

nitrogen + syngas

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Ammonium nitrate regulation

Syngas project listing

Smaller scale ammonia plants

Bimetallic tube for nitric acid applications

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Johnson Matthey
Process Technologies



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Cover: Fertilizer plant under construction.
Alfredo Allais/ iStockphoto.com



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N₂O abatement
Extra benefit of secondary catalyst.



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Small-scale ammonia plants
Minimising the transport risk and cost of ammonia.

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REGULARS

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No end in sight for nitrogen's bear market



Nitrogen prices have been trading at several year lows over the past couple of months, reaching levels not seen since the global financial crash in 2010-11. Declines have been most notable in the continental United States, where New Orleans ammonia barge prices dropped to \$220/short ton and mid-West ammonia prices \$360/st. Urea and particularly UAN prices were also at their lowest levels for some time.

A flood of new capacity is to blame for these falls, planned and often paid for a few years ago when prices were better. China alone has added several million tonnes of new capacity and is continuing to add several million more – nearly 15 million t/a between 2015 and 2020. While much of this is replacing older capacity based on more expensive anthracitic coal, and while China has been content to run at much lower operating rates than would be normal elsewhere, this makes for a variable tap of urea exports which have pushed prices to the level of Chinese marginal producers.

And there is more to come. In the US, new capacity is coming on-stream throughout 3Q 2016 at CF Industries sites at Port Neal, Iowa, and Donaldsonville, Louisiana, as well as the OCI plant at Wever, Iowa, and Dyno Nobel/Incitec at Waggaman, Louisiana. New ammonia capacity in the US totals 3.5 million t/a, mostly destined for UAN production, but 1.3 million t/a of which will be available for the merchant market. There is also new urea capacity in India, Indonesia and Malaysia, and a 700,000 t/a ammonia plant for Acron at Veliky Novgorod in Russia. As we noted in the previous issue, the easing of sanctions on Iran is also helping more of its product find the market, while the country's investment into new ammonia/urea capacity has been rejuvenated.

The surge in new capacity is not over yet – another 7 million tonnes of urea capacity is due next year and 6 million tonnes the year after. Some will no doubt be delayed, but capacity addition is going to outpace new demand until 2018 at least.

On the demand side, meanwhile, fertilizers traded in dollars are also more expensive for places outside the US and countries whose currencies are pegged to the dollar.

Low oil and gas prices and the slowdown in the Chinese economy have also played their part in reducing commodity prices across the board, and have filtered through into lower grain and fertilizer prices. Low prices impact on company profit margins and hence stock performance, so it is perhaps no surprise that it tends to be at the bottom of the market that mergers and acquisitions activity tends to pick up. In that context, the announcement of merger talks between Agrium and PotashCorp is perhaps no great surprise. Last year's discussions between OCI and CF Industries finally come to nothing, and nor did Yara's bid for CF, and Agrium-PotashCorp may go the same way, but it is a signal that we may expect some major deals and potential subsequent capacity rationalisation to follow. The M&A activity in downstream producers has also been mirrored by technology suppliers – KBR's purchase of Weatherly, for example, and Casale's acquisition of Chemoprojekt and then subsequently of the GPN nitrogen technology portfolio from Borealis. As margins tighten so all producers are likely to be looking hard at operating costs and efficiency and optimising their value chain.

Richard Hands, Editor

“The surge in new capacity is not over yet



Late seventies, Kuwait Melamine plant under construction

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Price trends



MARKET INSIGHT

Laura Cross, Senior Analyst, Integer Research, assesses price trends and the market outlook for nitrogen.

NITROGEN

The nitrogen market remains in a markedly weakened state amid burgeoning global oversupply coupled with recent decreases in the marginal cost of production. The summer months signal a period of quiet demand, and beyond the now familiar low nitrogen price environment, the key market trends in the last few months have centred on company updates and developments.

It was confirmed on 30th August 2016 that PotashCorp and Agrium are in discussions over a potential merger of equals. Integer has written at length about the need for consolidation in both the nitrogen and potash markets, and we think this merger makes sense in both cases. Indeed, following recently terminated merger discussions with CF and OCI in the nitrogen space, and PotashCorp and K+S in the potash industry, it was a matter of time before heard the next rumours of industry M&A activity. In the nitrogen business, Agrium and PotashCorp are direct competitors whose main focus is on the North American market, although both have international interests. The recent largescale merger proposals in the nitrogen sector have involved companies with asset bases and company structures more heavily nitrogen focused (such as the unsuccessful CF Industries-OCI

and the CF Industries-Yara options). Both Agrium and PotashCorp have been relatively cautious in investment in new nitrogen plants in the region, allowing others to take the lead in the wave of recent capacity investment in the region. Instead the two companies have generally focussed nitrogen investment on brownfield expansions. Combined, the two companies would rival CF Industries as one of the largest nitrogen producers in North America. At first glance, the merger seems unlikely to bring enough concentration in any nutrient to raise regulators' concerns, and consolidation would be welcome given that fertilizer supply competitiveness is intense while markets remain long on supply. The merger also makes sense in terms of vertical integration; Agrium has been developing its downstream business over a number of years, and the newly merged company would likely benefit from pushing more N, P and K product through the supply chain.

Also in the North American market, it is almost four years since the first wave of new nitrogen plants in North America began construction, and H2 2016 is set to see some key projects reaching completion. Incitec Pivot Ltd. (IPL) and CF Industries began construction of new ammonia plants in 2013 and according to the latest announcements from the producers, both sites are now on

schedule to begin production in the third quarter of this year. The new Incitec plant in Waggaman, Louisiana, will add 800,000 tonnes of ammonia to the market once it is running at capacity. CF's new plant is located at the existing Port Neal, Iowa, nitrogen complex and is now reported to be mechanically complete. The plant will have annual capacity of 850,000 tonnes of ammonia and 1.3 million tonnes of urea, with the added capacity at the plant expected to triple the Port Neal fertilizer complex's daily production of ammonia.

Of key importance to international urea market participants and watchers is the volume of Chinese urea exports and its sensitivity to urea prices. The rapid increase in exports over the last few years has had a profound effect on the international urea market balance and pricing – Chinese export volumes have gone up, prices have gone down. There is now official data showing that this is starting to move into reverse. China is withdrawing some production volumes from the international market unable to make money at current prices. Chinese urea exports declined by 25% year-on-year in the first half of 2016 to 5.05 million tonnes, according to Chinese customs data, and there is a similar pattern for other nitrogen products. Chinese UAN exports fell by 35% year-on-year to 208,646 tonnes in the first half of 2016, mainly due to reduced exports to the US. Chinese AN exports also deteriorated by 17% year-on-year to 152,296 tonnes during the same period, with a major decline in trade with Southeast Asia.

Given the seasonal slowdown in global demand in July and August, the decline in Chinese urea exports has not been sufficient in correcting the chronic oversupply and imbalance in the global urea market so far. Yet it is an important development as it confirms that Chinese urea production is reasonably rational, and there is a price floor. The drop in urea exports fits with our China urea cost model from which we can derive likely urea exports for a given international urea price. Also of interest are the developments in the Chinese coal market. Chinese coal prices had been falling, but this has stalled over the past few months and the latest price level is equivalent to around US\$3.2/MMBtu. The Chinese government also looks to be seriously looking at taking significant steps to rationalise the coal industry in order to deal with spare coal capacity, which suggests it is unlikely that Chinese urea production costs can fall far beyond current levels for long.

Table 1: Price indications

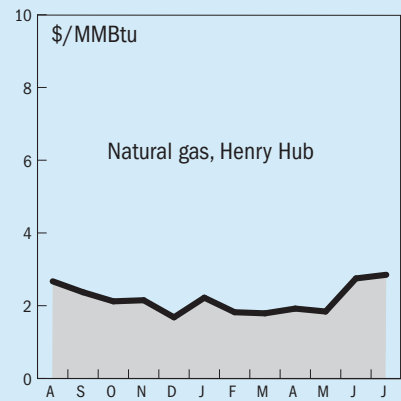
Cash equivalent	mid-Jul	mid-May	mid-Mar	mid-Jan
Ammonia (\$/t)				
f.o.b. Caribbean	245	280	270	270
f.o.b. Arab Gulf	305	335	320-340	308-323
c.fr N.W. Europe	295	358	325-355	348
c.fr India	340	383	340-388	368
Urea (\$/t)				
f.o.b. bulk Black Sea	176	201	200-204	220
f.o.b. bulk Arab Gulf*	173	190-199	230-265	201-211
f.o.b. bulk Caribbean (granular)	167	215	210-220	221
f.o.b. bagged China	197	209	200-205	222
DAP (\$/t)				
f.o.b. bulk US Gulf	340	345	360	395
UAN (£/tonne)				
f.o.t. ex-tank Rouen, 30%N	135	138	175-180	175

Notes: n.a. price not available at time of going to press
n.m. no market * high-end granular

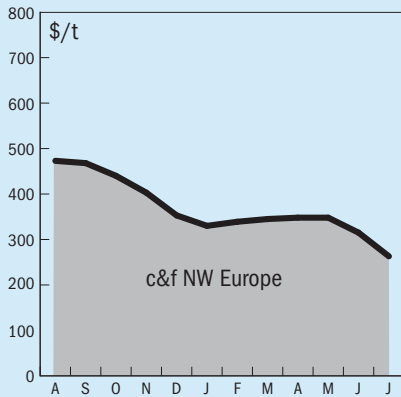
Source: Fertilizer Week

END OF MONTH SPOT PRICES

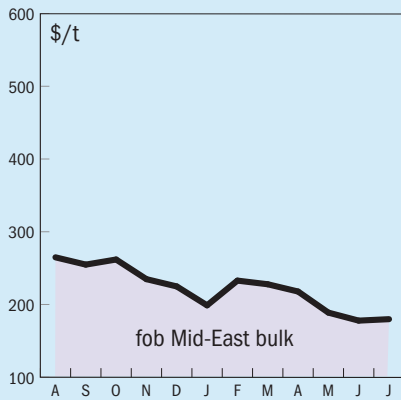
natural gas



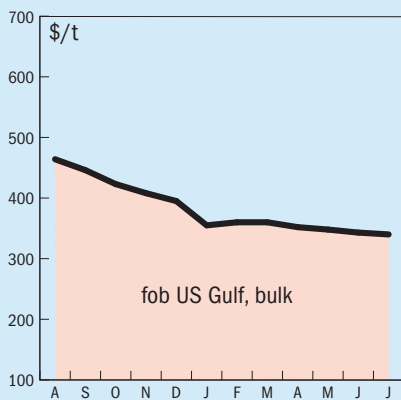
ammonia



urea



diammonium phosphate



MARKET INSIGHT

Mike Nash, Global Business Director, IHS Chemical, assesses the market for methanol.

METHANOL

In North America, the June's contract gas reference price was settled at \$2.73/MMBtu for Texas and \$2.79/MMBtu for Louisiana. Methanol demand was flat to slightly down. The slow downward drift in demand from construction applications continues while demand into MTBE and biodiesel is steady.

Mexican demand remains strong but demand into South America continues to be weak overall. On the supply side, an unexpected and extended natural gas curtailment caused by upstream work in Trinidad has limited production across all units at the end of August and into the start of September which is overlapping with the planned maintenance of the large M5 unit in Trinidad, leaving the region tight. Estimated lost production in Trinidad, including the typical 15% curtailment, 184,000 tonnes in August and 287,000 tonnes in September. Venezuelan units (2.5 million t/a) are believed to be running at rates around 70% and so far unaffected by the country's troubles as these provide a source of foreign currency and as such are highly incentivized to continue to run. However, North American operating rates were at 90%. Sources have indicated that the first steps in construction have begun at the Caribbean Gas Chemical site in Trinidad. This will have a methanol capacity of 1 million t/a with an associated 20,000 t/a DME unit. Start-up is expected in 2019.

Based on identified deals, IHS Markit posts the US spot price for September in a range of \$0.70-0.75/gallon (\$233-249/tonne). Spot activity over the next several weeks will remain elevated as participants cover positions and/or meet requirements as the market continues to cope with the gas curtailments in Trinidad and the turnaround in Trinidad and upcoming one in Venezuela.

Inventory levels in Northwest Europe continue to fluctuate. Production in the Mediterranean and parts of the Atlantic Basin has been constrained in recent weeks but demand is mostly stable overall in Europe. Iranian producers continue to eye export outlets in Europe but banking restrictions and logistical constraints continue to represent barriers to trade. The EMethanex

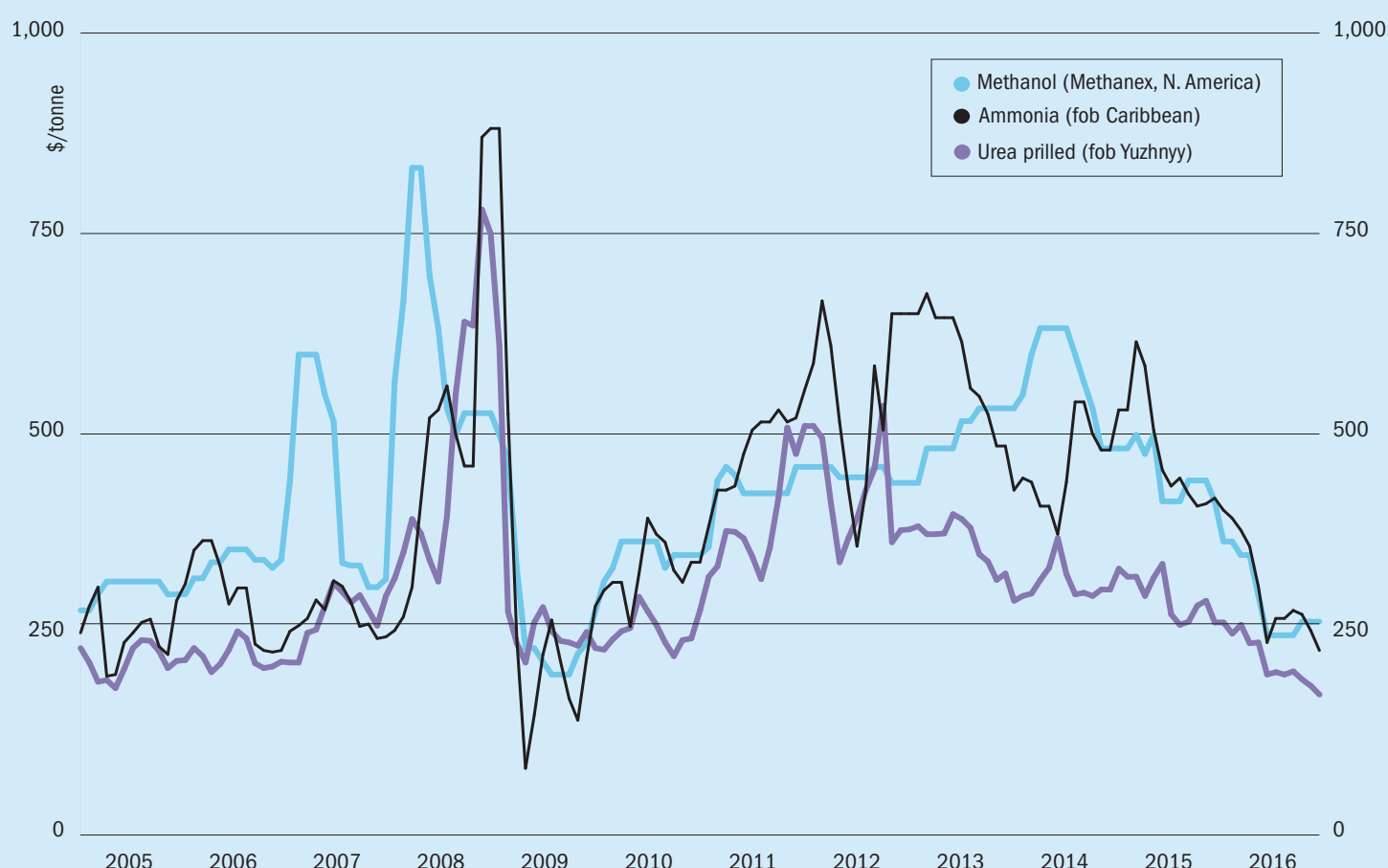
unit in Damietta, Egypt restarted in early May after a shutdown in early March due to natural gas supply restrictions and has since operated at reduced rates on an intermittent basis as gas has become available. The plant is expected to have to shut down intermittently during the remaining summer months when electricity demand is at its peak. Gas curtailments and a reduction in available methanol volumes from Trinidad have supported spot prices in the US and this is beginning to impact European prices. The European market, however, is fairly balanced in terms of supply and demand at present. Russian methanol demand into oil drilling applications is reduced this year but is otherwise stable into other segments and exports. For producers in the Middle East, is it more profitable to ship methanol to Asia than to the European market. If supply in the Mediterranean continues to be constrained, Europe will need to look to the US Gulf to supply additional tonnes or prices will need to rise to attract volume from the Middle East. Spot methanol prices trended upwards to trade as high as €210/t f.o.b. T2 Rotterdam for September loading.

Most Asian markets remain flat with a limited number of spot trades. Chinese market sentiment is healthy with a good number of spot trades. A middle-sized MTO unit in Shandong province resumed normal production. The remaining MTO units are running at high rates and are benefiting from the increasing price spread between methanol and ethylene. The average operating rate remains at 53% of nameplate capacity, or close to 67% of effective capacity.

Asian spot prices are posted in a range of \$220-238/t c.fr. In Korea, sustained weak buying interest and high inventory levels in the main ports continued to keep the market under downward pressure. In Taiwan, the spot market is quiet with few trade enquires in the current week. The market price is in line with the price of import materials in East China. End-user inventory is back to a comfortable level. In Southeast Asia, a large unit experienced unstable operation at the end of August; the unit is now back to normal operation. The regional market remains long with adequate supply to local end-users. Deals were concluded amongst traders with a slight discount. ■

Market outlook

Historical price trends \$/tonne



Source: BCInsight

AMMONIA

- The global ammonia market is expected to remain bearish until the end of the year due to continued oversupply, exacerbated by new capacity additions expected in the coming months.
- Any seasonal upswings in demand for merchant ammonia are most likely to appear from North America, however, this market is already well served by key ammonia exporters and more importantly, new domestic supply from plants that are close to commissioning, including CF Industries' two plants at Port Neal and Donaldsonville and Incitec at Waggenerman, Louisiana.
- The ammonia price remains inherently linked to energy costs to the highest cost producer, and the consensus is that energy markets (most notably LNG and hub-priced gas) will recover in time. Both US and European gas prices have moved upwards in recent months, but prices are expected to remain low in the short-term.

UREA

- The outlook for urea prices remains bearish, however, in the short-term some stabilisation is expected. Prices are expected to hold steady in September as the major exporters were largely committed until mid to end-month, given tight supply in August and maintenance work typical for this time of year.
- In Yuzhnyy, OPZ remained down at the end of August and there was no confirmation on a restart date, while Dnipro was due to conduct maintenance work for one month beginning from the 2nd-3rd September.
- Chinese urea producers will be focused on supplying upcoming domestic demand in mid-September, while India will likely return to the market in mid to late-September which could support Arab Gulf prices.
- Chinese coal prices seem to have found a floor in the region of \$3.20/MMBtu, and this is setting a lower limit for Chinese urea export pricing.

