scope for increasing the conversion per pass because of the reaction equilibrium constraint; therefore a large-capacity plant will require an increased circulation.

A possibility to reduce the synthesis requirements would be to install a purifier downstream of the methanation and thus to operate an almost inert free loop. As a refrigeration driver a nitrogen excess is required which is also used to compensate for the additional cost of a purifier by shifting load from the primary to the secondary reformer. Therefore the secondary reformer is operated with excess air and the primary reformer can consequently be reduced in size. As already stated above this increases the front end load in general and especially the CO_2 removal unit due to the higher amount of CO_2 to be scrubbed out. So by solving the synthesis scale-up problem additional scale-up problems in the front end are generated.

Coming back to the conventional synthesis the maximum circulation rate is limited by piping diameters and heat exchanger sizes, and the maximum conversion per pass is limited by reaction equilibrium. Hence, if both circulation rate and conversion per pass are approaching practical limits, some other means of increasing capacity is required. This leads to the concept of a two-stage process as a means of increasing capacity without increasing the circulation rate. A number of configurations have been evaluated, some well-known and some novel. Further aims for the new process were to utilise proven equipment designs wherever possible and to achieve the optimum integration of the overall process.

2.2 Dual Pressure Process

The requirement to reduce both, synthesis gas compression requirements and synthesis dimensions lead to the development of the dual pressure concept. By placing a make up gas synthesis unit in-between the two compressor casings and removing a part of the product at this stage both tasks are fulfilled. Conversion of synthesis gas to ammonia at a low pressure requires a special high activity catalyst. The first of the generation of low pressure catalysts, Johnson Matthey’s AMV catalyst, has been in commercial operation since the mid 1980s and has proved to be extremely reliable and trouble-free. With the basic material being magnetite a continuous future competitive pricing compared to some novel precious metal catalysts is ensured.

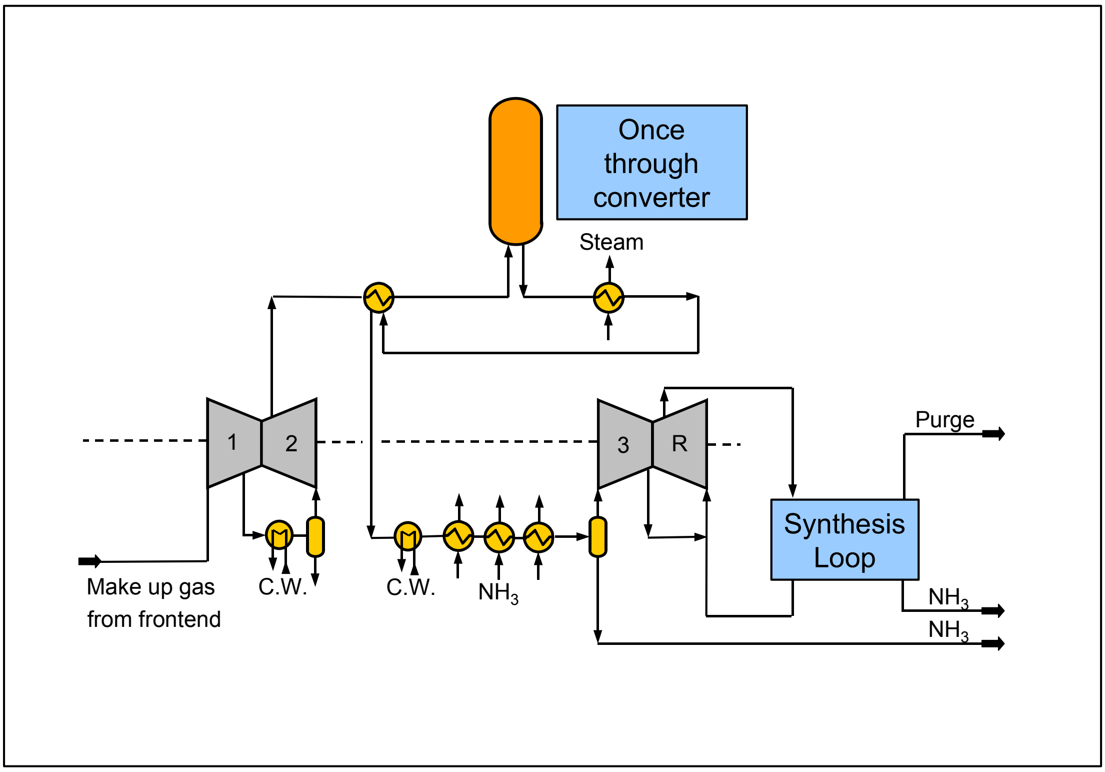

Fig. 4: Principle of the Dual Pressure Process

The patented ammonia synthesis configuration in such a process consists of the following stages:

1. Compression of make-up gas is carried out in two steps, first in a two-stage inter-cooled compressor. This is the LP casing of the synthesis gas compressor. At the discharge of the compressor the pressure is about 110 bar. The pressure range is comparable to the low-pressure processes, which operate with a single-casing synthesis gas compressor. A three-bed, inter-cooled, once-through converter in this location can produce about a third of the total ammonia by utilising Johnson Matthey´s AMV catalyst. Included with the make-up gas and fed to the reactor is recovered hydrogen and nitrogen from the purge gas recovery unit. This unit can be either a membrane unit or a cryogenic unit.

2. The effluent from the converter is cooled and ammonia product is separated. Final cooling is done in stages against ammonia chilling. About 85% of the ammonia produced is separated from the gas, which is further compressed to the synthesis loop operating pressure.

3. The HP compressor casing thus operates at a much lower temperature than normally seen. The benefit of the deep chilling is that each impeller in the HP casing produces more head than is typical for an inter-cooled synthesis gas compressor. That offsets most of the pressure drop throughout the once-through converter.

4. The ammonia synthesis loop operates in the normal pressure range of up to 210 bar and utilises Johnson Matthey standard magnetite synthesis catalyst. The high synthesis loop pressure is achieved by the combination of the chilled second casing of the synthesis gas compressor and a slightly elevated front-end pressure. The front-end pressure required is within the commercial ammonia plant experience of Uhde.

The detailed flowsheet shows that several measures were taken to restrict the number of additional equipment to a minimum by combining chillers having the same refrigeration level. Furthermore the equipment downstream of the make up gas synthesis fulfils a dual function, it is used for separation of the product from the make up gas synthesis as well as chilling of the synthesis gas for the next compression step.

