

Topsøe's Ammonia Technology Today

RESEARCH | TECHNOLOGY | CATALYSTS



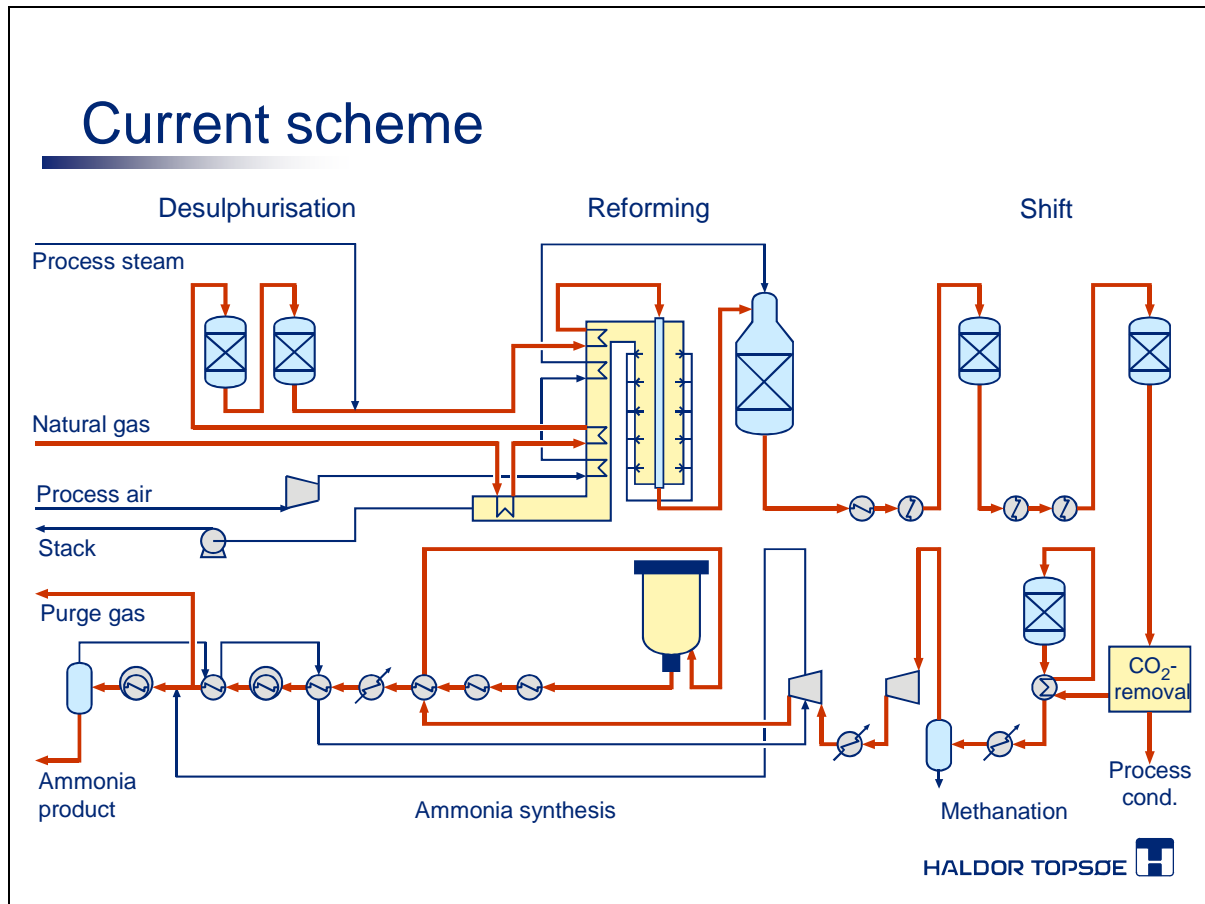
Outline

- Today's ammonia technology
 - Current design
 - Developments
- Highlights of specific process features
 - Reforming section
 - Ammonia synthesis converter
- Reference situation
- Future trends
 - Capacity
 - Process lay-out
 - Potential for large plants
- Conclusion

Outline

The current design will be described, and developments in reforming an ammonia synthesis will be described in detail. The actual reference situation will be considered as well.

Finally, the trends for future ammonia plants will be discussed, and alternative schemes for very large ammonia plants will be described.



Current Scheme

The Topsøe Low Energy Ammonia Process features a well-proven concept – desulphurization, primary and secondary reforming, two-step shift conversion, carbon dioxide removal, methanation, compression, ammonia synthesis, and product recovery.

The process lay-out is identical to the scheme proposed many years ago, but the performance has significantly improved due to improvements in catalysts and new developments in equipment designs.