METHANOL

- Gas curtailments continue to affect capacity, particularly in Trinidad, with 184,000 tonnes of methanol taken out of the market for August and another 287,000 tonnes in September. Coupled with planned turnarounds in Trinidad and Venezuela, this is likely to push prices up in the Americas in spite of good supply from US domestic capacity.
- Europe is also facing less supply from North Africa, and higher prices in Asia have also siphoned capacity from the region, also indicating that price rises are likely.
- China's MTO capacity continues to support the market there, though notional operating rates remain low, at around 53% of capacity, or 67% of effective capacity.
- Iranian producers are keen to sell to Europe via the Mediterranean and are investigating the potential for storage space in Rotterdam.

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CANADA

Agrium in merger talks with PotashCorp



Agrium Inc. has confirmed that it is in preliminary discussions with Potash Corporation of Saskatchewan Inc. (PotashCorp) regarding a potential “merger of equals”. Agrium said in a statement that; “no decision has been made as to whether to proceed with such a combination, no agreement has been reached, and there can be no assurance that any transaction will result from these discussions.”

Nevertheless, the announcement has caused considerable excitement in the fertilizer industry and beyond. The combined company would have sales of \$30 billion and pair the world’s third largest

potash producer and largest crop nutrient company by capacity with North America’s largest farm retailer. The fact that both companies are Canadian may ease competition anxieties that scuppered BHP’s attempted takeover of PotashCorp in 2010, while there are certain to be synergies that could lead to lower costs, something which could not be as readily identified with PotashCorp’s bid for K+S in Germany. However, the merged company would control 29% of North American nitrogen capacity and 62% of the continent’s potash mines, which may lead to anxieties by US farmers. ■

NETHERLANDS

Stamicarbon launches HSE portal

Catastrophic events in the process industry are often seen as “low-probability, high-consequence occurrences” and can gain considerable media attention at the time, and yet can be forgotten once the news cycle moves on. Incident investigations provide the opportunity to learn from reported incidents and to use this information to take corrective actions in order to prevent them from recurring, but effective incident investigation, reporting and follow-up are necessary to achieve a safe operational environment and translate learnings into design practices and operational practices. All international design standards that have been developed and form the basis of current safe plant designs have been derived largely from the experience of incidents.

As a result, leading urea technology licensor Stamicarbon is launching a pro-

cess safety incident sharing portal service at <http://hse.stamicarbon.com> in order to try and help improve process safety in urea plants. The company says that it has been recording major process safety incidents in urea facilities for 48 years, but this information contains limited data points as it only incorporates the infrequent major events, whereas near misses and lower-consequence incidents are increasingly thought of as the most important indicators of major accidents. Therefore a database of process safety accidents should also include these in the interest of improving understanding of failed barriers leading to process safety accidents. Stamicarbon says that urea manufacturers need to work together and build an incident database from which all can benefit.

Subscribers to the portal will be able to access the posted HSE information free of charge and will periodically receive an email report on relevant accidents and near

misses and possible improvements in terms of process design and operational practices. Customers who report an accident or near miss can receive tailored HSE support under an applicable service agreement. The periodic report and other relevant HSE information that Stamicarbon considers appropriate to share with its customers can also be downloaded from the HSE portal.

UKRAINE

No takers for OPZ

The Ukrainian government’s attempt to find a buyer for the country’s largest ammonia plant, Odesky Pryportovy Zavod (OPZ), aka Odessa Port Plant, has so far come to nothing. The government is attempting to raise cash by selling state assets, and had been offering its 99.567% stake in the company at a starting price of \$532 million. However, as a late July deadline passed with no bids received, the government admitted that it might have to fall back on an auction later in the year. A previous attempt to sell the company failed in 2008. The new law regulating asset sales was approved by the country’s parliament in February after the government postponed selling some of its main businesses, including power utilities. Investors have been suspicious of Ukraine’s legal system and the imposition of currency controls.

The plant employs 3,800 workers and produced 1.1 million t/a of ammonia and 950,000 t/a of urea in 2015. The company also made a \$8.5 million net profit in 2015 according to the State Property Fund, but lost \$16.9 million in 1Q 2016, as compared to a profit of \$3.6 million for the same period of 2015. Ukraine’s economy grew 0.1% in 1Q 2016, 0.8% down on the previous quarter. The government is relying on \$12 billion in international aid to boost its economy and bolster the national currency.

UNITED STATES

ITC to rule on alleged dumping of AS

The US International Trade Commission (ITC) said in its preliminary determination in July that there is “a reasonable indication that an industry in the United States is materially injured by reason of imports of ammonium sulphate from China”, alleging that the Chinese government is subsidising prices so that the AS is being sold below cost price (‘dumping’). The move follows a complaint from Pasadena Commodities International Nitrogen LLC of Texas and an ITC investigation was launched in May. The

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ITC says that it will continue to conduct its anti-dumping and countervailing duty investigations on imports of this product from China, with its preliminary countervailing duty determination due in August and its preliminary anti-dumping duty determination due in November this year.

Port Neal nears completion

CF Industries says that it has achieved mechanical completion at its 2,200 t/d ammonia plant and the facility is expected to begin production during 3Q 2016. Construction continues on the 3,500 t/d urea synthesis and granulation plant, which is expected to start up shortly after the ammonia plant according to the company. Construction began in 3Q 2013 and had been expected to be complete in 2Q 2016. Company staff have already begun the detailed commissioning process both plants must go through before production can begin. CF also says that all new offsites and utilities have been completed, including water collection and purification, power generation, the waste and fire water systems, cooling towers and various other functions.

KBR Weatherly launches new nitric acid technology

KBR, via its wholly owned subsidiary, Weatherly Inc., has launched its new Weatherly dual pressure nitric acid technology. Weatherly's new technology can produce nitric acid at up to 1,000 t/d, suitable for large-scale fertilizer complexes, at an operating cost that the company claims is \$4-5/t lower than other dual pressure plants of the same capacity. This is possible due to a more efficient heat recovery design which converts tail gas heat to energy, which in turn is used to power the plant. Weatherley says that it also requires up to 10% lower capital investment due to its compact design and proven vertical reactor, requiring less steel and piping than traditional plants.

John Derbyshire, President of KBR Technology & Consulting said: "We recognise the need for larger nitric acid plants as part of larger fertilizer complexes worldwide, so we expanded our portfolio to serve this market."

RUSSIA

Turbine upgrade at Togliatti

GE's Power Services business says it will provide TogliattiAzot with parts to upgrade two industrial steam turbines at the company's ammonia production facility at

Togliatti in the southwest of Russia. GE also will supply spare turbine parts for three additional compressor trains and will help Togilatti reduce its operational costs by doubling the length of time between maintenance intervals. The multi-phase project, which is due for completion by the end of 2016, will modernise the plant's low pressure and high pressure steam turbines, which drive their corresponding low- and high-pressure syngas compressors in mechanical-drive mode.

TogliattiAzot is one of the largest producers of chemicals in Russia and is listed

among the world's top 10 producers of ammonia. Its operates over 3 million t/a of ammonia capacity as well as 900,000 t/a of urea capacity.

AUSTRALIA

Oswals settle with Apache

Former owners of the Burrup ammonia plant Pankaj and Radhika Oswal have reached a settlement with US oil and gas company Apache as part of a huge A\$2.5 billion civil case currently running through the Australian courts. However, the main action, which



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CHALLENGE CONVENTION

the couple have brought against the Australian and New Zealand Bank (ANZ) over the sale of the ammonia business, continues. Talks between the Oswals and Norwegian chemical company Yara, which owned the remainder of the shareholding, are also continuing. The Oswals argue the US\$560 million sale of their stake in parent company Burrup Holdings in 2012 represented less than half its true value and the bank was simply interested in getting the debt the Oswals owed covered. In return the Oswals have been accused of misappropriating more than \$150 million of company funds for their own benefit, which the couple claim were partly in restitution of debts connected with the plant's construction.

Apache, which supplied gas to the plant, bought 49% of Burrup Holdings before selling its stake on to Yara. The settlement with Apache is subject to the Federal Court agreeing to vary an order freezing Mrs Oswal's assets in a separate case involving the taxation commissioner.

MALAYSIA

Chinese investors considering new urea plant

A memorandum of understanding has been signed between Malaysia's Sabah Oil and Gas Development Corporation and a Chinese consortium for a feasibility study into a proposed new ammonia/urea plant at the Sipitang Oil and Gas Industrial Park in Sabah, east of Brunei. The consortium consists of the China National Complete Plant Import and Export Corporation, Sichuan Chemical Industry Holding (Group) Co. Ltd and China Chengda Engineering Co. Ltd, according to local media reports. Deputy Chief Minister and Minister of Industrial Development Datuk Seri Panglima Raymond Tan said that the Malaysian government will fully support and cooperate with investors on their interest in Sabah.

A new 1.2 million t/a ammonia-urea plant – the Sabah Ammonia and Urea (SAMUR) facility – is already under construction at the site by state petroleum company Petronas and is expected to begin production imminently.

INDIA

New nitric acid plant for Deepak

Deepak Fertilisers and Petrochemicals Corp Ltd is planning to build a new green-field nitric acid plant in Dahej, Gujarat, at an estimated cost of \$82.5 million. The acid

produced will be supplied into the industrial chemicals market for the manufacture of nitro-aromatics, pharmaceuticals, dyes, steel rolling, and other industries. Deepak Fertilisers currently produces a total of 840,000 t/a dilute, concentrated and strong nitric acid at its Taloja (Maharashtra) facility, mainly used captively to produce explosive grade ammonium nitrate and ammonium nitrophosphate fertiliser, leaving only 160,000 t/a available for merchant sale. The new Dahej plant will provide an incremental 148,000 t/a of acid production. Deepak says that it has seen acid demand rise by 9% in the past year alone.

"We are the largest manufacturer of nitric acid in India and this new facility will be the first step of development of a mega multi-products site at Dahej which would cater to demand for many intermediates and specialty chemicals manufacturers in India. As an organisation, we have always been customer centric. This project is planned in a manner that we will be ready to cater to the growing demands of our customer's expansion plans," said Sailesh Mehta, Deepak's Chief Managing Director.

Land has already been acquired for the new project, which is earmarked for completion in the second half of 2018.

Yara acquires Tata's urea business in India

Yara International has entered into an agreement to buy Tata Chemicals Ltd's Babrala urea plant and the company's distribution business in Uttar Pradesh for \$400 million on a debt and cash free basis, according to Yara. The plant has 700,000 t/a of ammonia and 1.2 million t/a of urea capacity, and generated revenues of respectively \$350 million and EBITDA of \$35 million in the financial year ending March 2016. The plant was commissioned in 1994, and is the most energy efficient plant in India.

"This acquisition represents another significant step in our growth strategy, creating an integrated position in the world's second-largest fertilizer market. India has strong population growth and increasing living standards, and significant potential to improve agricultural productivity," said Svein Tore Holsether, President and Chief Executive Officer of Yara. "We are impressed with the world-class operations we have seen in Babrala. The workforce is committed to high HSEQ standards, and has a solid safety track record. This well operated

plant and its highly skilled employees will make an excellent addition to Yara's global production system."

Yara has operated in India since the 1990s, focusing in recent years on premium product sales in the west and south of the country.

Incremental progress on reviving old plants

Prime Minister Narendra Modi has laid the foundation stone for the reconstruction of the Fertilizer Corporation of India Ltd (FCIL) urea plant at Gorakhpur, which has been shut down since the 1990s. A consortium of NTPC Ltd, Coal India Ltd and Indian Oil Corp. Ltd has been formed to redevelop the site, and say that they are close to selecting a contractor. Meanwhile, fertilizer minister Amanth Kumar says that a similar plan to revamp and re-start the Ramagundam fertiliser plant at Telangana, 240 km from Hyderabad at an estimated cost of \$900 million is also under way, and that the facility will be commissioned by the end of 2019. It will have a capacity of 130,000 t/a of urea. The plant is being revived by a joint venture firm formed by the National Fertiliser Ltd (NFL), Engineering India Ltd (EIL) and FCIL. NFL has a 25% equity share. Talks are in process with SBI Capital as well as the Telangana government for each taking an 11% stake in the plant, Kumar said.

Investigation into AN dumping

India has initiated an anti-dumping investigation on imports of ammonium nitrate from Russia, Indonesia, Georgia and Iran between April 2015 and March 2016. The probe has been initiated by the Directorate General of Anti-Dumping and Allied Duties (DGAD), an arm of the ministry of commerce and industry, which said in a notification on August 5th that it had found "sufficient evidence of dumping" of AN from these countries. "There is a sufficient prima facie evidence that the normal value of ammonium nitrate in the subject countries is significantly higher than the ex-factory export price, indicating that the subject goods are being dumped by exporters from subject countries into the Indian market," DGAD says.

The investigation period will also cover the data from the previous three financial years, from April 2012, DGAD added. The probe was initiated following complaints from Deepak Fertilisers and Petrochemicals Corp. Ltd and its wholly owned subsidiary Smartchem Technologies Ltd.

New catalyst recycling facility

Heraeus, one of the world's largest recyclers of reforming catalyst, has opened a new facility in India to recover precious metals from spent catalysts. The new site in Udaipur/Rajasthan will be operated by a joint venture with the Ravindra Chokai family, Ravindra Heraeus, and will offer India's petrochemical industry more capacity to recycle platinum and palladium in the country. André Christl, President of Heraeus Metal Management, the companies precious metal recycling and trading unit, said: "the new recycling facility of Ravindra Heraeus in India will allow our customers from the petrochemical sector to receive outstanding catalyst recycling standards in India. We will be the only globally active precious metal company with local recycling capabilities in this very important sector. Together with our trusted and long-term partner Ravindra we will be able to offer fast, local and first class recycling services to our customers."

Financial results

Clariant has announced 1H 2016 sales of 2.9 billion Swiss francs, up 3% from the previous figure of 2.87 billion francs on the same period for 2015. In the company's results presentation, CEO Hariolf Kottmann also noted that cash flow had been expanded considerably and profitability – measured as earnings before tax and deductions – increased from 14.5% to 15.3%. He added: "our good business performance was primarily achieved by means of a continued shift to high margin specialties, the impact of the differentiated steering in Plastics & Coatings as well as good cost management. For 2016, we are on track to achieve our targets despite the continued challenging economic environment."

Growth was strongest in Latin America, where sales grew by 10 % in local currency. In the Middle East & Africa, year-on-year sales were up 7 % in local currency. North America saw a small decline of 2 % coming from a lower demand in Catalysis and Natural Resources, while Asia grew at 2 %, with more stability in China, and Europe at 1 % driven by volume increases. However, sales in the company's Catalysis business unit fell by 9% to 285 million francs due to lower demand, especially from China.

Clariant says that it expects the uncertain environment in commodity prices

IRAN

Start-up for Marvdasht plant

The Marvdasht ammonia-urea plant at Shiraz has been inaugurated, bringing Iran's total nitrogen capacity to 4.5 million t/a of ammonia and 5.5 million t/a of urea. The new unit, which forms 680,000 t/a of ammonia and 1,075,000 t/a of urea of that total, was inaugurated at a ceremony including Marzieh Shahdei, Managing Director of Iran's National Petrochemical Company (NPC), and the country's First Vice-President Es'haq Jahangiri, as well as Minister of Petroleum Bijan Zanganeh, and representatives of licensors and engineers Casale and Japan's Toyo Engineering Company. The project was completed at accost of \$750 million, most of that paid in euros, according to the company. The Managing Director of the Shiraz Petrochemical Facility Kianoush Kazemi said the complex had created 500 jobs directly and a further 4-5,000 indirectly.

and currencies, to continue. In emerging markets, it anticipates the economic environment will remain challenging, but foresees moderate growth in the United States, while growth in Europe is expected to remain stable but weak.

Johnson Matthey's 1Q 2016 figures have shown a 6% increase in group sales to £822 million, with strong sales growth in Emission Control Technologies and further progress in New Businesses. Overall demand was stable in the quarter for the company's Process Technologies, Precious Metal Products and Fine Chemicals divisions. Underlying profit before tax on a continuing basis is "broadly in line with last year at constant rates" and the company says that the full year outlook remains in line with previous expectations.

In emissions control, sales in light duty vehicle catalysts were up 14% to £331 million. The business saw growth across all regions with particularly strong growth in Europe, helped in part by robust car production growth in the region's key markets. Heavy duty catalyst sales were up 1% to £190 million (down 5% at constant rates). Sales in Process Technologies grew by 3% to £134 million (down 1% at constant rates) with sales growth in Chemicals offsetting reduced demand in the Oil and Gas businesses.



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TRINIDAD & TOBAGO

Methanol and DME plant renegotiated

The government of Trinidad and Tobago says that it has concluded renegotiation of a contract for the construction of a new methanol and dimethyl ether (DME) facility at La Brea. Agreement on the project was initially reached in April 2015 to form a joint venture company, Caribbean Gas Chemicals Ltd, in order to pursue the project. Partners in CGC include the state-owned National Gas Company, which took a 20% stake, local Trinidadian firm Neal & Massey (10%), and three companies of the Mitsubishi group; Mitsubishi Gas Chemical, Mitsubishi Corporation (each with a 26.25% share) and Mitsubishi Heavy Industries, Ltd. (17.5%). However, a final investment decision was not taken until early September 2015, only days before Trinidad’s general election brought about a change of government, and this

latter occurred before final sanction could be given by the Attorney General’s office. The banks financing the \$850 million project had been awaiting a so-called ‘letter of comfort’ from the Trinidadian government that they would support the project financially, but the incoming government decided that it was not happy with some of the terms of the agreement, and has insisted on the renegotiation. Several months of discussions now appear to have brought about final financial closure for the project, although the terms of the amended agreement were not disclosed.

The plant, in the south of the island, will produce 1 million t/a of methanol and 20,000 t/a of DME. According to Japanese Ambassador Mitsuhiro Okada, CGC will be the largest investment Japan has ever made in Trinidad.

UNITED STATES

Plan to relocate methanol plants to Virginia

US Methanol is planning to develop two methanol plants in West Virginia, using gas from the Marcellus and Utica shales. The first, which US Methanol calls Liberty No 1, will be a relocation of an existing 175,000 t/a unit from Brazil. Work on reconstructing it is expected to begin in November, and the plant, following revamps and modifications, is expected to start-up in July 2017 near the town of Institute in the Kanawha Valley, serving customers in the northeast of the US. It will be located next to an existing Dow Chemical facility. The second plant, Liberty No 2, will be a 150,000 t/a unit relocated from Eastern Europe, but a location or timetable has not yet been confirmed by the company.