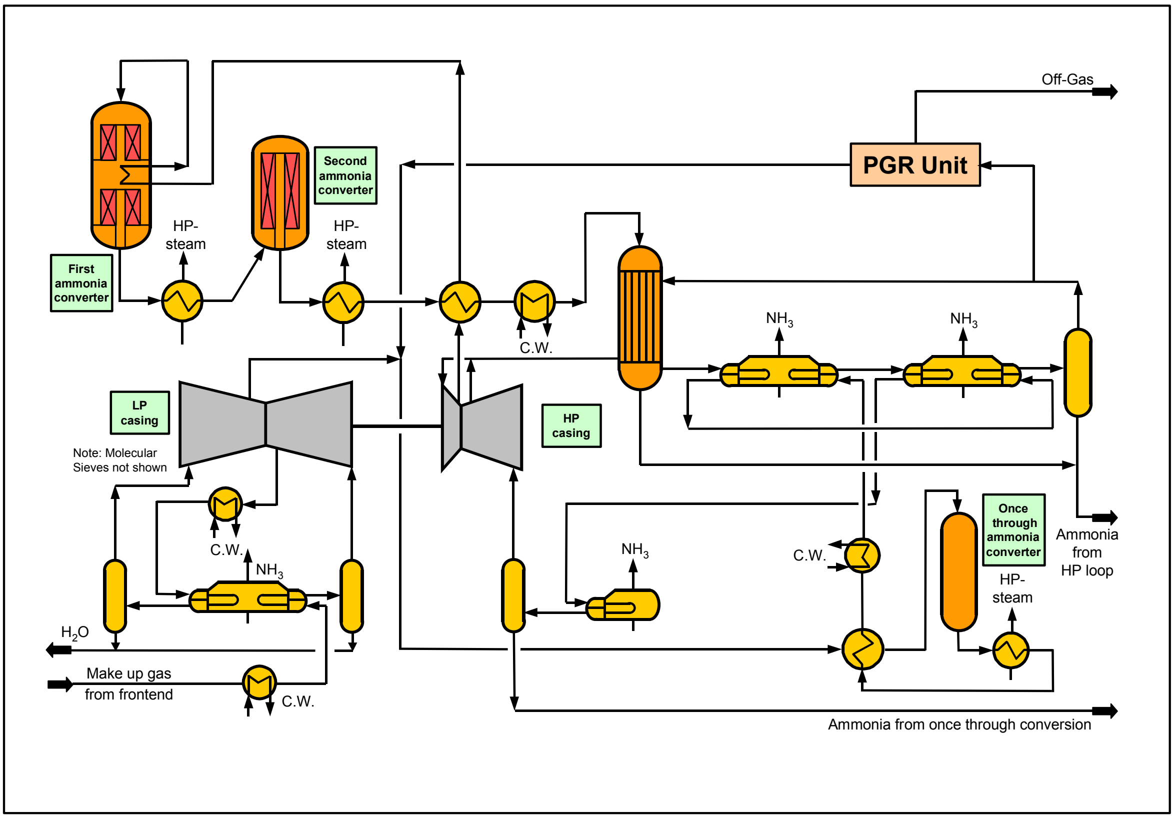

Fig. 5: Uhde Dual Pressure Process

By removing ammonia product at the intermediate pressure, the optimum inert level in the high-pressure synthesis loop is reduced somewhat in comparison with today's norm. That is because only about two thirds of the purge needs to be recompressed to the synthesis loop pressure. About one third is converted to ammonia and removed as product at the pressure level the purge gas is rejected to. The lower inert level improves the operating conditions in the high-pressure ammonia converter; further capacity increase of the synthesis loop is, therefore, possible. Another benefit is that the higher dew point of the reactor effluent stream enables the condensation of ammonia product to be carried out more effectively with more condensation occurring against cooling water. Overall, the result is an energy-efficient ammonia plant design with an ISBL consumption of about 7.1 Gcal/tonne (-33°C product) at climatic data typical for the Middle East.

Thanks to the low inerts level in once-through conversion, the partial pressure of the reactants is higher than in existing low-pressure loops. Therefore the amount of high-activity catalyst in the dual-pressure process is much less than in the existing low-pressure processes. Another advantage is that, in contrast to a high-pressure once-through converter, the first catalyst bed in the dual-pressure process is thermodynamically limited to an acceptable temperature, thus eliminating the need for ammonia injection.

Some of the benefits of the dual-pressure process are:

1. By applying three reactors the overall catalyst volume and heat of reaction can be utilised to a greater extent compared to conventional layouts with one or two converters. Long term proven standard magnetite based catalysts can be used in all ammonia synthesis reactors.

2. High conversion in the high-pressure synthesis loop combined with the reduced production requirement results in reduced piping sizes in the high-pressure loop. Using standard piping it will be possible to reach synthesis capacities of 4,000 mtpd and beyond in this configuration.

3. The synthesis gas compressor is about 20% smaller than in the comparable conventional process and can be mated with a high-efficiency turbine.

4. A very flexible process design is possible with a large number of process parameters available to optimise the utilisation of catalyst and machinery. Among these parameters are, naturally, the amount of product produced in the once-through conversion and the amount separated before compression into the high-pressure synthesis.

With the dual-pressure process it is possible to reach a synthesis capacity of about 3,300 mtpd of ammonia using equipment already in service in plants operating today. Thus the process offers a low-risk path to very large-scale ammonia plants.

3. DESIGN FEATURES OF THE 3,300-MTPD AMMONIA PLANT FOR SAFCO

There is a general requirement for very large plants to be extremely reliable because of the very large loss of revenue whenever the plant is shut down. For that reason, there are no major deviations from established process conditions, and scale-up of the front-end of the process is essentially a matter of pro-rating the current Uhde design but at 3 bar higher pressure which is still within the long term proven design range.

Concerning the natural gas compression and desulphurisation section there are no restrictions for this capacity and references exist from other natural gas processing plants. The natural gas feed has to be compressed using a turbine driven single stage natural gas compressor. Johnson Matthey´s cobalt molybdenum catalyst KATALCO 41-6 together with zinc oxide KATALCO 32-5 and 32-4 in a 85:15 % split will be used in the SAFCO IV plant for hydrogenation respectively sulphur absorption.