Developments

- High flux primary reformer with prereformer
- HTER (Haldor Topsøe Exchange Reformer)
- S-300 converter
- Improved catalysts

Developments

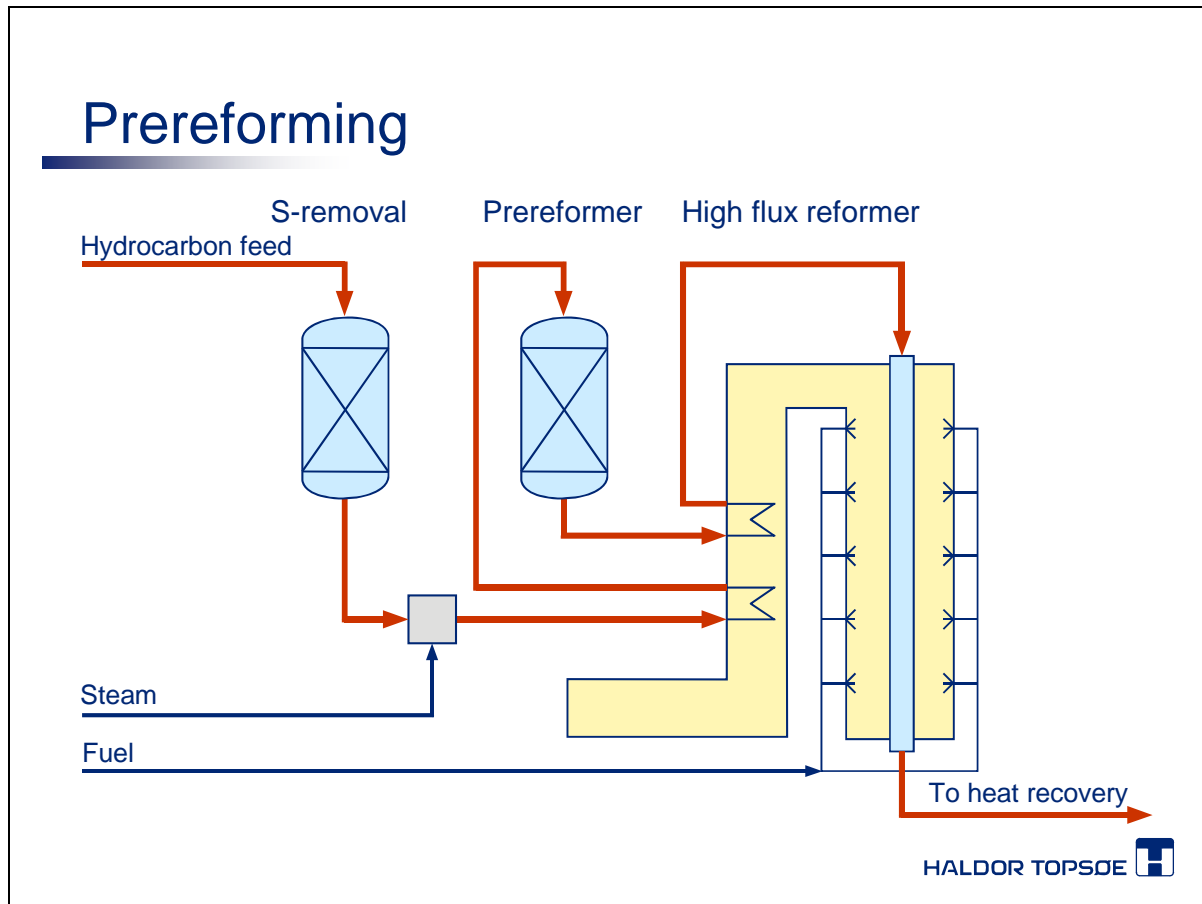
Two main areas have significant impact on the performance and cost of an ammonia plant – the reforming section and the ammonia synthesis section.

In particular the design and performance of the side-fired primary reformer has been significantly improved. This has been possible due to the availability of better tube materials with higher strength. Better tube materials permit a reduction in tube wall thickness, thus reducing the level of thermal stress in the tube wall, which again will give potentials for increased lifetime of the tubes. Very high heat flux can be accepted in a modern type reformer, and with a prereformer in front of the reformer the acceptable heat flux can be increased further.

A new Haldor Topsøe Exchange Reformer (HTER) has been developed and commercialised. This new equipment allows reduction of the size of the primary reformer, and of the plant steam production.

In the ammonia synthesis section, the 3-bed radial flow converter – the S-300 – has been developed and commercialised as an improved version of the work horse - the S-200. A highly efficient combination of the S-300 converter and the one-bed S-50 converter – the S-350 synthesis loop – has been developed.

In general introduction of improved catalysts have made the designs of the reactors more compact and efficient.