Another delay for Mississippi Power

Mississippi Power says that its Kemper Project clean coal power plant will be delayed at least another month to the end of October, adding an additional \$43 million to its cost, now up to \$6.8 billion. The company said it needs to make mechanical changes to the supporting systems for the plant’s two gasifiers. It also said that the syngas clean-up systems also require more work and that all of the systems have

yet to be integrated into one unit. The facility, which Mississippi Power says produced its first syngas on July 15th, will also have a side-stream of 20,000 t/a of ammonia. The plant, one of the few remaining from the Bush-era ‘Clean Coal’ initiative, is now more than two years behind schedule and three times over budget.

Start-up for pilot GTL plant

GasTechno Energy & Fuels (USA) LLC, the licensing subsidiary of Gas Technologies, has achieved successful start-up for its first commercial-scale *Mini-GTL*® gas-to-liquids plant at the New Haven Gas Storage Facility in Michigan. The modular ‘GTL in a Box’ unit was shipped from the company’s Charlevoix manufacturing facility to the gas field and tied in to mechanical and electrical connections in less than 24 hours. Over the next few months, GasTechno will perform extensive operational testing of the plant using a range of gas feedstocks before the plant is re-located to North Dakota. CEO, Walter Breidenstein commented that the *Mini-GTL*® plant “has the ability to handle both peak initial production and off-spec gases with high percentages of inert compounds straight from the wellhead. The ease of deployment validates our modular design philosophy of simple hardware, sophisticated software.”

GasTechno says that the process aims to capture value by using previously

wasted flare gas or stranded gas into high-value, saleable liquids including methanol. The company plans to hold its first operator training program in 4Q 2016 alongside workshops to construct a robust flare elimination business case for O&G producers and well-pad site planning.

China still driving methanol market, says IHS

Driven by significant economic growth during the past 15 years, China has surpassed North America and Western Europe to become the largest global consumer and producer of methanol. China now consumes 54% of global methanol demand, according to new analysis from IHS Markit.

“The global methanol industry has undergone dramatic changes in the past 15 years, with China becoming the dominant player in the global market,” said Mike Nash, global director of syngas chemicals at IHS Markit. “The Chinese market dominance for methanol and its derivatives, such as for direct gasoline blending and more recently MTO (methanol-to-olefins) is driving a significant shift in market dynamics and adding complexity for both methanol producers and consumers. These factors have resulted in new trade flows, pricing and economic dynamics that did not exist previously.”

According to IHS Markit, which will welcome methanol producers and other industry professionals to its 34th Annual World Methanol Conference in Budapest, Hungary, from 30th September to October 1st, in 2000, China represented just 12% of global methanol demand, while North America and Western Europe represented 33% and 22% respectively. By 2015, however, Chinese methanol consumption had grown to 54% of global demand while North American demand had fallen to 11% and Western Europe to 10%.

Chinese demand, Nash said, has grown significantly in traditional methanol derivatives, such as formaldehyde and acetic acid, but also in new end-uses, such as light olefins production, as well as expanded demand into energy applications, such as DME (dimethyl ether) and direct gasoline blending. China’s direct blending of methanol into the country’s gasoline pool has driven an average annual growth rate for this application of 25% from 2000 to 2015, making gasoline blending the third-largest methanol demand segment. A newer and rapidly growing demand segment for methanol

(exclusively in China) is in the production of light olefins using methanol-to-olefins (MTO) technologies. In just four years, this end-use has driven staggering growth in methanol consumption and made MTO the sixth largest end-use for methanol. During the next few years, IHS Markit expects MTO to become the second largest end-use for methanol.

Feedstock costs for methanol comprise as much as 90% of the total cash-cost and, as such, access to low-cost feedstocks is key to methanol economics. The primary feedstock for methanol has been natural gas, representing as much as 85% of installed global capacity. Regions with access to low-cost natural gas have seen a surge in methanol capacity additions, including the Middle East, Africa and South America. With the growth in Chinese methanol demand and the country's rich coal reserves, the industry has seen a sharp rise in coal-based methanol production. Uncompetitive feedstock economics led to capacity rationalisations in North America and Europe in the early 2000s, with North American methanol capacity all but extinguished by 2008. However, recent exploitation of unconventional natural gas supplies in North America has allowed this region to regain its position as a methanol production powerhouse. The sharp rise in North American production capacities and the cost position of these units has led to an increase in exports from the Americas that now add supply to both the European and Northeast Asian methanol markets. The expected growth in North American capacities will turn the region from a net importer to a net exporter by early 2019, IHS Markit said.

Supply and demand pressures have always driven methanol pricing, but now that methanol has significant volumes of derivatives that compete as alternatives to crude-oil derived products, the picture becomes significantly more complicated, since affordability of some methanol derivatives becomes dependent on crude oil price fluctuations, Nash said.

"Due to this linkage with crude oil markets, to assess the future direction of methanol demand, you have to assess not only the light olefins markets, but also the global fuel markets," Nash said. "With the drop in oil prices, methanol demand for these derivatives has been under pressure, with most consumers able to afford a much lower methanol price than in the past. This has been particularly the case for DME."

The IHS Markit report said the methanol industry will face more moderate demand growth rates as direct-gasoline blending has matured and the feverish pace of MTO projects moderates. Overall demand during the next five years will grow at an average annual rate of almost 7%, with MTO becoming the second-largest methanol derivative. IHS Markit expects natural gas prices to remain below \$5.00/MMBtu in the next five years, and oil prices to rebound from the currently low level, the growing spread between these two commodities should therefore support methanol demand going forward.

SOUTHEAST ASIA

Reforming methanol to hydrogen

Unitel Technologies, Inc. says that it has been engaged by "a major Southeast Asian conglomerate" to supply technology

and engineering know-how for the construction, start-up and operation of a methanol to hydrogen unit using the company's M2H technology, as well as a downstream hydrogen sulphide plant. The M2H unit will have a capacity of 1,000 Nm³/hour. Using methanol as a hydrogen source is a niche application for when pipeline natural gas or LPG are not readily available; unlike these alternatives, methanol, as a widely internationally traded liquid product, can be easily transported to remote points of use by truck or train. Its low cost and availability make it a potential hydrogen carrier under certain conditions. Serge Randhava, CEO of Unitel argues that; "in addition to selective supply chain advantages... some other pluses of the design versus conventional natural gas steam reforming are: higher overall efficiency; simpler metallurgy without any exotic materials; internal heat generation in lieu of indirect heat transfer; rapid start-up; faster dynamic response and better turn-up and turn-down capabilities; and reduced NOx emission problems."

The process consists of an oil-heated multi-tube methanol reformer. A controlled mixture of methanol and demineralised water is pumped into the top of the reformer. The hydrogen-rich synthesis gas is fed into a multi-column pressure swing adsorption (PSA) unit to yield 99.99% pure hydrogen.

CHINA

Another new MTO facility

Wison Engineering has been awarded the engineering, procurement and construction (EPC) contract for a new 300,000

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t/a methanol-to-olefins (MTO) unit which will constitute the first phase of Connel Chemical Industry Ltd's 600,000 t/a MTO complex at Jilin City. The two parties also signed a licensing and process design package contract for Wison's proprietary olefin separation technology, which is the tenth licensing of this technology. The project will use UOP's MTO+OCP (olefin cracking process) technology and Wison's high recovery olefin separation technology. Wison Engineering will be responsible for the engineering, design, procurement and construction of the MTO reaction and concentration unit, the olefin separation unit, the olefin cracking unit and additional auxiliaries. The project is scheduled to be delivered in October 2017.

Wang Daxiang, General Manager of Connel Group said: "The project is an important step for Connel Chemical's industrial upgrading as well as a key link in Jilin City's fine chemical supply chain. We are confident that Wison's advanced, high recovery technology and rich experience in MTO project execution will ensure a successful outcome."

Zhou Hongliang, Executive Senior Vice President said: "We are honoured to help facilitate Connel's business expansion and Jilin City's industrial upgrading. We have built up a robust EPC project track records, turning MTO into one of Wison's great strengths. In the Connel project, we'll deploy our first class team to ensure a successful delivery as we always do."

Connel is the largest aniline producer in the world. It says that its MTO project will boost the ethylene and propylene supply chain of the Jilin Economic & Technological Development Area as part of China's 13th Five-Year Plan.



Methanex's Chile methanol facility.

CANADA

Methanol a possible option for British Columbia

British Columbia is pondering methanol production as an option for its natural gas after failing to make progress on an LNG export project. BC's gas has historically mainly been exported south to the US, but the shale gas boom south of the border has turned the USA into a net LNG exporter, and BC had been looking to follow suit to find an overseas outlet for its own gas. However, LNG Canada, a consortium led by Shell aiming to develop an LNG export train at Kitimat, said recently that it will not be making an investment decision this year as previously planned. A deal to expand the existing Tilbury Island LNG facility has also fallen through, while Pacific NorthWest LNG, the remaining option, will not have a decision on its federal environmental assessment until September. In the meantime, the LNG industry has been suffering from overcapacity, and local gas minister Rich Coleman and members of the Resource Municipalities Coalition have reportedly been in discussions about a fallback plan for attracting investment in other gas-based value-added industries, possibly including petrochemicals, plastics, methanol, gas to liquids, and natural gas for transportation uses.

CHILE

Methanex secures gas supply

Methanex Chile SpA has reached an agreement with Chile's state-owned Empresa Nacional del Petróleo (ENAP) for gas supply for the period through May 2018. Methanex says that this supply, when combined with commitments from other sources, is expected to be sufficient to allow the 90,000 t/a Chile I methanol plant to achieve an average annual operating rate of approximately 60% of capacity. The company has also signed an agreement with GeoPark Fell SpA in order to extend that gas supply agreement with Methanex Chile for an additional 10 year term, beyond April 2017.

John Floren, president and CEO of Methanex, said, "these agreements reflect continued drilling success in Chile. We are optimistic that our underutilised 1.7 million t/a Chile facilities represent an excellent growth opportunity for Methanex as further progress is made in lowering the cost of developing these new gas reserves."

AUSTRALIA

Environmental approvals for Tassie Shoals extended

MEO Australia Ltd says that it has received updated environmental approvals extending the approval period for its proposed Tassie Shoal methanol and LNG projects proposed for offshore Northern Australia. Approval for the LNG project has been extended to 2052. The Tassie Shoal project comprises one 3 million t/a LNG train and two methanol plants, to be sited on a shallow water shoal some 275 km from Darwin, and surrounded by significant but undeveloped high CO₂ gas fields, currently held under retention leases. The two methanol plants would use 440 million scf/d, or 4 tcf over 25 years, and can accept raw gas with a CO₂ content of up to 30% – allowing them to use the highly sour gas present at the shoals. MEO says that it has offered to purchase raw unprocessed gas (including CO₂) for US\$3.15/MMBtu, although this was rejected by producers at the time.

MEO managing director and CEO Peter Stickland commented: "these updated environmental approvals for the LNG Project now align both the requirements for feedstock gas and the approval period to 2052. The Tassie Shoal Projects represent a high potential, low cost and long-term opportunity for MEO shareholders."

Feasibility study on GTL plant

Queensland-based PROCOM Consultants has recently completed a A\$0.5 million feasibility study on setting up a gas to liquids (GTL) processing plant in Australia's Northern Territory, and says that a A\$1.8 billion plant producing up to 10,000 bbl/d could be commercially viable. The study was conducted on behalf of the Northern Territory state government, which is looking at monetisation options for its plentiful natural gas resources. Chief Minister Adam Giles said the government would "seek a private operator". "We see potential from turning that gas into a synthetic diesel that's cleaner and greener than diesel that's currently burned in our cars and in our power stations out bush," he said. "It provides another avenue to monetise gas resources by producing other value-added products and has potential synergies with existing producers of condensate and gas giving them a local outlet for their product."

Northern Territories currently imports 100% of its liquid fuel requirements, including around 11,000 bbl/d of diesel, from Singapore and East Asia.

GERMANY

Linde confirms merger talks with Praxair

Linde AG has confirmed that it is in preliminary talks about a merger with Praxair Inc. According to Linde; “these discussions are ongoing and have not resulted in any concrete results or agreements yet. Accordingly it is currently not foreseeable whether there will be any kind of transaction. Should these talks be successfully continued, Linde will inform the capital market and the public in accordance with statutory requirements.”

A merger of the two companies would create the world’s largest industrial gases company, with combined annual revenue of roughly \$30 billion before possible divestitures. Praxair, with a market capitalisation of \$33.7 billion, posted 2015 revenue of \$10.7 billion and EBITDA of \$3.6 billion, and has 27,000 employees. Linde, with a market cap of \$28.9 billion, had 2015 revenue of €18.9 billion (\$20.0 billion) and EBITDA of €4.1 billion (\$4.6 billion) with 65,000 employees.

SOUTH KOREA

Completion for methanol-fuelled ship

Methanex subsidiary Waterfront Shipping Company Ltd. (WFS) and Marinvest/Skagerack Invest (Marinvest) were in attendance in August at the launch of the methanol-fuelled ocean tanker, *Mari Boyle*. This is the fifth of seven vessels built with MAN two-stroke dual-fuel engines which can run on methanol, fuel oil, marine diesel oil, or gas oil. The engine was developed by MAN Diesel & Turbo and is based on the company’s proven ME-series, of which there are approximately 5,000 engines in service. Hyundai Mipo Dockyard hosted the Korean ship naming ceremony, where this 50,000 dead weight tonne (dwt) vessel was built. *Mari Boyle* was named in honour of Irish chemist and physicist, Robert Boyle (1627-1691), who is regarded as the first modern chemist to isolate pure methanol in 1661.

“It is an honour to be in Korea again with our partners to welcome ground breaking marine technology to the sea,” said Jone Hognestad, President, Waterfront Shipping. “With only two more vessels to be delivered this year, we are proud to welcome the world’s first ocean-going vessels capable of running on methanol.”

Startup for gasification power plant

Korea Western Power Co. says that the company started commercial operation at its Taeon IGCC (integrated gasification combined cycle) demonstrator power plant on August 19th. The power plant project is part of the Korean government’s development plans to pilot “clean coal” utilisation technology. This is the government’s largest research project, involving Doosan Heavy Industries, domestic research organisations and colleges among others. Six IGCC power plants are in operation in the US, Japan and Spain. Work began on the Taeon facility in November 2011, and has taken 610,000 man-days and 49,000 pieces of equipment to complete over the 57 months of construction. The power plant began to generate power using a natural gas-powered gas turbine in April of last year. After the first ignition at the gasification plant in November of last year, a comprehensive test run and a legal inspection were subsequently completed.

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People

Having been ill with serious cancer for some time, **Henrik Topsøe** has decided to resign as chairman of the Board of Haldor Topsoe A/S as of today. **Jeppe Christiansen** has been elected the new chairman.

"Even though I regret leaving the exciting work in the Board, I am also delighted to be able to hand over a well-managed company to my successor. We are all very happy that Jeppe Christiansen has accepted the task as chairman of the board. He is not only inspiring to work with; he has a deep-rooted knowledge of the company and has done an excellent job," said Henrik Topsøe.

Jeppe Christiansen said that he looks forward to heading the development and expansion of the company: "I have really valued my collaboration with Henrik Topsøe. He is a modest man but is very highly respected both as an internationally acclaimed research scientist and among the company's customers and employees. His personal drive and unceasing commitment through 42 years have led to many and important results. Therefore, I am pleased that Henrik has accepted to remain in our Innovation Committee so we can continue to benefit from his unique insight into research and development. He will also keep on developing and nurturing customer relations internationally."

The position as vice chairman will be filled by **Jakob Haldor Topsøe**, who represents the family ownership on the board of Haldor Topsoe A/S and parent company Haldor Topsoe Holding A/S.

The company said that, in his time as chairman, Henrik Topsøe has headed the

effort to expand and strengthen the competences of the company's board so that it comprises strong scientific, engineering and business profiles at a top management level.

Johnson Matthey has announced that **Anna Manz** will join the company's board as from 17th October 2016, succeeding **Den Jones** as Group Finance Director. This follows the announcement on 2nd March that Den Jones will step down as Group Finance Director; Den will resign from the board at the Annual General Meeting on 20th July 2016 and will leave Johnson Matthey on 31st July 2016.

Anna Manz's previous experience includes 17 years at Diageo, where she has held a series of senior financial roles, at both group and regional level, including Finance Director Spirits North America, Group Treasurer and subsequently Finance Director Asia Pacific. In her current role as Group Strategy Director, Anna leads Diageo's strategy and business development activities and also leads the Mainstream Spirits business. Prior to joining Diageo, Anna worked in the Quest International business of Unilever/ICI.

Commenting on Anna's appointment, Robert MacLeod, Chief Executive of Johnson Matthey said: "I am delighted that Anna will be joining Johnson Matthey in October and I am looking forward to working with her. Anna's strong financial, strategic and commercial experience in a large global company, together with her background in chemistry, will enable her to make an immediate contribution to the development of Johnson Matthey as we

pursue our strategy of delivering long term profitable growth."

Michael Höllermann and **Johan P. Cnossen** are to join the management board of the thyssenkrupp Industrial Solutions business area from August 1st 2016. Höllermann, CEO of the Regional Headquarters South America since 2012, will be the new Chief Human Resources Officer (CHRO). Cnossen, who joined Industrial Solutions on May 1 as head of the transformation office for the implementation of "planets", will hold the new position of Chief Operating Officer. According to TKIS, the "planets" reorganisation aim is to secure growth, enhance performance, focus more strongly on customers, markets and high-margin service business, and drive culture change within the business area. A central element of this is the further development of the organisational structure towards one focused on customers and business fields and integrating the Marine Systems and System Engineering units more closely.

Jens Michael Wegmann, CEO of the Industrial Solutions business area since October 15, 2015, said: "by appointing Michael Höllermann and Johan P. Cnossen we have gained two very experienced managers to drive forward the reorganisation of Industrial Solutions in a difficult market environment and focus our organization even more firmly on the needs of customers." The new CFO, already in place since June 1, is **Stefan Gesing**. Also on the board is **Dr. Hans Christoph Atzpodien**, who concentrates on the management of Marine Systems.

Calendar 2016

SEPTEMBER

18-22

AICHE Ammonia Safety Symposium, DENVER, Colorado, US
Contact: AICHE Customer Service
Tel: +1 800 242 4363/
+1 212 591 8100
Fax: +1 212 591 8888
Email: xpress@aiiche.org

18-23

Ammonium Nitrate/Nitric Acid Conference, EINDHOVEN, Netherlands
Contact: Hans Reuvers, BASF, Karl Hohenwarter, Borealis
Email: johannes.reuvers@basf.com, karl.hohenwarter@borealisgroup.com

OCTOBER

11-13

29th AFA Int'l. Fertilizer Technology Conference & Exhibition, TUNIS, Tunisia
Contact: Arab Fertilizer Association
Tel: +20 2 24172347
Email: info@afa.com.eg

16-19

Gasification and Syngas Technologies Meeting, VANCOUVER, Canada
Contact: Gasification and Syngas Technologies Council, 3030 Clarendon Blvd. Suite 330 Arlington, VA 22201 US
Tel: +1 703 276 0110
Fax: +1 703 276 0141
Email: info@gasification-syngas.org
Web: www.gasification-syngas.org

25-27

IFA Production and International Trade and IFA Crossroads Conferences, SINGAPORE
Contact: IFA Conference Service, 28 rue Marbeuf, 75008 Paris, France
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

NOVEMBER

7-11

IFDC Granular Fertilizer Production Workshop, BANGKOK, Thailand
Contact: IFDC, P.O. Box 2040 Muscle Shoals, Alabama 35662, US
Tel: +1 256 381 6600
Email: training@ifdc.org

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Problem No. 38 Flares in urea plants

Flares in urea plants are designed to improve the site's safety performance by capturing and burning ammonia emissions from safety release points. This will prevent/reduce ammonia emissions from entering the environment and in turn reduce ammonia risks. Flares are becoming more common in new urea plants, but are they the optimum solution to improve safety and reduce environmental risks?