The reformer size is about 65% larger than for a 2,000-mtpd plant. For a top-fired box-type reformer, this presents no problem in the radiant section in view of the large-diameter tubes now commonly in use in the Uhde reformer. The standard Uhde reformer uses a cold, refractory-lined outlet manifold system, which is the ideal system for large-capacity reformers.

As stated previously, in the largest reformer based on the Uhde design, which is already operating in a methanol plant, the radiant box has about 100% more tubes than needed for a reformer in a 3,300 mtpd ammonia plant. The primary reformer for the SAFCO IV plant will consist of 408 tubes in 8 rows and will be equipped with 189 burners located at the reformer box ceiling. By applying a top fired reformer a cost efficient and long term proven, reliable design is utilised in this large capacity plant. The combination of a box-type reformer and a cold outlet system is ideal for the higher front-end pressure, which is advantageous for low-pressure synthesis conversion and also for the subsequent high-pressure synthesis. The higher front-end pressure is well within Uhde's operating experience. The 1,000-mtpd ammonia plant of the Zhong Yuan Dahua Group Ltd. located in Puyang, Henan Province, China has been operating with an even higher pressure trouble-free since 1989. Concerning the secondary reformer, the Uhde design utilising a circumferencial vortex burner is very well suited for large capacity plants. The single shaft process air compressor has a power consumption of 24.5 MW in normal operation and will be driven by a condensing turbine.

At 3,300 mtpd, the waste heat boiler downstream of the secondary reformer can be constructed as a single-shell fire-tube boiler. At higher capacity although it will be necessary to use two waste heat boilers in parallel.

The primary and secondary reformer will use Johnson Matthey´s steam reforming catalysts. For the primary reformer the KATALCO type 25-4Q and 57-4GQ will be used. This catalyst type of the latest generation feature an improved Quadralobe four hole shape, which enhances the activity by additional 20% whilst retaining the previous four-hole shape´s excellent heat transfer, pressure drop and strength.

The shift conversion section is conventional, with the normal arrangement of high-temperature (HT) and low-temperature (LT) shift converters and a BFW heater in between. The catalysts used are KATALCO 71-5 for the HT-Shift and KATALCO 83-3 for the LT-Shift. The LT-Shift is configured as a single reactor without separate guard vessel.

The BASF aMDEA system has been chosen for the SAFCO ammonia plant for CO_2 removal. Several manufacturers are capable of producing columns of the required size. However, more of an issue is plant location and transportation of the columns to the plant. The diameter of the absorber which will be installed in Al Jubail will be 6.1 m in the bottom section and 4.1 m in the top section using types of packing normally used in today’s plants. The LP Flash vessel will have a diameter of 7.6 m. The plant site is located close to the sea side with corresponding export facilities so transportation of the equipment to this construction site is no problem at all.

Following the proposal phase with a capacity of 3,000 mtpd the capacity was later revised to 3,300 mtpd to improve the economy of scale even further. Even at this capacity it is possible to utilise a synthesis gas compressor of a size currently used in today’s 2,000-mtpd plants. The Mitsubishi compressor type 5V-8B and 5V-7C has been chosen for the two casing synthesis gas compressor which includes three make up gas and one recycle stage. These compressor models are already in operation in ammonia plants with capacities in the range of 1,500 to 2,000 mtpd. For example at Petronas, Malaysia since 1997, or at SAFCO itself and at P.T. Kaltim, Indonesia since 1998. Also other compressor manufacturers like Nuovo Pignone would have been in a position to supply referenced compressor models for the Safco IV plant. By having a number of references for the most delicate equipment in an ammonia plant the risk of the capacity leap from 2,000 mtpd to 3,300 mtpd is reduced considerably.

A synthesis gas compressor in a conventional plant uses about 13.3 kW/mtpd (26.6 MW at 2,000 mtpd). This contrasts with about 8.7 kW/mtpd (28.6 MW at 3,300 mtpd) for the dual-pressure process, and the difference contributes to the efficiency of the process.

It is possible to reach even larger capacities if the casing sizes of the synthesis gas compressor train are increased to the next size. For a 4,000-mtpd dual-pressure process compressor manufacturers have already sized the synthesis gas compressor and turbine. The required HP casing has already been used in ammonia plants, whereas the required LP casing has so far only been in natural gas compression service.