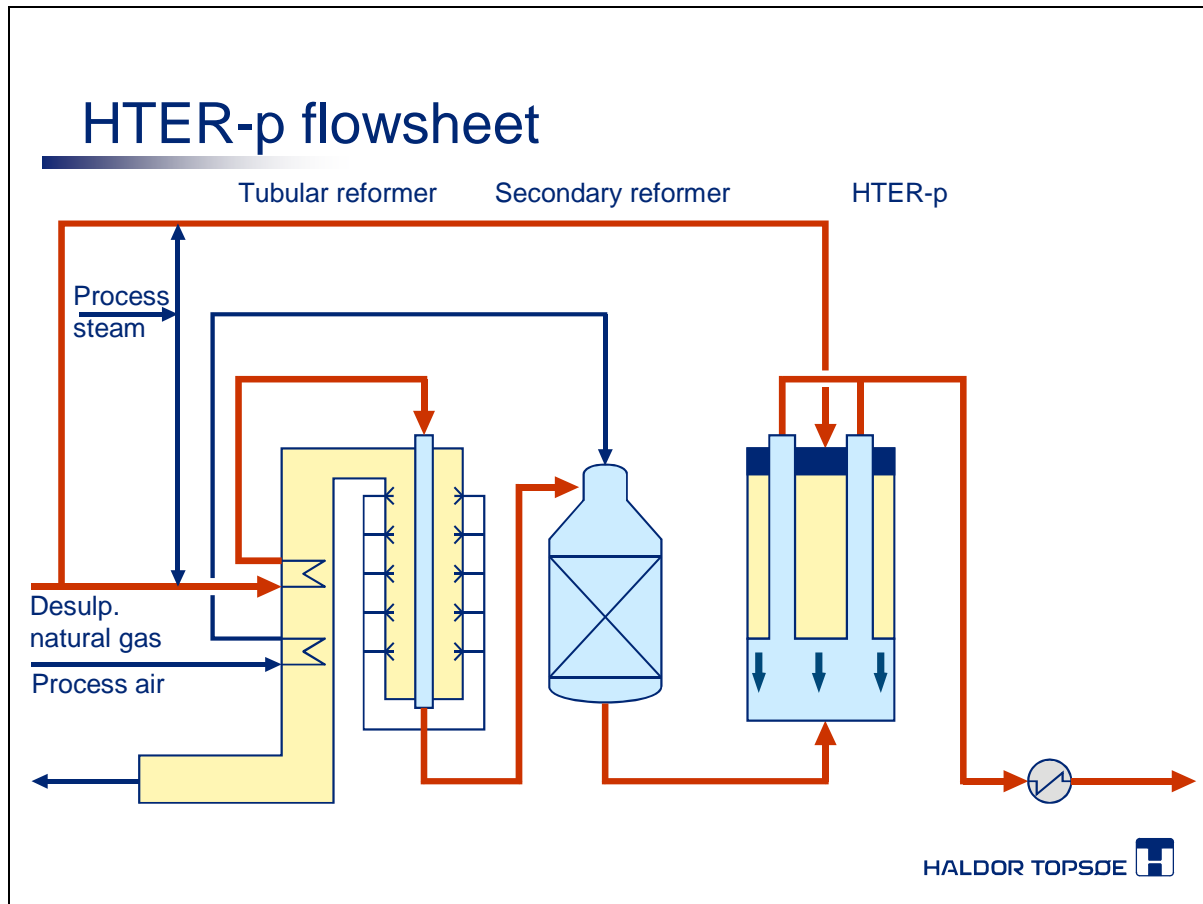


Prereforming

Adiabatic prereforming can be used for steam reforming of feedstocks ranging from natural gas to heavy naphtha. In the prereformer all higher hydrocarbon are converted into a mixture of carbon oxides, hydrogen and methane. When a prereformer is installed as shown in the figure, the primary reformer has to reform methane only, and at the same time at sulphur free conditions, because the prereforming catalyst will pick up sulphur components quantitatively. This is one of the reasons for allowing a much higher heat flux in the high flux reformer.

The prereformed feed can be reheated to 650°C before entering the primary reformer. This will result in reduced firing in the primary reformer, and thereby a reduced fuel consumption. When the hot flue gas is used to reheat the reformer feed, the amount of heat available for HP steam production is reduced. This will result in a reduced HP steam production in the ammonia plant.

In general, the reformer size can be reduced by about 25% in a natural gas based plant by incorporating a prereformer.

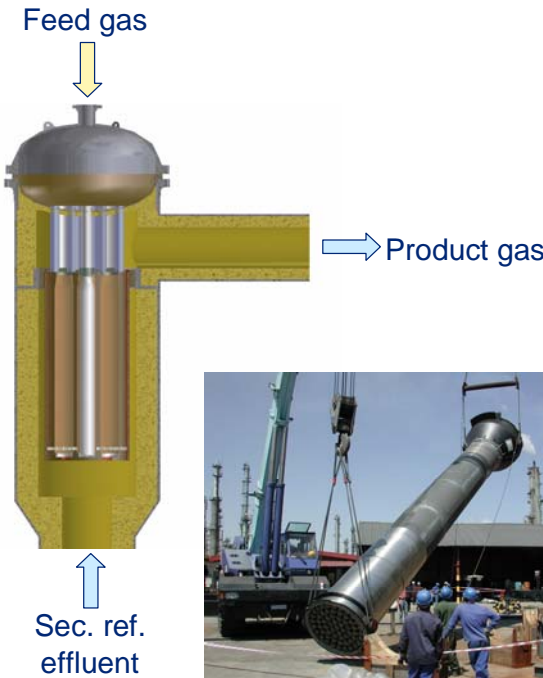


HTER Flowsheet


Another feature that can be used to reduce the size of the primary reformer, and at the same time reduce the HP steam production, is the HTER (Haldor Topsoe Exchange Reformer). This is a new feature, initially developed for use in synthesis gas plants. In ammonia plants this unit is operated in parallel with the primary reformer.