João Amilton from Petrobras, Brazil initiates this round table:

Recently I read about flare stacks to reduce ammonia emissions in Profertil, Argentina. Our manager wants to know more about flares to handle the discharge of pressure safety relief valves of the high pressure synthesis section because he is considering installing one in our plant. Is this kind of flare available and is it a good idea?

Mark Brouwer from UreaKnowHow.com replies to the question:

The relief case of a synthesis pressure safety valve has major consequences and requires careful investigation into how to reduce the likelihood of pressure safety valves from popping up and how to reduce the consequences. Installing a flare system is one option. Other options include installing instrumental safeguards (high pressure switch) and applying pilot operated safety valves. For your information please refer to the paper from Joey Dobree, Stamicarbon presented at the 2012 Asian Nitrogen+Syngas Conference, which gives a comprehensive view on the environmental consequences of a flare system.

João asks another question: Thanks Mark, do you know of any plants where the flare system is operating now?

Mark replies: There is a flare system in operation at the Proferil's Saipem plant in Argentina as already indicated. There is also a flare system in operation at PIC's Stamicarbon plant in Kuwait.

B Suresh from NFCL, Kakinada, India provides more examples of flares in operation in urea plants: In many urea plants in India, ammonia safety valve discharge and vents are connected to blow down headers and the header is elevated to the prill tower height i.e around 100-110 m. But, continuous flaring is used in the vent stacks of ammonia storage tanks and there are flares in the front end and back end of ammonia plants.

Dading Abdul Kadir from PFK S/B, Malaysia, provides another example of an operating flare: There is a flare system operating in our urea plant at PFK Sdn.Bhd. in Malaysia. There is a high pressure flare stack for relief valves, one for medium pressure vent and one stack for low pressure vent and tanks.

Noureldeen Abbas from Petrochemical Industries Company, Kuwait provides information about a dedicated ammonia flare in a urea plant:

We have installed a flare system in our urea plants in Kuwait (PIC) and connected all safety valves and vent stack to a dedicated flare system. All ammonia sources whether continuous or intermittent are connected to the flare system and it is working well.

Mark provides conclusions from two papers that were presented at the 2012 Nitrogen+Syngas conference and gives new suggestions: Two interesting papers about flares in urea plants were presented during the Nitrogen+Syngas Conference in Athens. The main conclusions were:

- Flares introduce new risks (crystallisation and explosive mixtures in the headers) and more environmental concerns (NO_x versus NH₃).
- Do not simply specify a flare system in your inquiry for a new urea plant, define which continuous and discontinuous emissions are acceptable.

In my view there are better alternative solutions than a flare such as:

- design the piping around the centrifugal HP pumps for higher pressure to delete the safety valves on these pumps;
- use high pressure switches in the synthesis section to reduce the risk of blowing of synthesis safety valves;
- use emergency separators or absorbers;
- disperse gaseous ammonia at safe locations.

Several urea plants have been safeguarded according to these alternative solutions.

Ramchandra Nesari, a freelance consultant from India shares his experiences:

I have seen flare stacks installed in some Saipem urea plants in the Middle East. These plants have separate flare stacks for continuous and non-continuous emissions. There is a separate flare stack for blowdown from safety valves. They are operating satisfactorily, but you have to provide a small quantity of natural gas as fuel for the pilot burners.

This series of discussions is compiled from a selection of round table topics discussed on the UreaKnowHow.com website. UreaKnowHow.com promotes the exchange of technical information to improve the performance and safety of urea plants. A wide range of round table discussions take place in the field of process design, operations, mechanical issues, maintenance, inspection, safety, environmental concerns, and product quality for urea, ammonia, nitric acid and other fertilizers.

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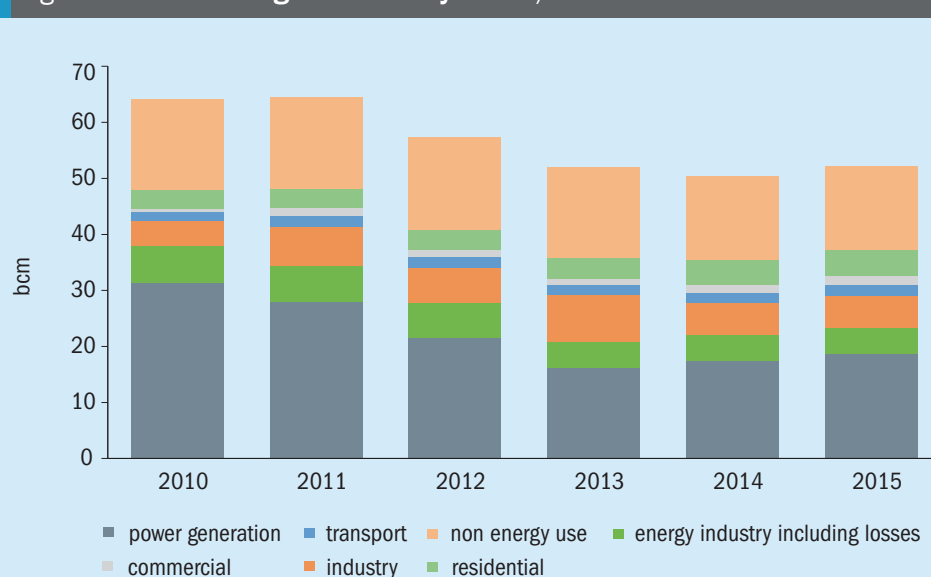
The outlook for India's natural gas and fertilizer sectors

Nelly Mikhael, Senior Consultant, and **Priyanka Khemka**, Consultant with Nexant Inc look at how recent and future changes to India's natural gas industry may impact upon future nitrogen fertilizer production.

India's gas industry is in a state of transition. The country faces a broadening gap between indigenous supply and demand. Thanks to India's rising population and the ongoing quest to provide a better standard of living for its people, the country's outlook for energy demand growth is robust. The role of gas in the country's energy mix, however, is hard to determine. Today, gas occupies less than 7% of India's primary energy mix. Because the ability of end-users to pay high prices for gas-fired power generation and/or gas as a fuel or feedstock is limited, India's future demand growth is contingent on several factors. These include, but are by no means limited to: government backing for indigenous gas production and equitable pricing for upstream producers; New Delhi's continued support for gas allocations to the fertilizer sector; and (in light of the country's growing import dependency), the price of India's broadening portfolio of imported liquefied natural gas (LNG).

India's gas demand is dominated by the power, industrial, and non-energy use sectors, as shown in Figure 1. The latter covers gas used for 'non-energy purposes', namely the fertilizer and petrochemical sectors, where gas is used as a feedstock. In recent years, constrained supplies have affected the country's gas industry. Filling this gap, however, has not been easy. Indigenous production has been on the decline, thanks in no small part to dwindling output from mature fields and the disappointing performance of the Reliance-operated KG-D6 block. Although India has no less than four LNG import terminals serving the western and southern parts

Fig 1: India's historic gas demand by sector, 2010-2015



of the country, robust oil prices through 2014; a supply-tight global LNG market between much of 2011 and 2014; and the post-2009 switchover in the pricing terms of Petronet LNG's 7.5 million t/a LNG supply contract with Qatar's RasGas combined to yield correspondingly high imported prices. The fertilizer and power sectors serve a large section of India's predominantly low-income agricultural population, and cannot absorb high natural gas prices. This concomitant of factors resulted in a degree of gas demand destruction in India between 2012 and 2014. This is also shown in Figure 1.

Feedstock costs

For the fertilizer industry, access to reasonably-priced natural gas is a key concern. Given the conversion of the country's urea

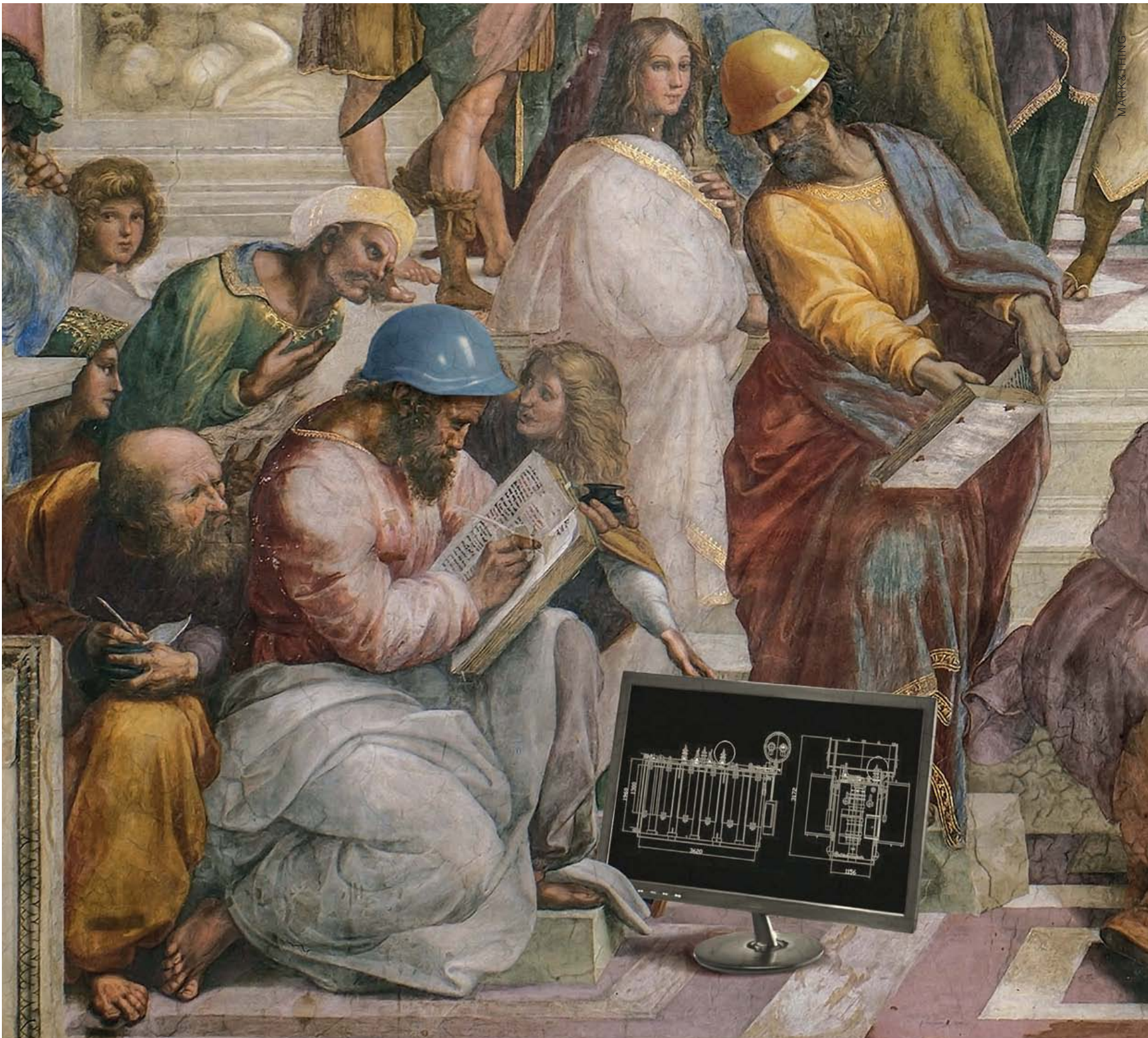
manufacturing plants from naphtha to natural gas, access to competitively-priced feed gas is essential for fertilizer producers, especially since fertilizer production is an integral part of New Delhi's emphasis on food production security. This explains why the fertilizer sector receives priority access to domestically-produced gas.

Following a few years of consecutive declines, India's natural gas supply and demand outlook is changing. This is attributable to two factors. The first is the promulgation of new upstream and domestic gas pricing policies, which are conducive to higher domestic gas production in the medium to long-term. India's domestic gas pricing was reformed in late 2014, with the partial aim of boosting the price of gas paid to India's upstream producers. In the recent past, dwindling upstream

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Fig 2: India's historic and projected gas balance, 2005-2025

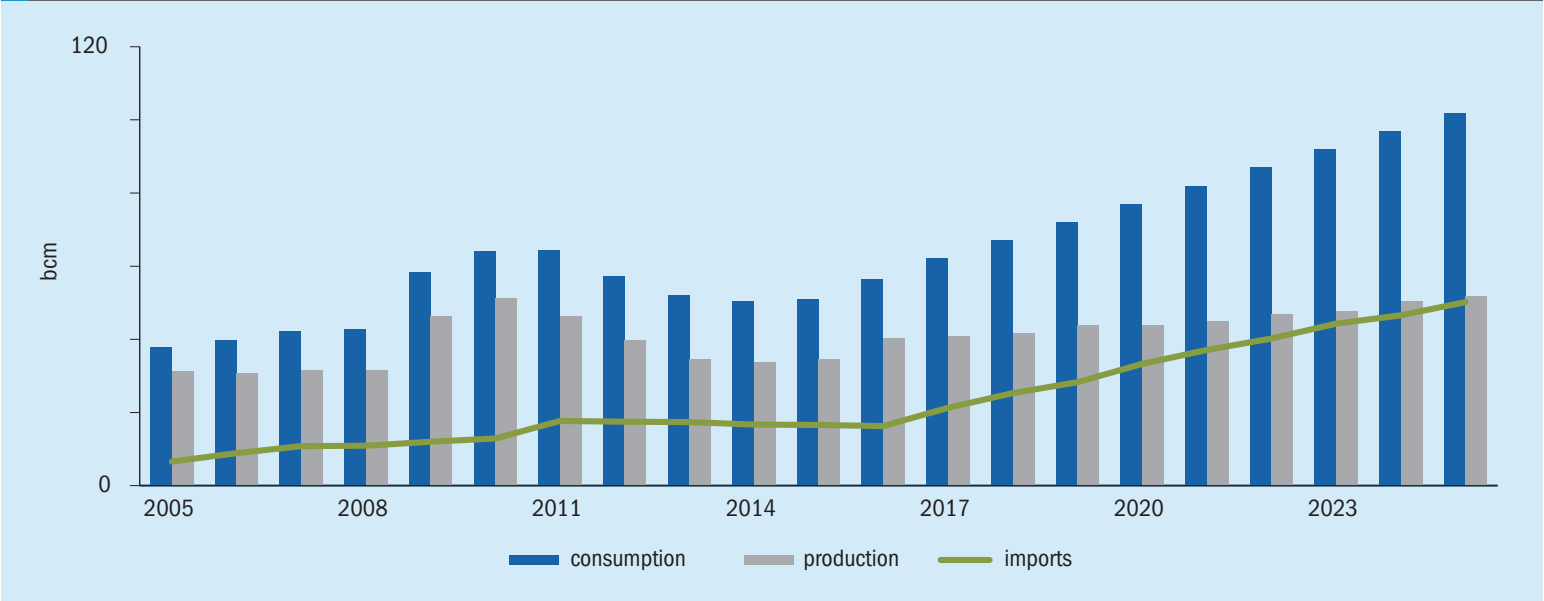
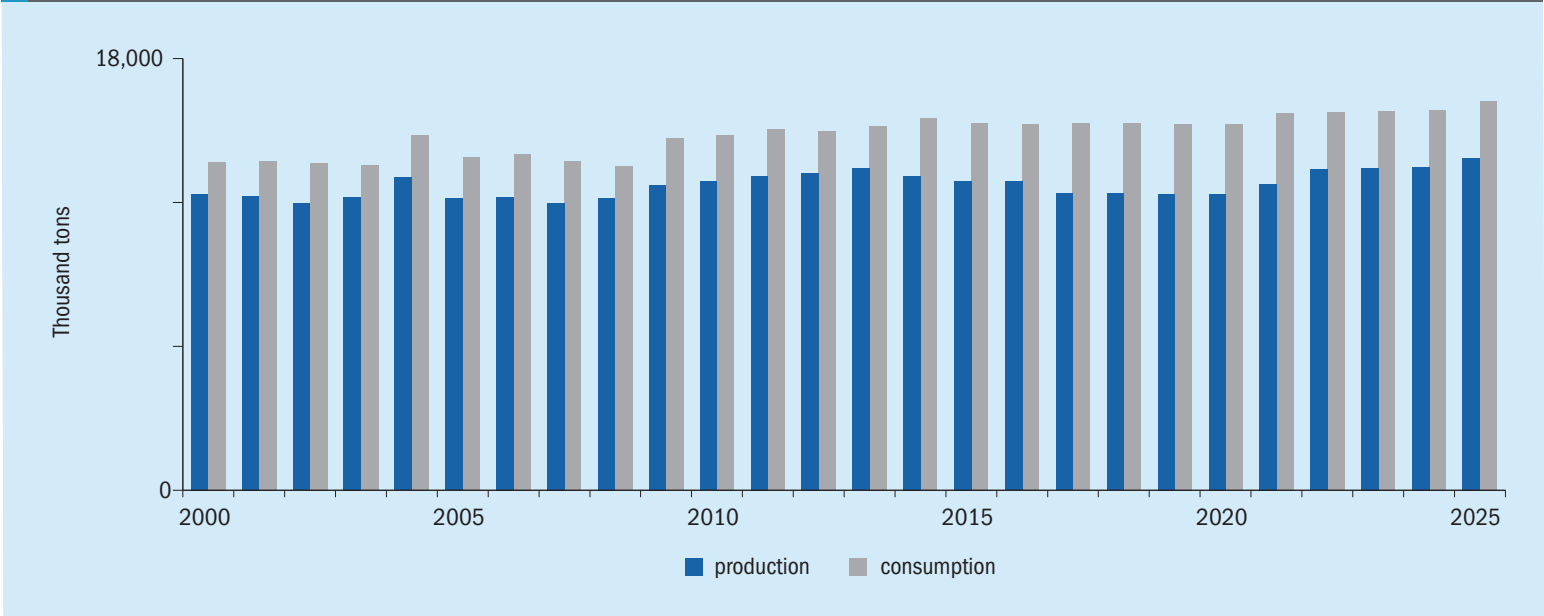


Fig 3: India's ammonia supply/demand outlook



production and a lack of investment in new petroleum fields was partially attributable to a lack of financial incentives for upstream producers. This initiative was followed up with a March 2016 initiative by the Indian Ministry of Petroleum and Natural Gas allowing producers in “challenging” areas to sell gas under a special pricing regime. The effects of these policies may take some time to materialise, but in the longer run, they bode well for increased indigenous gas output. The second factor is New Delhi’s enactment of a so-called “gas pooling policy” in March 2015. This policy ensures the supply of gas at a uniform delivered price to all fertilizer plants on the gas grid for ammonia and urea production. The policy was enacted because of uneven gas procurement prices for urea producers, where prices were contingent

on whether the gas was sourced from the domestic or import market, or varying combinations of both. Based on these supply and demand policy responses by the Indian government, the country’s overall gas consumption is forecast to rise through 2025. But projected domestic production growth will be unable to keep abreast of consumption increases, as shown in Figure 2. This will result in growing LNG import dependency for India. Based on current global LNG market dynamics, however, spot LNG import prices are tipped to be competitive over the next several years. This is the result of an oversupplied market stemming from the start-up of new projects in Australia and North America, and indifferent demand prospects in key consuming markets like Japan, Korea and (in the short-term),

China. Access to competitively-priced sources of imported gas likewise bodes well for increased Indian gas consumption going forward, especially for the nitrogen fertilizer/ urea sector.