The once-through converter is a three-bed, inter-cooled design in a single vessel utilizing KATALCO 74-1 catalyst. This is a high-activity catalyst that was specifically developed for low-pressure synthesis in ICI's AMV and LCA processes. High activity over many years has now been demonstrated, with several charges of this catalyst giving excellent performance after more than 10 years. A particularly relevant example is the 1,000 mtpd ammonia plant of the Zhong Yuan Dahoa Group Ltd. in Puyang, China, where KATALCO 74-1 has been operating since 1989 in a converter designed by Uhde. The proposed once-through converter will be similar to that one, although the catalyst volume will be smaller because of the very low concentration of inerts and zero ammonia at the inlet. Heat recovery downstream of the once through converter will be accomplished by HP steam generation and boiler feed water preheating. With the deep chilling down to –16°C for condensation of the product downstream of the once-through synthesis reactor the third stage of the synthesis gas compressor can operate very effectively and the pressure drop of the once-through synthesis is more than compensated.

For the high-pressure synthesis loop, a conventional magnetite-based catalyst such as KATALCO 35-4 remains the most cost-effective option. The catalyst inventory loaded in the synthesis loop reactors is comparable to a conventional 2,000 mtpd ammonia plant. Another benefit of the dual pressure system is that the whole synthesis loop can be constructed with 20" or smaller standard piping. Due to the availability of also 24" standard piping even larger ammonia plants can be constructed economically. The specific steam production from the synthesis loop will remain the same as in a 2,000-mtpd plant; the waste heat boilers will be of about the same duty and size.

There are two main contributions to the refrigeration duty; chilling downstream of the once-through converter and chilling in the high-pressure loop. The overall refrigeration requirement per tonne of ammonia increases slightly, by about 10% on account of the reduced syngas compression requirements. A single turbine driven two casing compressor with four stages will be used for all refrigeration duties. Conventional, well-proven machines has been chosen for both the compressor and the steam turbine.

4. UREA PLANT, OFFSITES AND UTILITIES

Beside the 3,300 mtpd ammonia plant an urea plant and the necessary offsites and utility facilities belong to the fertiliser expansion project of SAFCO and are included in the contract.

An Urea Plant with a capacity of 3,250 mtpd will be installed downstream the ammonia plant using part of the ammonia and the CO2 produced in the ammonia plant as feed for the STAMICARBON urea synthesis. The product is a granular type urea produced in a HYDRO AGRI urea granulation section which is designed to produce 3,600 mtpd granular urea product.

The required offsites and utility units for an independent operation of the new installation consist of the following units:

- Atmospheric ammonia storage tanks

30,000	mt	at plant location
20,000	mt	at port location

- Urea bulk storage

56,800	mt	at plant location
66,000	mt	at port location

- Sea water cooling tower for the expansion with a design circulation rate of 66,000 t/h

- Closed cooling water system, design circulation rate 27,500 t/h

- Water demineralisation and condensate polishing

- Two package boiler producing 150 t/h MP steam each.

and all the other secondary units e.g. instrument air supply, inert gas generation, fire fighting systems, chilling units etc. All units and subsystems are designed such to accommodate all possible modes of operation e.g. start up and shut down of individual plant sections and partial load of operation. Furthermore the new installation is extensively integrated into the existing facilities to allow a flexible, reliable and economical operation of the existing plants as well as the new installations.

5. SUMMARY

Following the reduction in specific energy consumption and the relocation of production to areas of low cost natural gas the only chance left to improve production economics is an increase in the plant size. The challenge is to achieve the desired economies of scale whilst retaining proven technology to minimise the scale-up risk. Uhde has therefore developed the Dual Pressure Process which allows the design of a 3,300 mtpd ammonia plant with no critical high-pressure equipment exceeding the sizes of current 2,000 mtpd plants. The key to the new flowsheet is the implementation of a once-through synthesis in-between the two synthesis gas compressor casings at a pressure of 110 bar.

The first commercial application of the new technology will be the SAFCO IV ammonia plant in Al-Jubail, Saudi Arabia. This plant will have a name-plate capacity of 3,300 mtpd which is about 60% higher than the largest name plate capacity being currently installed world-wide. The SAFCO IV ammonia plant is part of a new ammonia / urea fertiliser complex being already under construction and will commence operation in early 2006