The HTER is heated by the exit gas from the secondary reformer, and thereby the waste heat normally used for HP steam production can be used for the reforming process down to typically 750–850°C, depending upon actual requirements. Operating conditions in the HTER are adjusted independently of the primary reformer in order to get the optimum performance of the overall reforming unit. Typically up to around 20% of the natural gas feed can in this way by-pass the primary reformer.

The HTER-p



- Compact
- Optimised utilisation of pressure vessel volume
- Allows for removal of internals
- No restriction of thermal movement



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The HTER-p

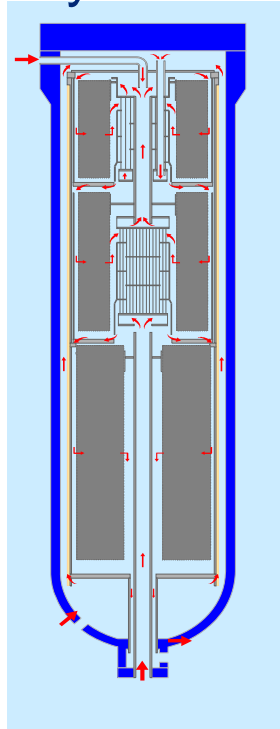
The HTER is a very compact, combined heat exchanger and catalytic reactor. Heat transfer surfaces match the catalytic reactions taken place in the catalyst in such a way that the pressure vessel volume is minimised.

The steam to carbon ratio can be adjusted individually to the HTER-p and the tubular reformer to assure optimal conversion of methane.

The HTER-p is like a normal heat exchanger where the tube bundle can be removed, if desired.

Thermal movement due to changing operating conditions is unrestricted since mechanical design allowing the bundle to expand freely downwards.

S-300 ammonia synthesis converter



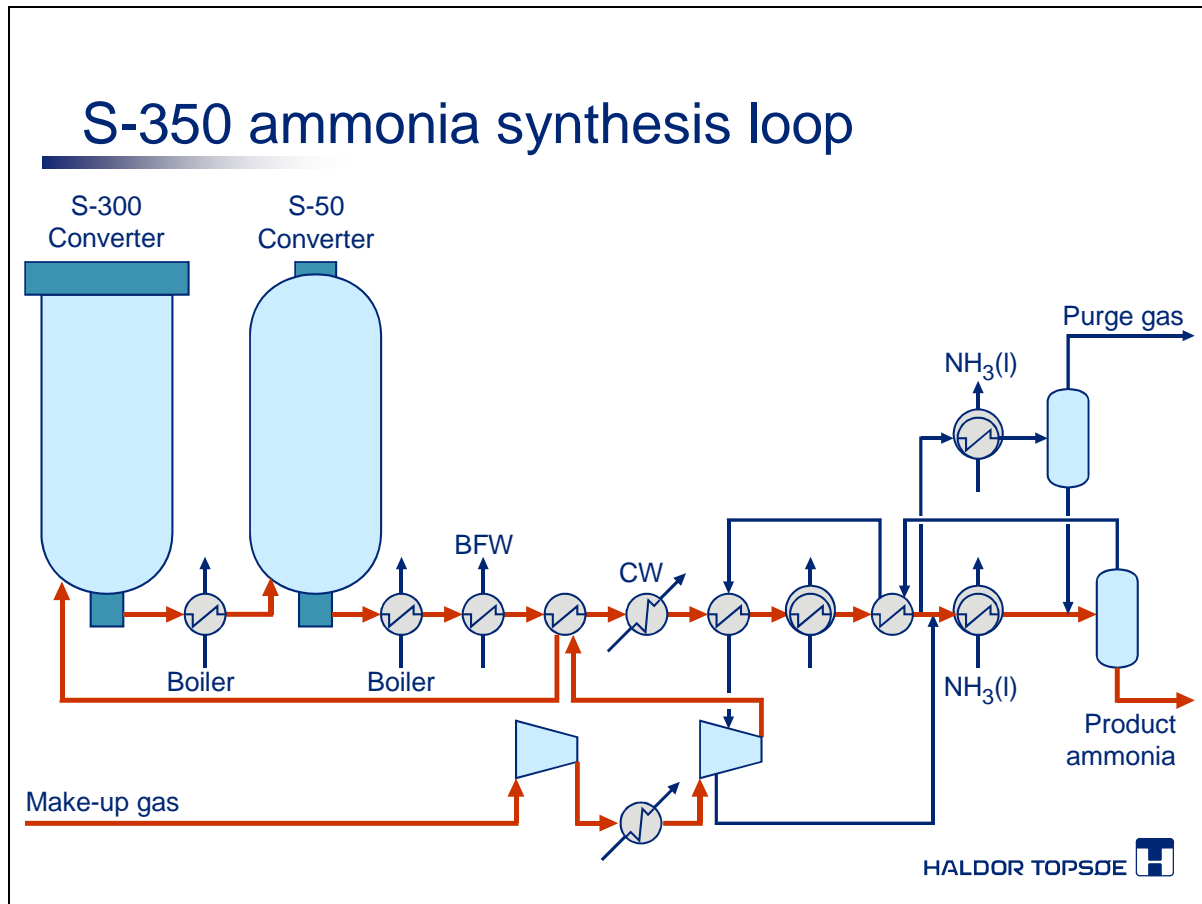
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S-300 Ammonia Synthesis Converter