Nitrogen market

Behind China and the United States, India is the third-largest ammonia consumer in the world, with an estimated demand of about 15 million t/a in 2015. About 15% of India’s ammonia requirements – over 80% of which is used for urea production – are met via imports, mainly from the Middle East. In the past, India’s ammonia/urea facilities have been forced to temporarily suspend operations due to gas shortages. However, the recent fall in natural gas prices and the introduction of India’s gas pooling policy for the fertilizer sector

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has boosted ammonia and urea supply growth of late. In 2015, FACT re-opened a mothballed 200,000 t/a ammonia facility in Kochi, Kerala. The plant was shut down in January 2014, when delivered LNG prices reached \$24/MMBtu. However, a drop in crude oil prices; a fall in oil-indexed LNG prices to \$10.90/MMBtu (excluding value added tax; VAT); and the government of India's VAT waiver in the first half of 2015 all combined to help FACT restart its ammonia plant. Looking ahead, India's ammonia imports are expected to decline slightly as domestic output increases. These increases, which are illustrated in Figure 3, are the result of new gas or coal based units entering service; the ongoing conversion of naphtha based units into gas-based feedstock; and improvements in operating efficiencies.

In 2015, India produced a record 24.5 million t/a of urea, increasing output by 2 million tons from 2014, and operating at close to 100% of nameplate capacity. This improved performance is attributable to the government's new urea policy and the National Democratic Alliance (NDA) government's reform-oriented action plan. Urea is strongly favoured over other nitrogenous, phosphate and potassium fertilizers due to a subsidy scheme that promotes urea consumption. Farmers in India tend to heavily favour urea, as it is cheaper and highly subsidized compared to phosphorous and potassium fertilizers. Indeed, this has resulted in the over-use of urea, which in turn has adversely affected soil quality and crop yield in many regions.

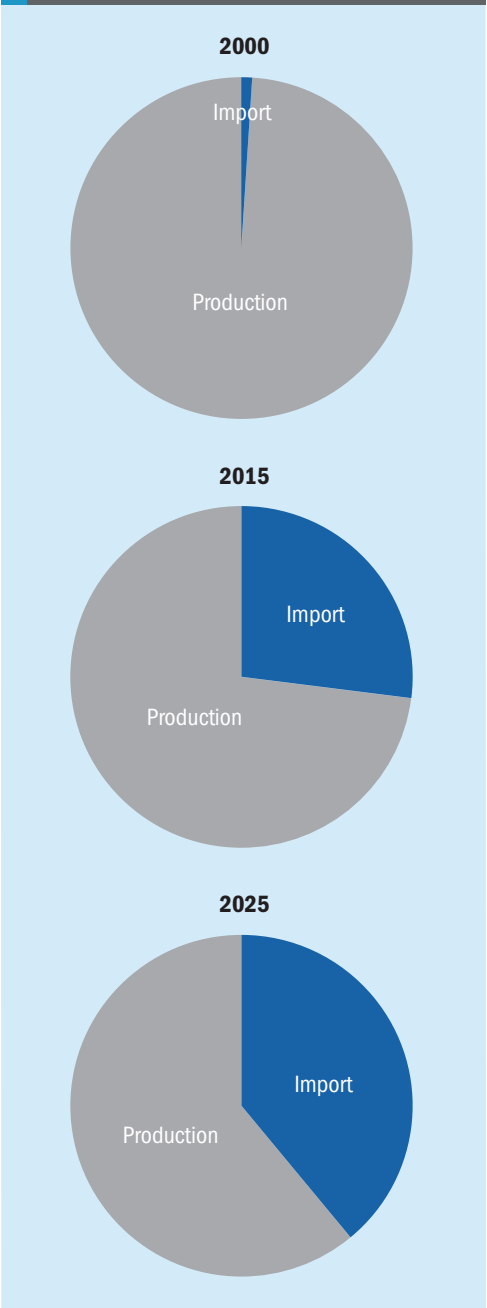
To address the environmental implications of urea over-use, and prevent the diversion of urea to the industrial sector, the government has mandated that least 75% of the nation's urea production be coated with neem. Neem-coated urea offers the benefit of the slower release of nitrogen; consequently, smaller quantities for soil application are required relative to uncoated urea. Despite the enactment of this policy, forecast population growth and India's ever-growing agricultural requirements ultimately all translate to rising urea demand, albeit at a slower rate relative to historic levels. Nexant believes that the nation's urea demand will increase by about 7 million t/a between 2015 and 2025. India's anticipated urea demand growth has grabbed the government's support for new domestic urea manufacturing capacity, especially in light of the government's emphasis on agricultural self-sufficiency.

New capacity

More than a dozen ammonia/urea projects, based on gas as well as coal, are under consideration. For example, Coal India Limited (CIL) and National Thermal Power Corporation (NTPC) have recently entered into a joint venture to revive Fertilizer Corporation of India's fertilizer plants in Sindri and Gorakhpur. Feedgas will be sourced from GAIL's proposed Jagdishpur-Haldia pipeline. Meanwhile, Indian Oil has formed a joint venture with Coal India Limited and NTPC, called Hindustan Urvarak, to undertake the revival of the closed fertilizer plant at Sindri in Jharkhand province. It is also considering investing in the ammonia-urea plant at Barauni and urea plant at Gorakhpur in Uttar Pradesh. In addition, ONGC and CFCL are planning to build a gas based ammonia/urea facility in Tripura. Further, Adani Group has signed a memorandum of understanding (MoU) with the government of Chhattisgarh, India to develop a coal to poly-generation (CTP) plant which will include an ammonia/urea and substitute natural gas (SNG) complex. This is just one of the ten proposed coal-based fertilizer plants which were announced by the government in 2015, as a step to make India self-sufficient in fertilizer production.

Though numerous projects and plans have been announced, securing capital investment is a major hurdle. None of the above-mentioned plants have achieved financial closure. The huge backlog of government subsidies, which stood close to \$8 billion for urea fertilizer in fiscal year (FY) 2015-16, may deter private sector company investment in the fertilizer sector. The estimated unpaid fertilizer subsidy carried forward has been rising from less than \$2 billion in FY 2011-12 to \$8 billion in FY 2015-16. Some companies are also considering the possibility of manufacturing urea overseas, in low cost locations such as Iran, and importing into India. Of the more than a dozen new projects under consideration, Nexant believes that only 3 or 4 new world scale urea plants will come on-stream by 2025. Chambal Fertilizers and Chemicals' proposed gas based ammonia-urea complex in Kota, Rajasthan is in a fairly advanced stage (as compared to other projects in India) and has a higher likelihood of materialising. Nevertheless, the capacity growth rate is expected to be much slower than that of demand, thereby increasing the trade deficit in the country, as shown in Figure 4.

Fig 4: India's urea net imports vs domestic production



Gas price the key

To conclude, the outlook for growing gas use in India across the board is promising, but a key determining factor is price. This point is especially crucial in light of India's growing dependency on imported gas. Pricing and ongoing government support in the form of volume allocation and sectoral subsidies both are crucial for the expansion of India's nitrogen fertilizer sector. New Delhi appears optimistic that the country will be self-sufficient in the production of nitrogen fertilizers, but given India's gas price sensitivity, the slow pace of new project development, a convoluted bureaucracy, and a large outstanding subsidy balance, Nexant believes that current government projections are overly optimistic.

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Syngas project listing 2016

A round-up of current and proposed projects involving non-nitrogen synthesis gas derivatives, including methanol, hydrogen, synthetic/substitute natural gas (SNG) and gas- and coal to liquids (GTL/CTL) plants.

Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
CANADA							
n.a.	Sasol	Sasol	Strathcona, AB	GTL	7,400	P	2021
n.a.	Primus Green Energy	n.a.	Montney, AB	Methanol	160	BE	2018
CHINA							
n.a.	JM (DAVY™)	China Shenhua CTL	Urumqi, Xinjiang	Methanol	5,500	C	2016
n.a.	JM (DAVY™)	Suxin Energy Hefeng	Tacheng, Xinjiang	SNG	2 bcm/a	BE	2018
n.a.	JM (DAVY™)	Shaanxi Yanchang	Shaanxi	Methanol	5,500	UC	2018
n.a.	JM (DAVY™)	China Coal Shaanxi Yulin	Shaanxi	Methanol	5,500	CA	2019
n.a.	JM (DAVY™)	Qinghai Provincial Mining	Qinghai	Methanol	5,800	BE	2019
Casale	Casale	Shandong Jinmei	Zhangqiu, Shandong	Methanol	2,000	UC	2016
Casale	Casale	Shanxi Jinmei Huayu	Jincheng, Shanxi	Methanol	4,000	UC	2016
Casale	Casale	Xinneng Energy Ltd	Erdos, Mongolia	Methanol	2,000	UC	2017
Casale	Casale	Xinjiang Xinye	Wujiaqu, Xinjiang	Methanol	2,000	UC	2016
Casale	Casale	Precious Tyrone Qitaihe	Qitaihe, Heilongjiang	Methanol	2,000	UC	2017
n.a.	n.a.	Sinopec Henan	Hebi, Henan	Methanol/MTO	5,500	C	2016
n.a.	n.a.	Gansu Pingliang	Pingliang, Gansu	Methanol/MTO	5,500	UC	2017
INDIA							
Engineers India Ltd	Haldor Topsoe	Assam Petrochemicals	Namrup	Methanol	525	UC	2019
n.a.	Haldor Topsoe	Bharat Petroleum Co	Mumbai	Hydrogen	148	RE	2017
n.a.	Haldor Topsoe	HPCL Mittal Energi	Bhatinda	Hydrogen	2 x 131	RE	n.a.
IRAN							
Namvaran/IIND	JM (DAVY™)	Kharg Petrochemical Co	Kharg Island	Methanol	4,450	CA	2020
Namvaran	Haldor Topsoe	Marjan Petrochemical	Marjan	Methanol	5,000	UC	2017
TCC	Haldor Topsoe	MEKPCo	Pars	Methanol	5,000	UC	2017
Namvaran	Haldor Topsoe	Badre-Shargh Pet Co	Chabahar	Methanol	5,000	CA	2019
PIDEC	Casale	Kaveh Methanol	Bander Dayyer	Methanol	7,000	UC	2016
PIDEC	Casale	Apadana Methanol	Assaluyeh	Methanol	5,000	UC	2017
n.a.	Casale	Bushehr Pet Co	Assaluyeh	Methanol	5,000	UC	2017
KAZAKHSTAN							
Fluor	Compact GTL	Kazoil	Aktobe	GTL	350	DE	2018
PAPUA NEW GUINEA							
n.a.	n.a.	Sojitz/NPCP	West Papua	Methanol	3,000	P	2020
PHILIPPINES							
n.a.	Haldor Topsoe	Petron	Bataan	Hydrogen	2 x 69	CA	2018

KEY

BE: Basic engineering
C: Completed/commissioning
CA: Contract awarded

DE: Design engineering
FS: Feasibility study
n.a.: Information not available

P: Planned/proposed
RE: Revamp
UC: Under construction

Conversion:
1 t/d of hydrogen = 464 Nm³/h
1 t/d of natural gas = 1,400 Nm³/d

Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
RUSSIA							
n.a.	Haldor Topsoe	Shchekinoazot	Shchekino	Methanol	1,350	UC	2017
Casale	Casale	Metafrax	Gubakha, Perm	Methanol	3,375	RE	2016
n.a.	Haldor Topsoe	Lukoil	Volgograd	Hydrogen	258	C	2016
TRINIDAD AND TOBAGO							
n.a.	MGC	Caribbean Gas Chemical	La Brea	Methanol	3,000	DE	2019
n.a.	MGC	Caribbean Gas Chemical	La Brea	DME	300	DE	2019
TURKMENISTAN							
Hyundai/LG/Itochu	Haldor Topsoe	Turkmen GTL	Ashgabat	GTL	2,200	UC	2018
Hyundai	Haldor Topsoe	Turkmenbashi Refinery	Turkmenbashi	Hydrogen	100	BE	2019
UNITED STATES							
Fluor	JM (DAVY™)	South Louisiana Methanol	St James Parish, LA	Methanol	5,000	DE	2019
OCI	Air Liquide	Natgasoline LLC	Beaumont, TX	Methanol	5,000	UC	2017
n.a.	ExxonMobil	Natgasoline LLC	Beaumont, TX	MTG	3,000	DE	n.a.
Proman	JM (DAVY™)	Big Lake Fuels	Lake Charles, LA	Methanol/MTG	4,200	DE	2020
n.a.	JM (DAVY™)	Northwest Innovation	Clatskanie, OR	Methanol	2 x 5,000	P	2020
n.a.	JM (DAVY™)	Northwest Innovation	Kalama, WA	Methanol	2 x 5,000	DE	2019
n.a.	Primus Green Energy	n.a.	n.a.	Methanol	160	BE	2017
n.a.	Technip	Air Products	Baytown, TX	Hydrogen	2,500	DE	2018
UZBEKISTAN							
n.a.	Sasol	Oltin Yo'l GTL	Shurtan	GTL	5,000	DE	2020?



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The future of ammonium nitrate

Ammonium nitrate's storage and use continues to face scrutiny on two fronts – one related to safety, the other to security.

As we noted in last issue's Editorial (*Nitrogen+Syngas* 342, Jul/Aug 2016, p4), ammonium nitrate faces continuing regulatory pressure around the world due to concerns about its potential for accidental detonation or deliberate misuse. Turkey has recently joined the list of countries which have banned the sale of AN as a fertilizer, including the Philippines, Afghanistan, China and Colombia. Other countries ban the sale of 'pure' AN, such as Pakistan, Germany, Ireland, the UK and Australia, and India has reclassified it as an explosive, severely tightening the regulations on its storage and handling. While most of these have been security related, the accidental explosions at West, Texas in the US in 2013 and Tianjin in China in 2015 have shown that poorly enforced regulations on storage and handling still have the potential to lead to catastrophic loss of life.

US regulations are often very influential worldwide, and the way that the regulatory environment is moving in the US is likely to be very much determined by two recent developments – first the report into the West accident by the US Chemical Safety Board and secondly the Department of Homeland Security's Ammonium Nitrate Security Programme (ANSP).

West, Texas

The accident at the West Fertilizer Company (WFC) at West, Texas occurred on April 17th, 2013 at a fertilizer blending and distribution facility. It appears to have been due to a fire which broke out – the cause of which has still not, to this day, been firmly established by local authorities. The Texas State Fire Marshal's Office (SFMO) carried out an investigation in conjunction with the Bureau of Alcohol, Tobacco and Firearms (to establish if there had been any malicious intent) and three lines of

investigation reportedly still remain under consideration: faulty electrical wiring, a short circuit in an electrical golf cart, or an intentional act of arson.

Within minutes, local volunteer fire departments were in attendance. The facility was known to be storing up to 17 tonnes of anhydrous ammonia in several pressurised tanks, and it was these that the firefighters concentrated their attention on, trying to avoid a rupture and accidental release of ammonia. However, unbeknownst to them, there was also 140-160 tonnes of fertilizer grade ammonium nitrate (FGAN) at the facility – 100 tonnes in a railcar which had been partially unloaded, and 40-60 tonnes already offloaded and stored in the warehouse where the fire was raging. At 7:51pm, around 20 minutes after the alarm had been raised, some 30 tonnes of this stored AN detonated. The explosion killed 15 people outright, including 12 emergency responders, and injured 260 more as it ripped through nearby buildings, including three schools, a nursing home and an apartment complex. Only the fact that the blast occurred in the evening, when the schools did not have pupils in attendance, prevented much greater loss of life. The CSB notes in its report that the fact that the railcar, although it was blown over by the blast, also did not detonate, otherwise the incident could have been worse still. Likewise most of the ammonia tanks actually remained intact, preventing the disaster being exacerbated with a large ammonia release.

CSB investigation

The US Chemical Safety Board (CSB) began an investigation into the incident in 2013 which produced its final report in January this year. The report notes several contributory factors to the fire and explosion. Firstly, the molten FGAN melted in

the heat of the fire and came into contact with various other contaminants, including seed materials, zinc (from fertilizer stored in nearby bins), and other organic products, including the plywood-constructed bins themselves. There was also a period when the warehouse was full of thick black smoke, which likely deposited soot and other part-burn organic material into the AN. The fire was then observed to change character 5 or 6 minutes before the explosion, burning brighter and with paler smoke – the CSB believes that this was due to a wall or roof of the warehouse burning through, allowing more ventilation and hence oxygen into the flames. In the meantime however the AN had been sensitised by the presence of contaminants. The CSB concludes that there are three potential mechanisms for the detonation itself – detonation from the top of the FGAN pile; detonation in heated FGAN along exterior wall exposed to fire; or detonation in elevator pit that spread to main FGAN bin.

The report's key findings include that the presence of combustible materials used for construction of the facility and storage bins, in addition to the practice of storing combustibles near the FGAN pile, contributed to the progression and intensity of the fire and likely resulted in the detonation. The WFC facility also did not have a fire detection system to alert emergency responders or an automatic sprinkler system to extinguish the fire at an earlier stage of the incident.

CSB's analysis of the emergency response highlights shortcomings with the West Volunteer Fire Department's accident planning and training, as well as deficiencies in federal and state regulations and standards that could reduce the risk of another incident of this type. Occupational Safety and Health Administration (OSHA) oversight of facilities that store and handle FGAN is criticised for not promulgating

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more widely Section (i) of the OSHA Explosives and Blasting Agents standard, and omitting AN from the List of Highly Hazardous Chemicals, Toxics and Reactives in its Process Safety Management (PSM) standard. Likewise, because West was covered under the EPA Risk Management Program rule for its anhydrous ammonia tanks but not for its FGAN, employees and emergency responders demonstrated a greater awareness of the hazards associated with onsite storage of anhydrous ammonia than those associated with FGAN. AN is not on the EPA Risk Management Program list of chemicals, so the West Fertilizer Company was not required to take safety measures for FGAN similar to those for ammonia. Finally, Federal and state of Texas manuals used for hazardous materials (HAZMAT) training and certification of firefighters placed little emphasis on emergency response to storage sites containing FGAN.

Recommendations

The report’s recommendations are directed on an agency by agency basis. It suggests that:

Environmental Protection Agency (EPA)

The CSB suggests that the EPA develop guidance on Emergency Planning and Community Right-to-Know Act (EPCRA) requirements which explains which chemicals are exempt and which must be reported, and which describes how emergency responders should use Tier I and Tier II inventory reports and Safety Data Sheets, such as in safety training, practice drills, and for emergency planning. It should also develop a general guidance document on the agricultural exemption under EPCRA to clarify that facilities that store or blend fertilizer are covered under the act. Finally, the EPA is asked to revise its Risk Management Program rule to include fertilizer grade ammonium nitrate at an appropriate threshold quantity on the List of Regulated Substances. The offsite consequence analysis should consider “the unique explosive characteristics of FGAN explosions to determine the endpoint for explosive effects and overpressure levels”.

Occupational Safety and Health Administration (OSHA)

The CSB argues that fertilizer grade ammonium nitrate should be added to the OSHA Process Safety Management (PSM) standard List of Highly Hazardous Chemicals,

with an “appropriate” threshold quantity, and revise the OSHA Explosives and Blasting Agents standard to ensure that the standard applies to facilities which store “bulk quantities” (again unspecified) of FGAN, using requirements similar to those in NFPA 400, Hazardous Materials Code. In particular, the CSB recommends the prohibition of using combustible materials for new FGAN facilities and storage bins, and a 3-5 year time frame for replacement of such storage by existing facilities. As detailed below under fire regulations, the CSB would also like to include automatic sprinkler and fire detection systems for indoor storage areas, and “adequate ventilation” and separation distances, as well as requiring that all FGAN storage areas be isolated from combustible, flammable, and other potentially contaminating materials.

Fire regulations

The CSB recommends that – in a subsequent edition of the International Fire Code – the International Code Council (ICC) should develop a chapter or section under Chapter 50 (“Hazardous Materials”) or Chapter 63 (“Oxidizers, Oxidizing Gases and Oxidizing Cryogenic Fluids”) which lists additional requirements for the storage and handling of ammonium nitrate (AN), including: automatic fire detection and suppression systems in existing buildings constructed of combustible materials; ventilation requirements to prevent the accumulation of off-gases produced during AN decomposition, as well as smoke and heat vents to remove heat from AN during fire situations; the prohibition of using combustible construction materials for AN storage areas; and establishing minimum safe separation distances between AN and combustible materials to avoid contamination in the event of fire.

Training

As noted above, deficiencies noted in the area of training have led the CSB to recommend that the Texas Commission on Fire Protection (TCFP), in conjunction with the State Firefighters’ and Fire Marshals’ Association of Texas (SFFMA) and Texas A&M Engineering Extension Services (TEEX), develop training standards for better hazard awareness of fertilizer grade ammonium nitrate (FGAN) and materials stored near to it, and including pre-incident planning and on-scene emergency response. The CSB also asks the Federal Emergency Management Agency (FEMA) to help fund

and promulgate such training via regional, state and local career and volunteer fire departments.

El Dorado Chemicals

Lastly, El Dorado Chemicals, which supplied the AN involved in the incident, are asked that – for all of the company’s distributors and bulk customers that receive fertilizer grade ammonium nitrate – there should be encouragement to conduct internal monitoring and auditing, via established product safety programs, including ResponsibleAg. As regards product stewardship, the company is asked to encourage distributors to provide Safety Data Sheets and FGAN safety guidance to their customers and bulk retail sites to which FGAN is sold or shipped, including written procedures for the safe handling of FGAN, including employee training, and emergency response plans to be sent to Local Emergency Planning Committees and fire departments.

Ammonium nitrate security programme

On the security side of the equation, meanwhile, in 2007 the US Congress passed the Secure Handling of Ammonium Nitrate Act. The bill mandated a regulatory system to help keep ammonium nitrate out of the hands of those with criminal intent. Specifically, it would require all producers, sellers and purchasers who take custody to register with the Department of Homeland Security (DHS). DHS began working on the regulations in 2007, and finally published its Ammonium Nitrate Security Program – Notice of Proposed Rulemaking in August 2011. The notice was then available for public consultation until December 2011, with the public and stakeholders able to comment on how the program could affect different industries. However, there then passed a period of a further four years during which DHS said it was ‘evaluating’ responses to the consultation. Specifically, while the fertilizer industry was generally accepting of the proposed changes (The Fertilizer Institute in the US had been instrumental in pushing for the bill to be passed in the first place), the explosives industry and the Institute of Makers of Explosives, had voiced a number of concerns, especially as regards transportation, and the overlap of the proposed programme with existing Bureau of Alcohol, Tobacco, Firearms, and

Explosives (ATF) regulations. The National Mining Association also noted that the regulation allows the DHS to exempt from its strictures persons producing, selling or purchasing ammonium nitrate exclusively for the production of an explosive, as these individuals are already regulated by the ATF.

The proposed Ammonium Nitrate Security Program would require purchasers and sellers to register with the DHS and be vetted against the Terrorist Screening Database. Upon successful completion of the vetting process, purchasers and sellers would then be issued registration numbers, which would authorize them to engage in the sale, purchase, or transfer of ammonium nitrate. The proposed program also provides for records inspections by DHS to ensure compliance among purchasers and sellers, additional reports of any theft or loss, inspections and audits by the Department, and the potential for civil penalties and adjudications. The rules would apply to anyone who buys, sells or transfers at least 25 lbs (11kg) of ammonium nitrate (of at least 30% AN by weight).

However, the explosives industry was concerned that the verification process at point of sale/delivery would be complicated by the potential transportation and delivery of multiple shipments of ammonium nitrate that may have been purchased in a single transaction. Likewise, they were concerned that additional burdens on commercial carriers, in addition to Hazardous Materials Safety Permits and other applicable ATF certifications, would also complicate the shipment and transportation of AN. Post-sale recordkeeping was also seen as potentially onerous. As a result, a final rule was not issued by the DHS until 2015, and as of time of writing that rule has still not been approved.

Where next?

The CSB report rightly concentrates on shortcomings in the reporting and management structure that led to firefighters not being aware of the hazards they might be facing. One area touched on by the report but not subject to recommendations is the question of changing land use. At the time of its construction, the West Fertilizer Company facility was surrounded by open fields, and no zoning regulations existed when it began operations. However, as the city of West developed over the years, it expanded toward the facility.

The report notes that in Texas alone, of the existing 40 AN storage facilities as of October 2015, 48% are within 0.5 miles of a school, nursing home, or hospital, while 83% are within 0.25 miles of a residence. As has been discussed in this magazine before (*Nitrogen+Syngas* 335, May/June 2015, p32), this kind of creeping urbanisation has been a factor in other accidents, like Toulouse in 2001, and potentially presents a major challenge for the fertilizer industry.

However, the thrust of the recommendations as regards the EPA and OSHA

seems to be gradually shifting towards treating solid fertilizer grade AN and explosive grade AN in much the same way. This is also the path that the DHS seems to be moving down, and the same decision that India in effect took in the wake of a series of bomb attacks a couple of years ago. While the US market has largely moved towards UAN solutions rather than use of solid FGAN in any event, it remains to be seen whether this continued convergence might also begin to shift thinking in other countries on the regulation of AN. ■



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Bimetallic tubes for nitric acid applications

Corrosion problems in nitric acid plants often occur where there are alternating wet and dry zones e.g. the nitric acid cooler/condenser. A heat exchanger with tubes built entirely of zirconium would solve the problem but would be very expensive. A novel alternative solution has been developed by Sandvik, a bimetallic tube consisting of an outer component in stainless steel mechanically bonded to an inner component of zirconium. **D. Gullberg, J. Wallin, and M. Senatore** of Sandvik Materials Technology give a detailed description of the bimetallic tube and all its potential benefits.

Nitric acid is one of the strong acids and is a powerful oxidising agent which has great importance in the production of fertilizers. Stainless steels are commonly used for the construction of nitric acid plants. Low carbon austenitic stainless steels such as AISI 304L and AISI 310L, are particularly well suited for most nitric acid equipment¹. The stainless steels are protected by a thin chromium oxide layer (Cr₂O₃) which spontaneously forms in air, however it also forms when suspended in moderately concentrated nitric acid due to the oxidising character of the acid. As long as the corrosion potential remains in the passive domain the chromium oxide will be renewed at least at the same rate as it is dissolved ensuring passive corrosion¹⁻³. Corrosion resistance of an austenitic stainless steel in nitric acid is very much dependent upon the chromium content, which will reduce the corrosion rate and increase the limits of use with respect to temperature and concentration. It is also important with low impurity levels such as carbon, sulphur, and phosphorus to ensure good performance. Carbon can form chromium carbides and chromium depleted zones during sensitisation after heat treatment or welding. Sulphur and phosphorus can segregate in grain boundaries and decreases the resistance to intergranular corrosion. An optimised quench annealing is required to attain an optimal microstructure¹.

Optimised stainless steels are well suited for nitric acid use; however in some

cases they are not enough. Transpassive corrosion can cause severe intergranular corrosion also on non-sensitised and optimised stainless steels. Transpassive corrosion can be caused by increasing temperature and concentration, or if oxidising chemical species co-exists¹⁻². Several corrosion studies have shown the mechanisms for nitric acid corrosion of stainless steels and the influence from several factors on transpassive corrosion¹⁻⁵. In nitric acid plants transpassive corrosion is often caused by nitric condensates. The large surface area to solution volume ratio and the slow condensate renewal lead to a fast increase in the corrosion potential as reduction products are accumulated in the condensate film¹. Balbaud et al. showed how much more severe the condensate corrosion is compared to liquid bulk conditions⁴. The nitric acid cooler/condenser is a typical place where corrosion problems occur in a nitric acid plant and where condensates cannot be avoided. Normally it is only at the alternating wet/dry zones that the corrosion rate is accelerated. The life time can, in many cases, be elongated by switching material to an advanced nitric acid grade,

but sometimes even high alloyed nitric acid grades do not provide a satisfactory lifetime.

Zirconium is often chosen for the most critical parts in terms of corrosion and is the last option when it is not possible to use stainless steels. Zirconium has excellent corrosion properties in nitric acid, with the drawback of being an exclusive and expensive material. Special fabrication is required, including post weld heat treatment, adding to the high cost for a zirconium heat exchanger. A new, innovative solution is to use a bimetallic tube for nitric acid applications. This paper describes the new product and the benefits it can give in certain applications.

Product description

The bimetallic tube consists of two mechanically bonded components. An outer component consists of Sandvik 2RE10 (UNS S31002), which is a high alloyed specialised stainless steel for nitric acid applications. The inner component is Sandvik Zr 702 (UNS R60702) characterised by exceptional corrosion resistance in nitric acid. Chemical composition of the components can be seen in Table 1.

Table 1: Chemical composition (nominal) wt.-%								
	Zr+Hf	Hf	Fe+Cr	H	N	C	O	
Sandvik Zr 702	≥99.2	≤4.5	≤0.2	≤0.005	≤0.025	≤0.05	≥0.16	
	C	Si	Mn	P	S	Cr	Ni	Mo
Sandvik 2RE10	≤0.015	≤0.15	1.8	≤0.020	≤0.005	24.5	20	≤0.10

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Fig 1: Utilisation of the bimetallic tube in a nitric acid cooler condenser

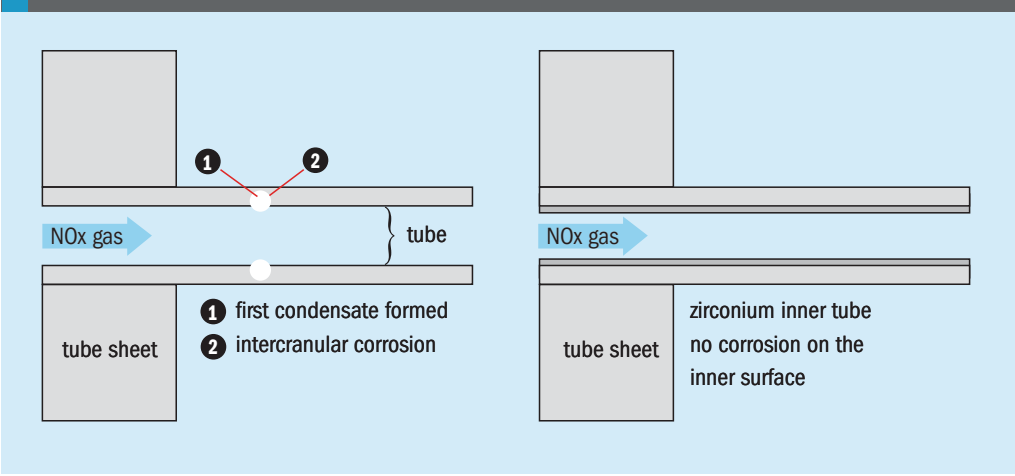


Table 2: Heat transfer properties

Temperature, °C	Thermal conductivity, W/mK		Specific heat capacity, J/kgK	
	2RE10	Zr 702	2RE10	Zr 702
20	13	22	470	285
100	15		495	
200	17		530	
300	19		555	

Thickness of the inner component is approximately 0.7 mm and acts as a corrosion barrier with the purpose to protect the stainless steel component. It is produced in accordance with ASTM B523. The outer load bearing component meets the requirements of ASTM A213 and ASME Code Case 2591. Outer dimension of the bimetallic tube is 19.05 mm (3/4"); however other dimensions are also possible. Tube to tube sheet joining only involves the outer component which enables the use of a stainless steel tube sheet.

Any welding will be stainless to stainless and, therefore no post weld heat treatment is required.

Use in nitric acid cooler/condensers

The concept is to use the bimetallic tubes in nitric acid cooler/condensers with the acid on the tube side that previously had suffered from corrosion at the point of condensation. However, the bimetallic tubes can also be used in other nitric acid equipment where corrosion is forming on the inner surface of heat exchanger tubes. Nitric acid is produced from ammonia which is oxidised over a platinum-rhodium gauze to nitrogen dioxide and steam. Nitric acid is formed when the gases are condensed and the nitrogen dioxide is absorbed in the water. The condensation takes place in the cooler/condenser. The

most corrosive environment is formed where the condensation takes place since condensate is much more corrosive than the liquid bulk. Depending on the process conditions the point of condensation can be too corrosive for stainless steels with intergranular corrosion as a consequence, while the other parts are still in a passive state. With a bimetallic tube it is possible to protect the surface subject to corrosion with zirconium without any other changes in the process. How the bimetallic tube can be utilised is showed in Fig. 1.

Thermal conductivity

Thermal conductivity is of course an important property of a heat exchanger tube. The standardised methods of measuring thermal conductivity are made on flat specimens, therefore no measurements of the thermal conductivity of the bimetallic tube has been performed, since the mechanical bond is dependent on the cylindrical geometry of the tube. However, the thermal conductivity has been calculated and modelled. Heat transfer properties of the components can be seen in Table 2 and these were used in the modelling. The model was a 2D set-up with a bimetallic tube with the dimensions 19.05 x 2.3 mm. The thickness of the outer component was 1.6 mm and the inner component 0.7 mm. The boundary conditions were to use a

fixed temperature on both surfaces; 50°C on the outer surface, and 100°C on the inner surface. It was found by the modelling that the corresponding effective heat conductivity of the bimetallic tube was 16 W/mK, under the assumption that full contact was attained between the two components. However, since there is no metallic bond between the components it is reasonable to assume that small gaps can occur. Therefore it was interesting to also simulate the effect of delamination on the effective heat transfer.

Small gaps were added in the model in the bond interface in order to simulate delamination. Three parameters were used; the number of gaps, gap height, and gap length, which together gave the total contact length. Several simulations were performed where the different parameters were altered calculating the effective heat transfer and thermal resistance for each different setting. Fig. 2 shows the geometrical set-up and one of the simulations.

For example; if the gap size is 5 x 61.6 µm the heat transfer is almost not affected if the total contact is larger than 50%. Even at only 10% contact the effective heat transfer is still above 15 W/mK, compared to 16 W/mK at full contact, see Fig. 3. The gap height was found to have very low impact at short gap lengths. In reality, long gaps are considered as unlikely considering the mechanical bond and contact stress between the two components. Smaller gaps can form due to surface roughness. However, based on the simulations; short gaps will, in principle have a negligible effect on the effective heat transfer. The results are considered as credible, supported by the knowledge that similar bimetallic tubes are used as stripper tubes in the urea industry, where an even heat transfer is important for the performance.

Welding trials

The tube to tube sheet joining shall only involve the outer component which will be the pressure bearing component. However, both expansion and welding can potentially damage the mechanical bond. Therefore, it is not completely straight forward to do the tube to tube sheet joints. Certain aspects need to be taken into consideration. The heat-input from the welding can cause relaxation of the bond, create a heat-tint on the zirconium, and in a worst case scenario could melt the zirconium layer. Mixing of the two components must be avoided.

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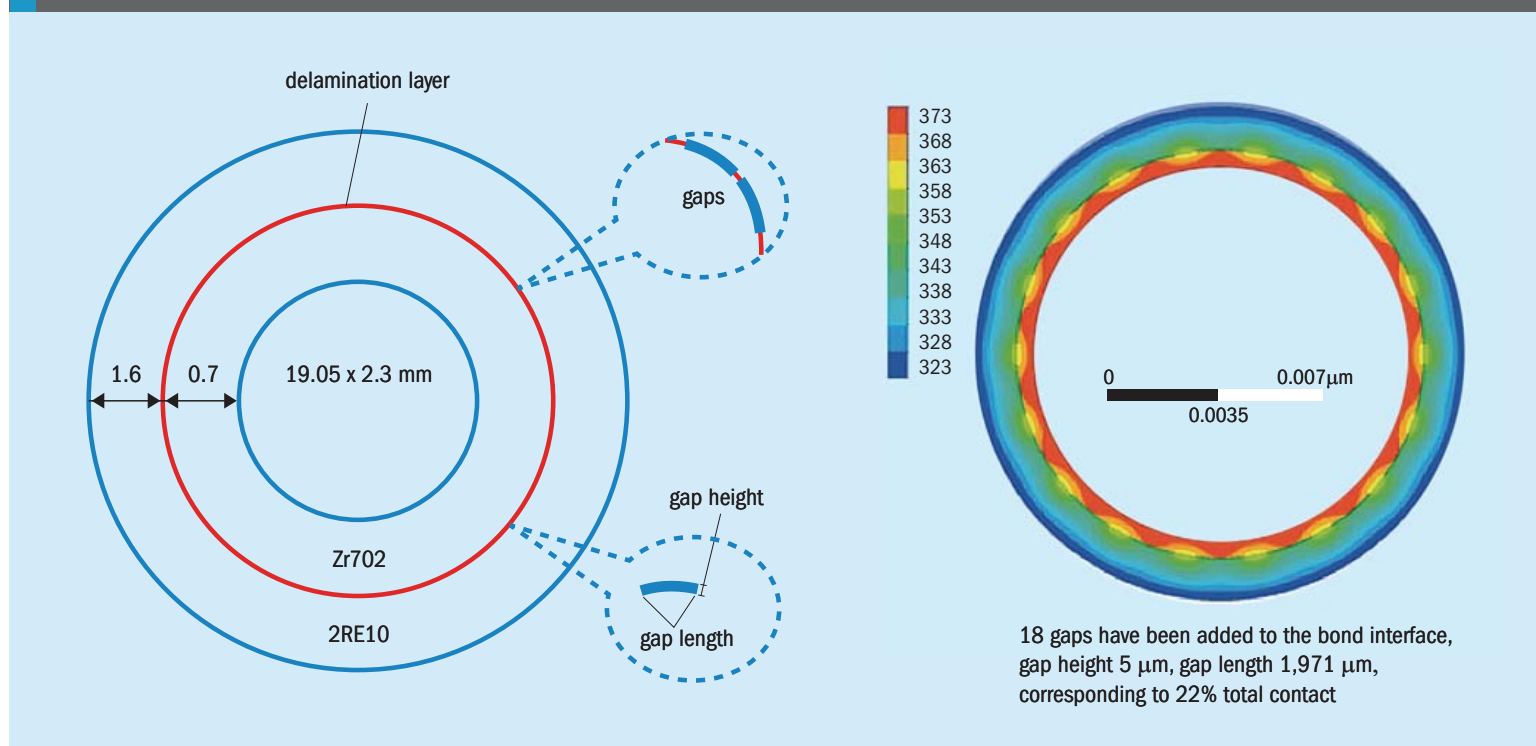
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Fig 2: Modelling set-up of delamination: a) 2D model geometry; b) example simulation with 18 gaps added to bond interface



One way to remove the risk of affecting the bond is to remove the zirconium at the end of the tube to a safe distance from the weld. It was decided to do a mock-up to investigate what removal distance would be required and how the bond would be affected by expansion.