In the ammonia synthesis loop, an updated version of the radial flow converter has been developed – the S-300.

The S-300 converter features three radial flow catalyst beds and two interbed heat exchangers.

With the S-300 converter, the catalyst volume can be reduced by approx. 20% compared with the S-200 converter for the same ammonia conversion. Alternatively, when the feedstock is expensive, the ammonia conversion can be increased for the same catalyst volume to reduce to specific energy consumption.



S-350 Ammonia Synthesis Loop

The figure above describes a typical Topsøe ammonia synthesis loop.

As can be seen, the loop comprises two ammonia converters, i.e. a S-300 followed by a S-50 converter. The S-50 converter is a single bed radial flow converter, which is added downstream of the main converter to increase the ammonia conversion, and at the same time to improve the steam generation. By having two converters, the heat of reaction after the last bed in the first converter can be utilised for boiling or superheating of HP steam, and the two converter configurations can be used as a mean to close the overall plant steam balance, if the waste heat available for boiler feed water preheat and boiling of steam is not in balance.

References – current scheme

- Profertil, Argentina started up 2000
 - With a capacity of 2,050 MTPD of ammonia in one single line, this is one of the world's largest grassroots plants. The plant produces ammonia for urea
- PT Kaltim Pasifik Amoniak, Indonesia started up 2000
 - This ammonia plant has a capacity of 2,000 MTPD in one single line. The ammonia plant is a stand-alone plant
- Sohar, Oman, start up ultimo 2007
 - This ammonia plant has a capacity of 2,000 MTPD in one single line. The ammonia plant produces ammonia for urea
- Engro, Pakistan, start up 2010
 - This ammonia plant has a capacity of 2,200 MTPD in one single line. The ammonia plant produces ammonia for urea

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References – Current Scheme

Profertil in Argentina with a nominal capacity of 2,050 MTPD is the largest operating grassroots ammonia plant designed by Topsøe. It is part of an ammonia-urea complex constructed by Snamprogetti, Italy, and has been in successful operation since year 2000.

P.T. Kaltim Pasifik Ammoniak plant in Indonesia is a stand-alone ammonia plant with a nominal capacity of 2,000 MTPD constructed by MHI (Mitsubishi Heavy Industries), Japan and successfully started up in year 2000.

The Sohar plant in Oman is under construction by MHI. This will be a 2,000 MTPD ammonia plant producing ammonia for urea. Start-up is scheduled for the end of year 2007.

Finally, the Engro Plant in Pakistan is in the engineering and procurement phase with Snamprogetti as the Contractor. This will be a 2,200 MTPD ammonia plant producing ammonia for urea. Start-up is scheduled for year 2010.

General reference information

■ Energy consumption

- Lowest specific energy consumption achieved in PT Kaltim Pasifik Amoniak, Indonesia: 6.6 Gcal/MT NH₃
- Generally: Figures between 6.5 – 7 Gcal/MT NH₃ can be achieved in a new plant depending on site conditions

■ Maximum production

- Highest ammonia production achieved in Profertil, Argentina: 2,295 MTPD

General Reference Information

The ammonia plant with P.T. Kaltim Pasifik Amoniak was designed for low specific energy consumption. The plant features aMDEA CO₂-removal, ammonia synthesis loop with a S-200 and a S-50 converter and a cryogenic purge gas recovery unit.

The highest recorded capacity in a Topsøe designed ammonia plant was achieved in the Profertil plant in Argentina. This plant has produced as much as 2,295 MTPD of ammonia on a continuous basis.

Trend in capacity

- Capacity year 1980 - 1995
 - 1,000 – 1,750 MTPD

- Capacity year 1995 – 2006
 - 2,000 – 3,300 MTPD

- Capacity year 2007 - ?
 - 2,000 - ?