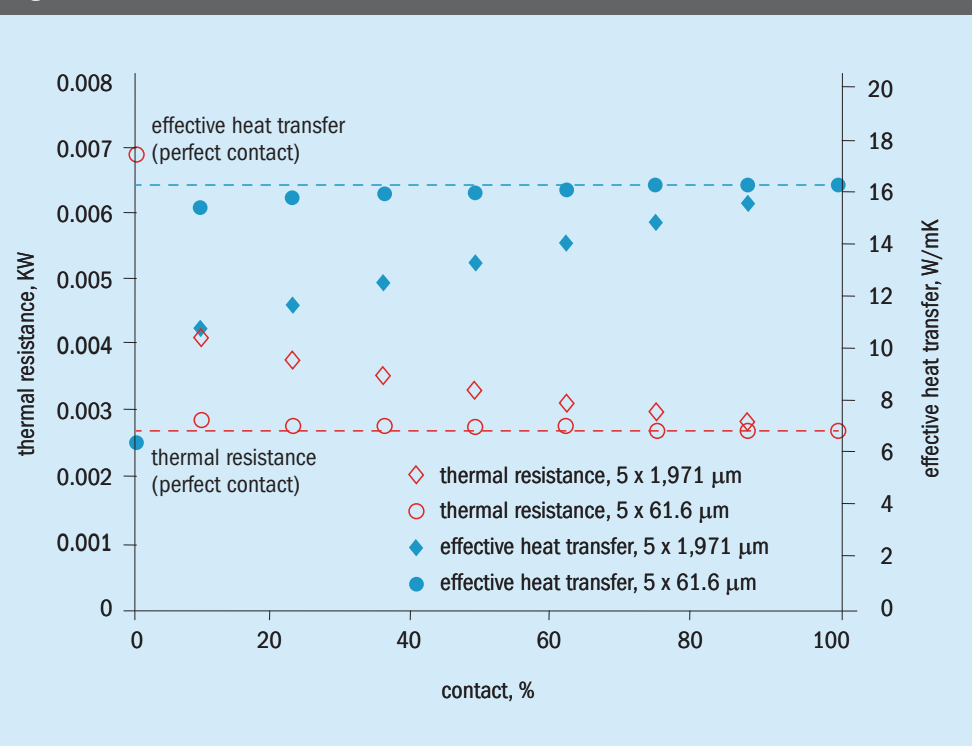
Mock-up fabrication

Sandvik 2RE10/Zr702 bimetallic tubes with the dimension 19.05 x 2.11 mm (the Zr 702 thickness was 0.7 mm) were used for the welding trials. The tube sheet was of AISI type 304L material with a thickness of 50 mm. A 0.8 mm AISI type 310L welding wire was used in the automated TIG-welding process. Each tube to tube sheet joint was seal welded with two passes. Argon was used as shielding gas.

The inner component was machined away from the tube end to four different distances; 5, 8, 10, and 20 mm. To see the effect from expansion three different expansion rates were tested; no expansion (0%), mild expansion (<2%), and expansion (3-5%). Expansion was performed after the welding by rolling and was always started at a set distance from the zirconium edge.

Subsequently the mock-up was cut in pieces so that each piece contained only one tube with a weld and the surrounding tube sheet. The mechanical bond was examined microscopically after the tube to tube sheet joining. Two cross-cuts were examined using an optical microscope; one at the interface at the edge of the

Fig 3: Effective heat transfer and thermal resistance for bimetallic tubes



zirconium, and one in the expansion zone 20 mm from the back end of the tube sheet. The tube to tube sheet joints were also corrosion tested. This was a modified Huey test (ASTM A262 pr. C) where each test piece was boiled in 65% HNO₃ for five 48 hour periods. The test pieces were the mounted tube surrounded by the full thickness tube sheet. All cut surfaces were polished with 600 grit paper before the exposure. It was not possible to determine a corrosion rate due to the complex

geometry and mix of materials, therefore the corrosion test was evaluated by visual inspection.

Results from mock-up evaluation

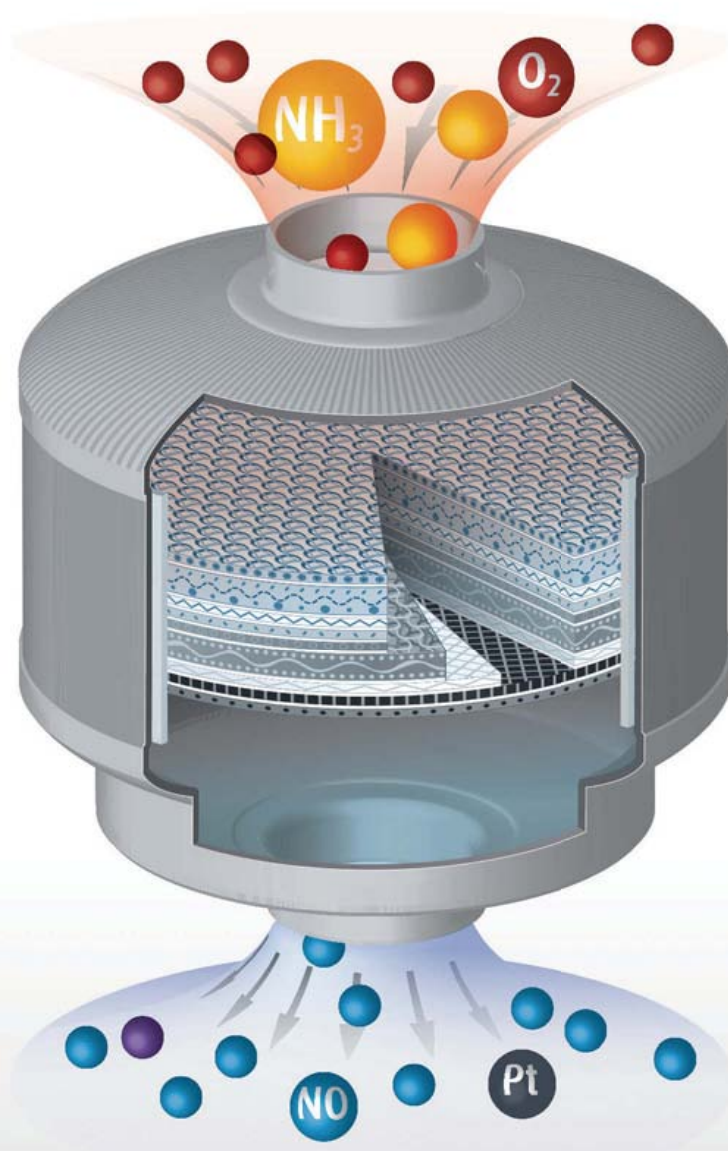
Examination of the mock-up after welding and expansion showed how the different removal distances affected the oxidation of the zirconium. A heat-tint formed on the inner surface of the tube that reached the zirconium from the smallest removal distance which was 5 mm. For

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Fig 4: Comparison of different removal distances

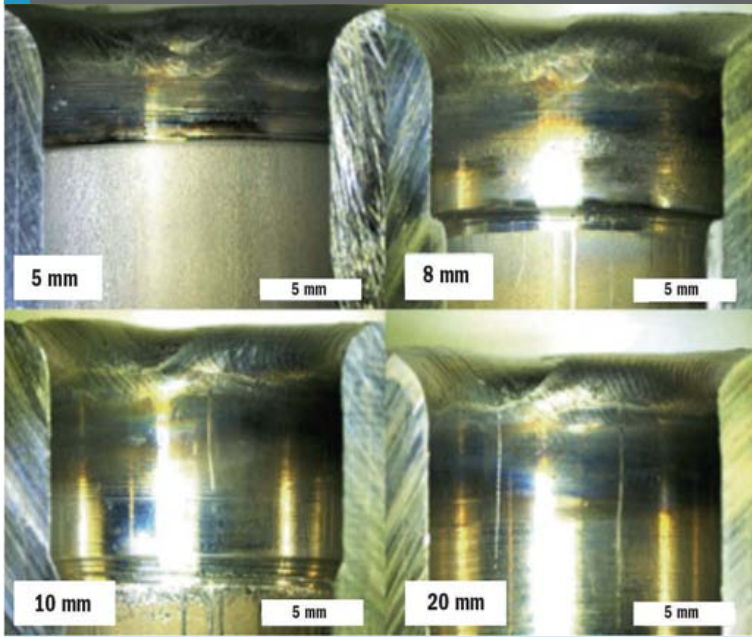


Fig 5: Bond between 2RE10 and Zr 702 at four locations on the tube

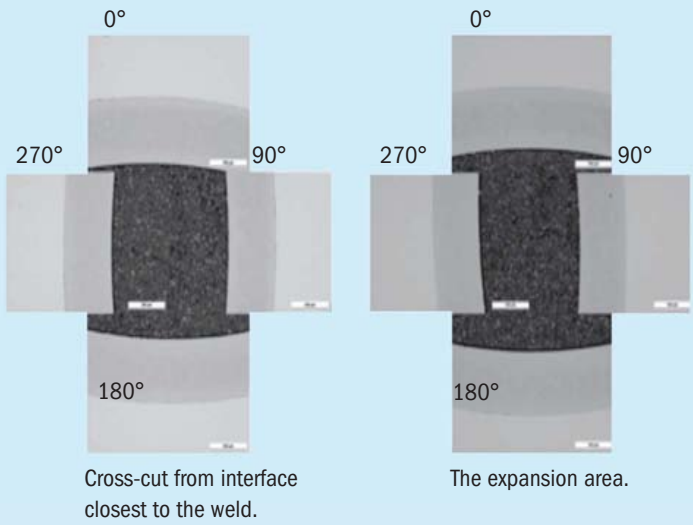


Fig 6: Tube sheet after corrosion: a) weld and HAZ; b) inner surface and zr interface



the 8 mm removal distance the heat-tint almost reached the zirconium, however no oxidation of the zirconium was observed. A comparison between the different removal distances can be seen in Fig. 4. It should be noted that the type of seal weld that was performed in this trial would not have been possible to do without melting the zirconium if it had not been removed from the tube end. Based on the results, it is recommended to remove the zirconium at least 10 mm from the tube end.

Examination of the bond at the zirconium interface closest to the weld showed that the heat from the welding did not cause disbonding even at the closest distance of 5 mm.

No difference was observed between the different removal distances, which was interpreted as that the bond was intact. Small bond gaps were observed which is

normal for bimetallic tubes. It should be noted that it was not possible to measure the strength of the mechanical bond, just to confirm that the components were still in contact.

The examination of the bond in the expansion zone showed that it was also free from disbonding. In fact the appearance of the bond zone was the same independent of the expansion rate. The results indicate that it is possible to perform expansion up to 5% without disbonding or gapping between the two components. However, it is still recommended to start the expansion away from the zirconium end as was done in this investigation since it has not been possible to measure the remaining bond strength after expansion. Fig. 5 shows images from the bond zone of a sample where the zirconium was removed 5 mm

and subsequently expanded (3-5%) after welding.

Visual inspection of the corrosion samples showed no severe corrosion of the weld metal, HAZ, bond zone, or on the zirconium (Fig. 6). The worst corrosion that was detected was on the tube sheet, especially on the cut and polished surfaces. As the tube sheet should be the material with the lowest corrosion resistance it was expected that it would corrode to some extent in the corrosion test. The most interesting part is the surface which corresponds to the inlet in a cooler/condenser, and especially the interface between the zirconium and stainless steel tube which is the difference compared to a normal stainless steel tube to tube sheet construction. This area showed discoloration, but no signs of severe corrosion. The zirconium was unaffected, and no indications were seen on the interface between the zirconium and stainless steel that suggested a weak spot.

Tube production and first installation

The first bimetallic tubes for a test installation were recently produced with the dimension 19.05 x 2.3 mm. The outer pressure bearing component was tested according to ASTM A213, which includes tensile testing and hardness testing.

Additional corrosion testing and a bond test were also performed. Results from the mechanical testing of the bimetallic tubes, which were divided in two lots, can be seen in Table 3.

The corrosion test was only performed on the outer component and involved a Huey test according to ASTM A262 practice C. Average corrosion rates for all five periods were 0.067 and 0.065 mm/year respectively for the two different lots. No selective attack larger than 10 µm was detected on any of the specimens. The bond test is a customised test for bimetallic tubes with the purpose to measure the strength of the mechanical bond. It is performed by measuring the elastic springback of the inner component in three steps; first the inner diameter is measured, secondly the outer component is removed, and last the inner diameter is measured again.

Any change of inner diameter is used as a measurement of the bond strength. In this case the components were separated by hydraulic pressing. The bond was measured on ten specimens from each lot. Both lots had an average value above 70 µm and no specimen had a value below 60 µm. The results from the bond test are considered as very good and are most likely close to the maximum which can be attained.

Table 3: Delivery testing results of the bimetallic tubes for the first installation

Lot	Yield strength, MPa	Tensile strength, MPa	Elongation, %	Hardness, HRB
1st lot	394	585	38	88*
2nd lot	410*	590*	36*	88*

*Average value from two or more tests.

The test installation is a small heat exchanger in a nitric acid plant. So far there are no results from the actual installation; the performance of the bimetallic tubes will be presented in future papers.

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Colourless start-up and shutdown of a nitric acid plant

J. Dammeier, A. Anheyer, P. Kern, C. Perbandt and C. Renk of thyssenkrupp Industrial Solutions (tkIS) propose plant modifications to reduce emissions during the start-up and shutdown of nitric acid plants. The options presented are linked to available utilities and will allow operating companies to custom design or revamp their plant to meet emission targets.

Worldwide the limits for gas emissions are becoming stricter. With nitric acid plants generating nitrogen oxides (NOx) and nitrous oxide (N₂O), a high efficiency gas cleaning system is required. The EnviNOx® system provided by tkIS enables the producer to meet the requested emissions in normal operation. In many countries however the emission limits also include start-up, shutdown and even malfunction. For example, in the US an emission maximum can be defined by a moving average over the period of 30 days. Additionally many operating companies request invisible start-up and shutdowns as local communities are irritated by orange/brownish clouds from the stack. The estimated value for a colourless NOx emission is below 50 ppmv.

For these reasons reduced emission or colourless start-up and shutdown were investigated. Several options covering a range of approaches were studied. Each option can only cover a certain part of the emission reduction. However, by combining the methods developed, an efficient emission reduction can be achieved for different operating conditions.

In nitric acid plants, the nitrogen oxides that are not absorbed in the absorption tower remain in the tail gas. The tail gas is preheated by the process stream from the ammonia burner. It is then treated in an EnviNOx® reactor where selective catalytic reduction takes place. Depending on the EnviNOx® unit ammonia or hydrocarbons are employed. The exiting gas stream is colourless and meets the required emission limits.

During start-up the heat exchanger chain is cold, so that the EnviNOx® reactor may still be at a too low temperature for operation. This may also occur after shutdown of the plant when the heat supply from the ammonia burner has ceased.

A crucial problem of low temperatures is the possible formation of ammonium nitrate. Besides the risk of explosion, it can also cover the surface of the catalyst in the EnviNOx® reactor or corrode the material of the downstream tail gas expander.

In order to limit the emissions and to avoid ammonium nitrate formation during these modes of operation the following measures are proposed.

Emissions abatement during start-up

During downtime of nitric acid plants, HNO₃ decomposes to NOx in pipes and apparatus. These nitrogen oxides are blown out during start-up while the DeNOx section inside the EnviNOx® reactor is still cold. For good gas cleaning performance, a temperature of at least 200°C, preferably 300 to 550°C is required. The subsequently described methods provide approaches for faster heating and NOx emission reduction during the heating-up period.

Import of start-up steam for the process gas cooler

One possibility for heating up the gas cleaning system is the use of high pressure steam. The required steam pressure is around 50 bar, preferably 60 bar (265-275°C). The steam is supplied to

the process gas cooler (PGC) and heats up the compressed air flowing through the process side. For this heat transfer existing coils are used preferably. Alternatively additional coils can be installed if necessary. With the provided steam, a PGC air outlet temperature of around 230 to 250°C results. The heat in the air is transferred to the tail gas. Temperatures of 200 to 220°C in the EnviNOx® reactor are expected. Fuel or electric power are alternative heat sources to steam in the described quality.

Bypass of the absorption tower

The absorption tower holds a significant volume of nitrogen oxides during start-up of the machine set. The intention of this measure is to retain these nitrogen oxides inside the absorption tower by means of a bypass (Fig.1) until the DeNOx system has been heated up. The bypass is opened when the plant is shut down. During the subsequent startup, the EnviNOx® reactor is allowed to reach operating temperature before gradually closing the bypass, opening the absorption tower to a slowly increasing flow and starting to fill the tower. This delayed release of the retained gases with water seal results in decreased NOx emission.

Dynamic operation/catalyst as storage for NOx

This measure uses the NOx storage capacity of the catalyst at temperatures below 230°C.

The iron-zeolite catalyst used in the EnviNOx® unit adsorbs NO₂ on the surface.