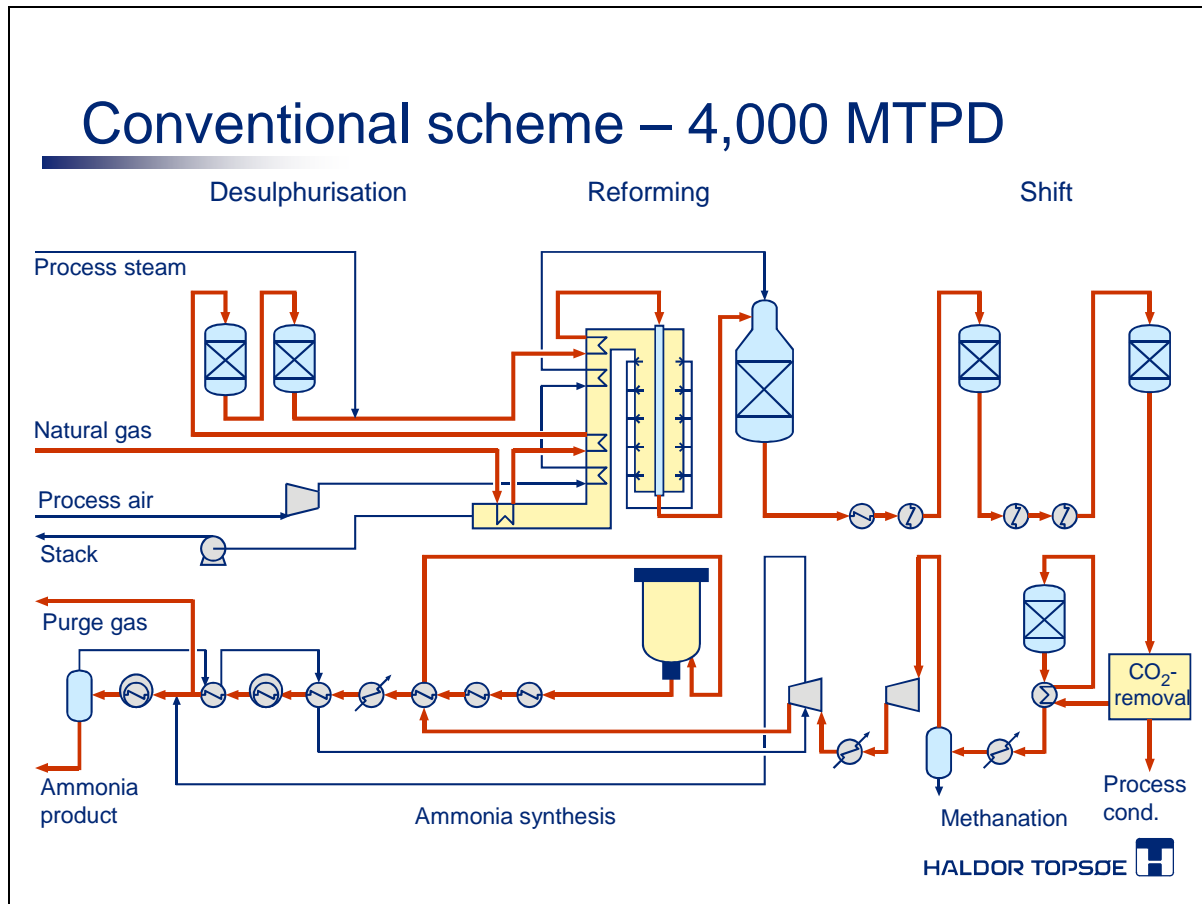
- What are the possibilities?

Trend in Capacity

What is the future trend of the ammonia technology?

The market is focusing on larger and larger plants in areas where the gas cost is low, like The Middle East, Australia, and Trinidad. Capacities have already gone up for the last 25 years, and the experience with scaling up is therefore quite significant.

Will a further scale up of the plant capacities known today still be possible with the technology known today. The available possibilities will be described in the following.



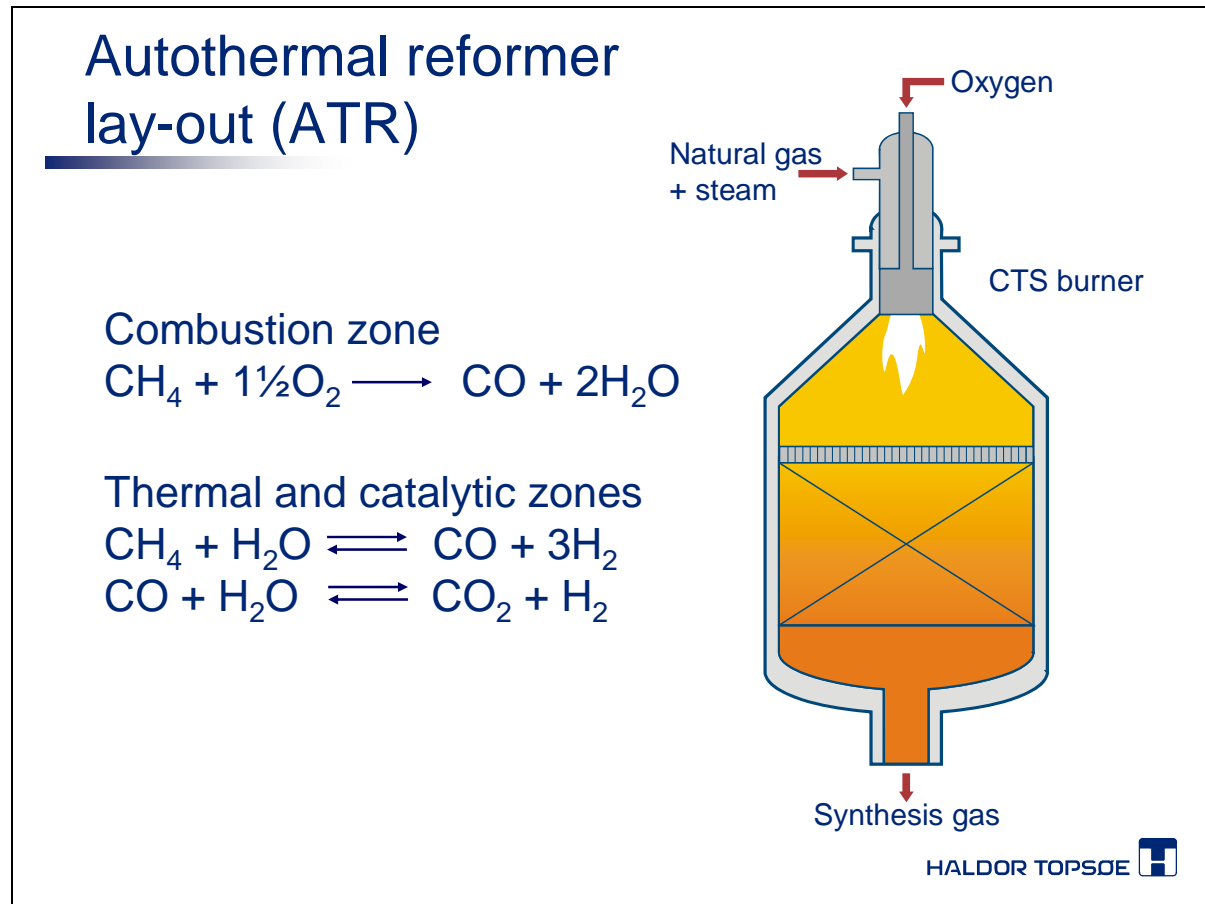
Conventional Scheme – 4,000 MTPD

The 'conventional' scheme can be scaled further up compared to the capacities being considered today. This is a simple scale-up where optimised operating conditions for the reforming section and the ammonia synthesis loop in particular are defined in order to keep the equipment size at a minimum.

Looking at the investment cost, the reformer cost goes up more or less proportionally with the number of tubes, and since the reformer cost is a significant part of the overall plant cost, fully effect of economy of scale is not applicable in this scheme when the reformer becomes larger and larger.

From an energy point of view there is, however, no doubt that this scheme is very energy efficient and gives the lowest specific energy consumption figures of all schemes considered for large-scale plants.

Our investigations show that up to a capacity of approx. 4,000 MPD this is the preferred scheme.



Autothermal Reformer Lay-out (ATR)

In the ATR, partial combustion of the hydrocarbon feed with oxygen is followed by conversion by the steam reforming reactions in the catalyst bed. The exit temperature is typically above 1000°C, and this ensures low CH₄ leakage even at high pressure.

Contrary to the primary reformer (where the cost increases almost proportionally with the number of tubes), the ATR is scaled up by increasing the size of the adiabatic reactor. In such a case there is a benefit of the economy of scale, and the cost will not increase proportionally to the capacity increase.

Also for the air separation unit (ASU), supplying oxygen for the ATR and nitrogen for the NWU, there is a benefit of economy of scale. Especially for capacities above 4000 MTPD the ATR along with an ASU becomes attractive from investment point of view compared to the "conventional" scheme previously described.

Energy consumption is however, slightly higher for the ATR scheme compared to the "conventional" scheme. Mainly due to the energy consumption of the ASU. However, in cases where the gas is cheap, this is normally considered of minor importance.

The autothermal reformer (ATR)

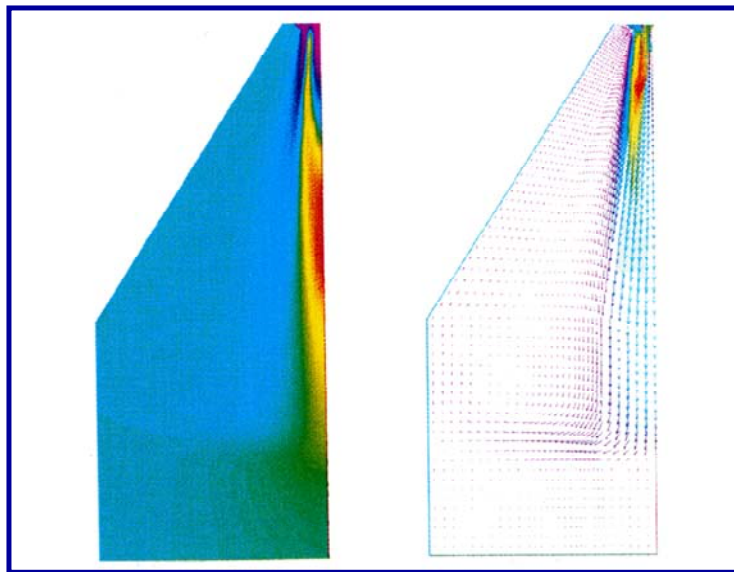
- Refractory-lined pressure vessel
- Combustion and thermal and catalytic reactions
- Special designed burner

The Autothermal Reformer (ATR)

The ATR is a refractory-lined pressure vessel, in principle similar to the secondary reformer.

Combustion of the hydrocarbon feed takes place with oxygen, and this requires a different burner design than the nozzle type burner normally used in the air-fired secondary reformer.

Computational fluid dynamics

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Computational Fluid Dynamics

The design and further development of the ATR reactor is carried out by advanced models which have been developed and optimised over many years. Transient simulations in 3 dimensions by computational fluid dynamics (CFD) are used to calculate the flow distribution in the combustion chamber and for design of the CTS burner. The graph shows the calculated temperature distribution and the velocity profiles in the combustion chamber.

CTS burner

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CTS Burner

The photo shows a burner for the ATR under final preparation in the workshop. The burner supplied by Topsøe is a proprietary piece of equipment.

ATR features

- ATR is used in many different industries
 - Gas-to-liquids (GTL)
 - Methanol
 - Ammonia
 - Synthesis gas generation
- Simple unit operation
- Well-proven technology in Topsøe ammonia plants since 1958
- Easy to scale up to very large capacities

ATR Features

The ATR is not a new development. Topsøe has designed ATR's for many years. The first ATR was installed in an ammonia plant in 1958.

Since then the ATR has been found useful in many different types of process plants such as gas-to-liquids (GTL) plants, methanol plants and for various synthesis gas applications. This means that the knowledge and experience from these technologies can advantageously be transferred and used also for designing very large ammonia plants.

References – ATR scheme

- Statoil, Norway, start up 1997
 - Capacity corresponds to 2,700 MTPD NH₃
- Sasolburg, South Africa, start up 2004
 - Capacity corresponds to 2 x 2,600 MTPD NH₃
- Oryx, Qatar, expected start up 2nd Q 2006
 - Capacity corresponds to 2 x 6,150 MTPD NH₃
- Escravos, Nigeria, expected start up end 2008
 - Capacity corresponds to 2 x 6,150 MTPD NH₃
- Ar-Razi, Saudi Arabia, expected start up 2008
 - Capacity corresponds to 5,700 MTPD NH₃

References – ATR Scheme

The capacities of selected reference plants are given above. The production of H₂ and CO in the ATR has been converted into equivalent ammonia production.

As can be seen, the equivalent ammonia capacities are impressive, and the reforming unit as such is not the bottleneck for the plant capacity. Actually, the ATR can be made even bigger than shown above.

For the rest of the plant equipment, we have studied a capacity of 5,000 MTPD, and found it possible to design a single stream plant for this capacity. For even higher capacities some of the equipment might be duplicated, however depending upon a case to case decision.

Comparison of process schemes for very large ammonia plants

Process concept	Steam reforming	ATR
Capacity, MTPD	4,000	5,000
Steam reforming	Yes	No
Secondary reforming	Yes	No
ATR	No	Yes
Final purification	Methanation	N ₂ wash
Synthesis loop configuration	S-350 with inert	S-350 Inert-free
Net energy consumption, Gcal/MT NH ₃	Base	+ 6%
Rel. specific investment (per MT NH ₃ capacity)	Base	-14%

Comparison of Process Schemes for Very Large Ammonia Plants

At very high capacities, the ATR scheme has an advantage with respect to investment cost due to the economy of scale considerations mentioned earlier.

The energy consumption is approx. 6% higher, mainly due to the consumption of the ASU.

Potential for large plants

- Economy of scale
 - Conventional scheme beneficial up to about 4,000 MTPD NH₃
 - Benefit for the ATR scheme above 4,000 MTPD NH₃ (ASU and ATR size scale up)

- Front-end size
 - Very large synthesis gas production units based on ATR can be constructed, e.g. for several synthesis units like ammonia and methanol

Potential for Large Plants

For ammonia plants, a change in technology around 4000 MTPD of ammonia is beneficial. The ATR scheme is preferred at higher capacities. This is due to the scale up advantages of the ATR and the ASU in particular.

An ATR based front end can be made to produce even very large amounts of synthesis gas. One ATR can produce synthesis for several large downstream synthesis unit, like for example ammonia and methanol.

Conclusion

- Ammonia technology is continuously developed by introduction of new equipment designs and improved catalysts
- Two viable schemes based on Topsøe technology
 - Conventional
 - ATR
- The most attractive scheme will depend on:
 - Plant capacity
 - Operating cost (cost of natural gas)
 - Investment (cost of capital)

Conclusion

Today we see two viable schemes for ammonia production. The choice between the two schemes depends on plant capacity, cost of plant feedstock and cost of capital.

The optimum design will be tailor-made by Topsøe based on the actual conditions for the specific site.