Fig 1: Bypass of the absorption tower

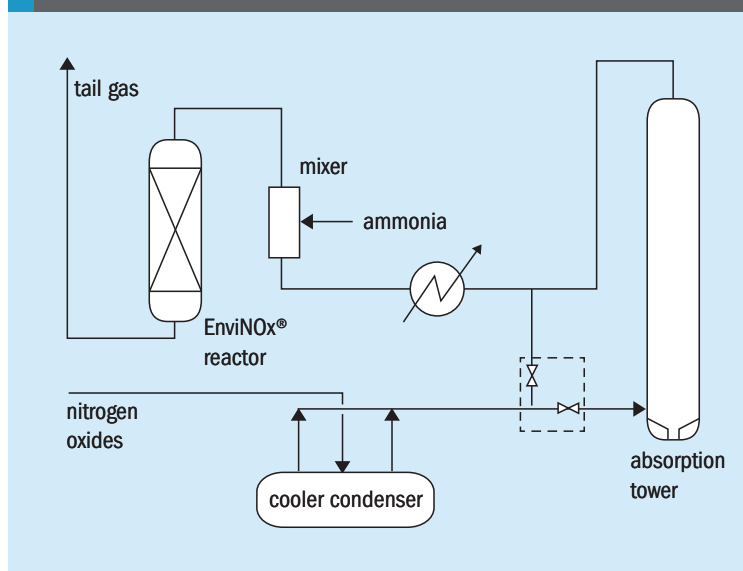
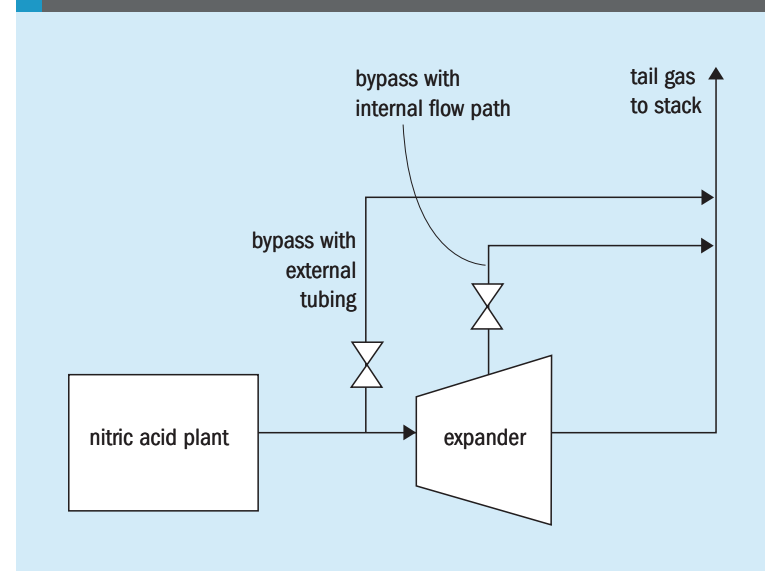


Fig 2: Installation of an expander bypass



At temperatures above 230°C, the NO₂ is desorbed at a rate depending on the heating speed of the catalyst bed.

Nitrogen oxides reaching the catalyst at low temperatures are adsorbed and stored. When the reactor in dynamic operation mode reaches a minimum temperature, the early introduction of the reducing agent (NH₃) reduces the adsorbed nitrogen oxides thus avoiding their release during further heating. An optimised feeding strategy of NH₃, preferentially combined with slippage monitoring, is necessary.

All of the above measures require sufficient catalyst activity at low temperatures (200-300°C) which is ensured by the catalysts used in the EnviNOx® technology. Injecting ammonia at these temperatures enables the reduction of the nitrogen oxides and reduces emissions.

For the subsequent colder tail gas expander any ammonia slippage poses the risk of downstream formation of ammonium nitrate. This issue is addressed in the following section.

Prevention of ammonium nitrate formation

NO_x and ammonia can form solid ammonium nitrate at low temperatures. This can occur with ammonia slippage at the EnviNOx® reactor. The solids can form a layer on the catalyst. Ammonium nitrate can also form inside the tail gas turbine where it is corrosive and can also pose a risk of explosion. For that reason the injection of ammonia to the EnviNOx®-reactor is not permitted below 80°C at the outlet of the tail gas turbine. The DeNO_x function ceases in that case.

Installation of an expander bypass

This measure aims to increase the gas temperature inside and after the expander to over 80°C.

During start-up, the gas temperature at the entry of the expander is significantly lower than during normal operation due to system inherent reasons. As the plant is already pressurised during start-up, the gas temperature decreases when depressurised in the turbine. An exit temperature below the critical temperature of 80°C may occur.

With the installation of an expander bypass the gas flow that is cooled due to volume work decreases. This leads to lower turbine efficiency and hence the gas exit temperature at the turbine increases. The bypass can be installed as external tubing or as an internal flow path as shown in Fig. 2. For an internal design, the cooperation with a manufacturer is required. Additionally it has to be taken into account that the power output of the expander is reduced. This has to be compensated by using a different source of energy (e.g. steam turbine or electrical motor). If an electrical drive is possible, this method can be applied without the availability of steam.

Steam injection upstream of the expander

The following described method prevents the formation of ammonium nitrate by an increase of the partial pressure of water in the gas stream.

Introducing steam into the line upstream of the expander, the thermodynamic reaction equilibrium is shifted, avoiding the formation of chemically stable ammonium nitrate. This approach has already been successfully tested. The

required amount of steam depends on the gas temperature and the expected temperature drop of tail gas exiting the expander. In addition, the proportions of ammonia and NO_x in the gas mixture must be taken into account. The partial pressure of the water vapour is set in the range between 50 and 500 mbar.

It is mandatory to avoid the formation of liquid water drops inside the expander due to oversaturation. The risk of nitric acid formation in the last expander stages must be considered for the material selection.

Emissions abatement during shutdown

During the shutdown period, the EnviNOx® reactor can be operated as long as temperature and flow are sufficiently high. To maintain the flow, operation of the compressor train with imported steam is advised.

Blocking of the plant/EnviNOx®-Dynamics

This measure ensures tail gas cleaning at low flow rates towards the end of the shutdown process.

After a normal shutdown or failure of the compressor train, the residual pressure can be used to generate sufficient flow for regular DeNO_x/EnviNOx® units until the operating pressure is approximately halved. Then the plant can be blocked in and subsequently gradually depressurised using a smaller additional DeNO_x unit (EnviNOx®-Dynamics) as shown in Fig. 3. This smaller unit is suitable for reduced flows and removes the residual nitrogen oxide gases. The EnviNOx®-Dynamics unit is permanently ready for operation, as small flows can be heated up easily by electricity or external steam.

Options for colourless start-up and shutdown

Start-up

In this section the abatement measures described are combined to achieve different options (Table 1). The suitability of an option depends on the availability of heating media and the given plant design. Additionally the extra costs for investment and operation are considered.

Option 1: High pressure steam

In this option steam is used for two functions: to heat up the process gas cooler and to prevent ammonium nitrate formation by injection of steam upstream of the expander, as shown in Fig. 4. This option requires either an auxiliary boiler or high pressure steam as utility. The minimum steam pressure for the heating is approximately 50 bar leading to temperatures of about 200-220°C at the EnviNOx® reactor. If these preconditions are fulfilled, import of start-up steam for the process gas cooler in combination with dynamic operation/catalyst as storage for NOx can be implemented. In this context, it must be judged whether the storage capacity of the catalyst is sufficient to adsorb the entirety of the nitrous gases. If this is not ensured, bypass of the absorption tower should also be applied. During start-up the residual gas in the plant is laden with nitrogen oxides and is still cold. The nitrogen oxides are adsorbed on the catalyst surface in the EnviNOx® reactor. During heating desorption occurs and ammonia must be added to reduce the desorbing nitrogen oxides. Correct dosing during the desorption process is difficult and a certain risk of ammonia slippage cannot be ruled out completely. Therefore the risk of ammonia nitrate formation is higher in dynamic operation mode. To avoid the formation of ammonium nitrate, steam injection upstream of the expander, or the use of an external or internal expander bypass, is mandatory.

Required investments:

- if necessary, additional coils in the process gas cooler;
- auxiliary boiler, if no utility high pressure steam is available;
- pipes (short distance) and automatic valves for absorber tower bypass;
- pipes and automatic valves for steam injection before the expander;

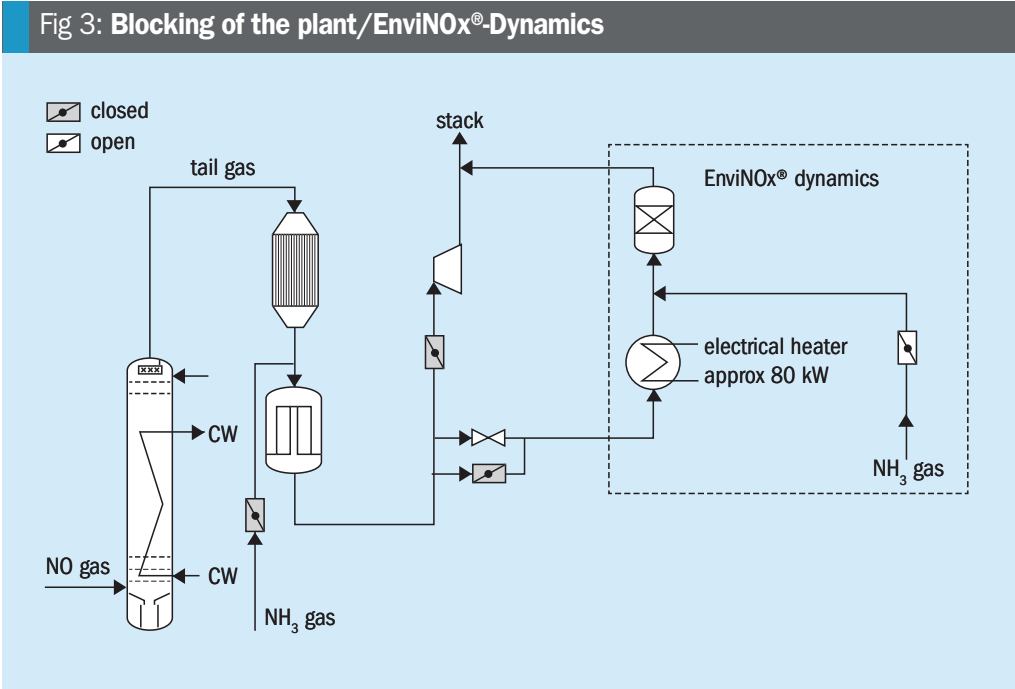


Table 1: Overview of start-up options depending on the availability of heating media

Availability of heating media	Option 1	Option 2
Steam	x	
Fuel		x
Electrical Heating		x
Import of start-up steam for the process gas cooler	x	
Bypass of the absorption tower	x	x
Dynamic operation/catalyst as storage for NOx	x	x
Installation of an expander bypass	x	either x
Steam injection upstream of the expander	x	or x

- material selection of the expander for steam injection upstream of the expander.

Operating costs during start-up:

- steam consumption for the injection upstream of the expander or to compensate for the loss in power recovery caused by the expander bypass;
- either high pressure steam for the supply to the PGC;
- or heating medium for auxiliary boiler.

Option 2: Fuel burner or electrical heating

When sufficient fuel is available, the tail gas can be heated with a burner as presented in Fig. 5. To avoid NOx emissions dynamic operation / catalyst as storage for NOx should be implemented in combination with bypass of the absorption tower.

In some cases the customer might want to keep the plant free from carbon compounds or the fuel supply may be insufficient. In these cases an alterna-

tive option is to use electrical heating as long as the target temperature can be achieved.

Required investments:

- Heat exchanger with burners/electrical heating;
- Automatic valves for the heat exchanger;
- Pipes (short distance) and automatic valves for absorber bypass.

Operating costs during start-up:

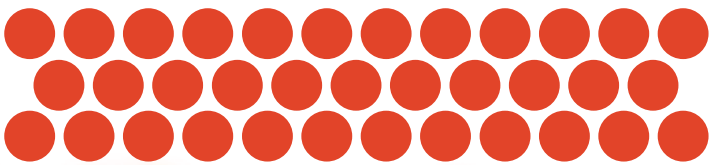
- fuel consumption of the burner/electrical power.

Shutdown

During shutdown of the plant, the heating medium (high pressure steam, fuel or electrical heating) can be applied as soon as the ammonia burner is switched off. For Option 1 and 2 this is sufficient to maintain the minimum temperature needed for continuous operation of the EnviNOx® reactor.

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Fig 4: Excerpt from the flow sheet for Option 1

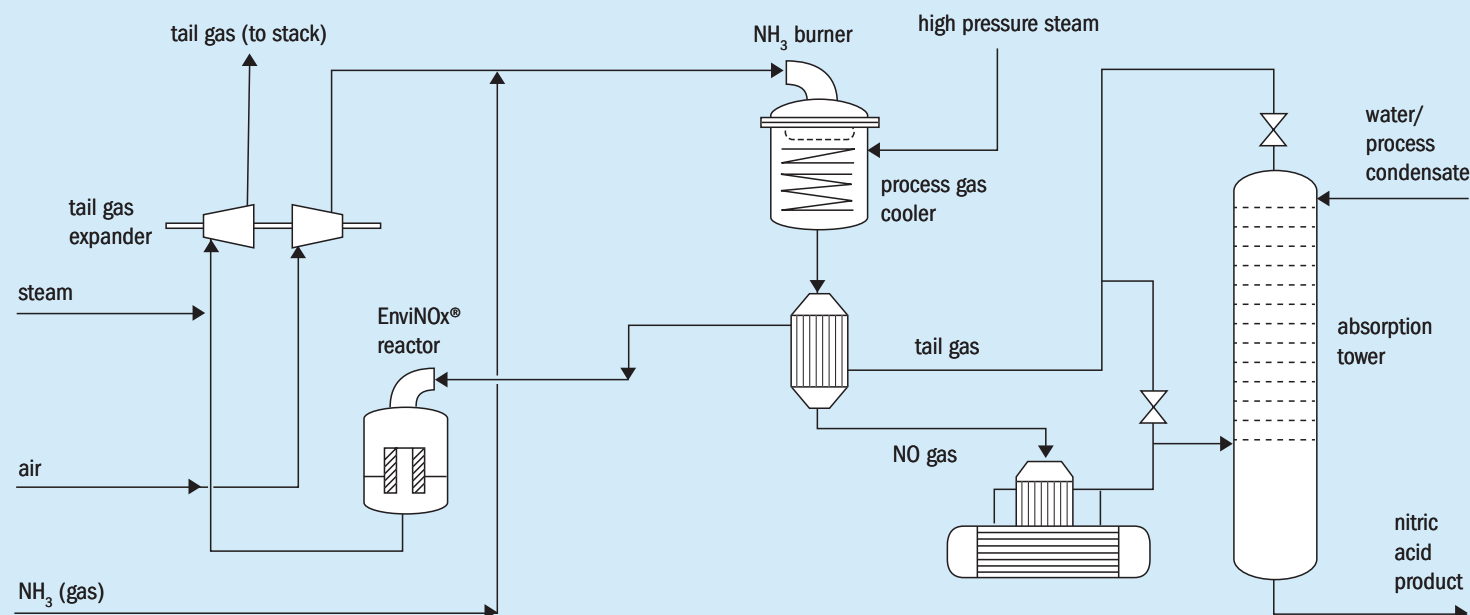
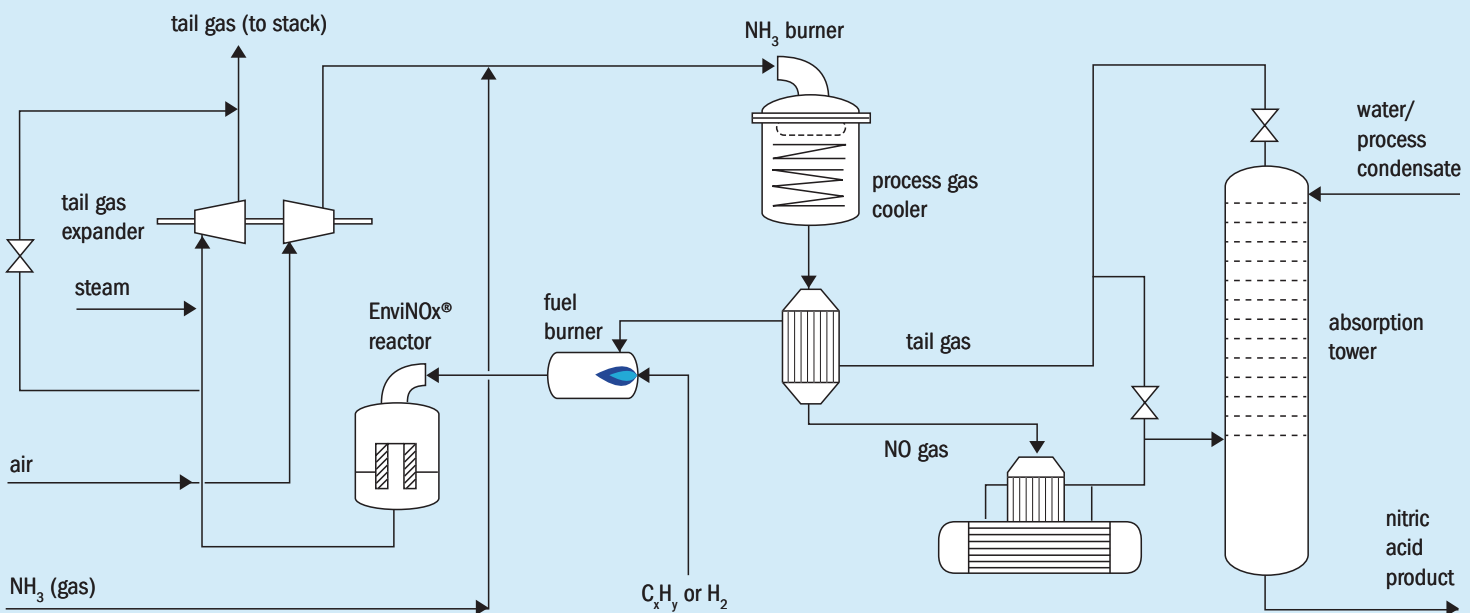


Fig 5: Excerpt from the flow sheet for Option 2 (with burner)



As soon as the plant pressure is too low to maintain sufficient flow through the EnviNOx® reactor in blocking in of the plant/ EnviNOx®-Dynamics can be implemented to remove the remaining nitrogen oxides.

Required investments:

- EnviNOx®-Dynamics unit;
- electrical heating unit;
- Pipes and automatic valves for ammonia addition.

Operating costs during shutdown:

- if applicable, consumption of heating medium (high pressure steam/fuel/

electricity) during operation of the EnviNOx® reactor;

- Electricity for heating of the tail gas for the EnviNOx®-Dynamics unit after blocking in.

Summary and outlook

Several measures to ensure emission-reduced or colourless start-up and shut-down of nitric acid plants have been described. The measures are combined as options to respond flexibly to conditions and customer requests. The options can be offered to customers as tailored packages during the bid phase or as revamp options.

They are linked to available utilities and will allow operating companies to custom design or revamp their plant to meet emission targets. Additionally required investments and potential operation costs have been highlighted.

For a choice of options the integrity and lifetime of the equipment should be carefully considered. A large burner that is only used during start-up is idle capital and can still be exposed to a corrosive environment leading to a short lifetime. The development and the implementation of the expander measures require close collaboration with the compressor train manufacturer.

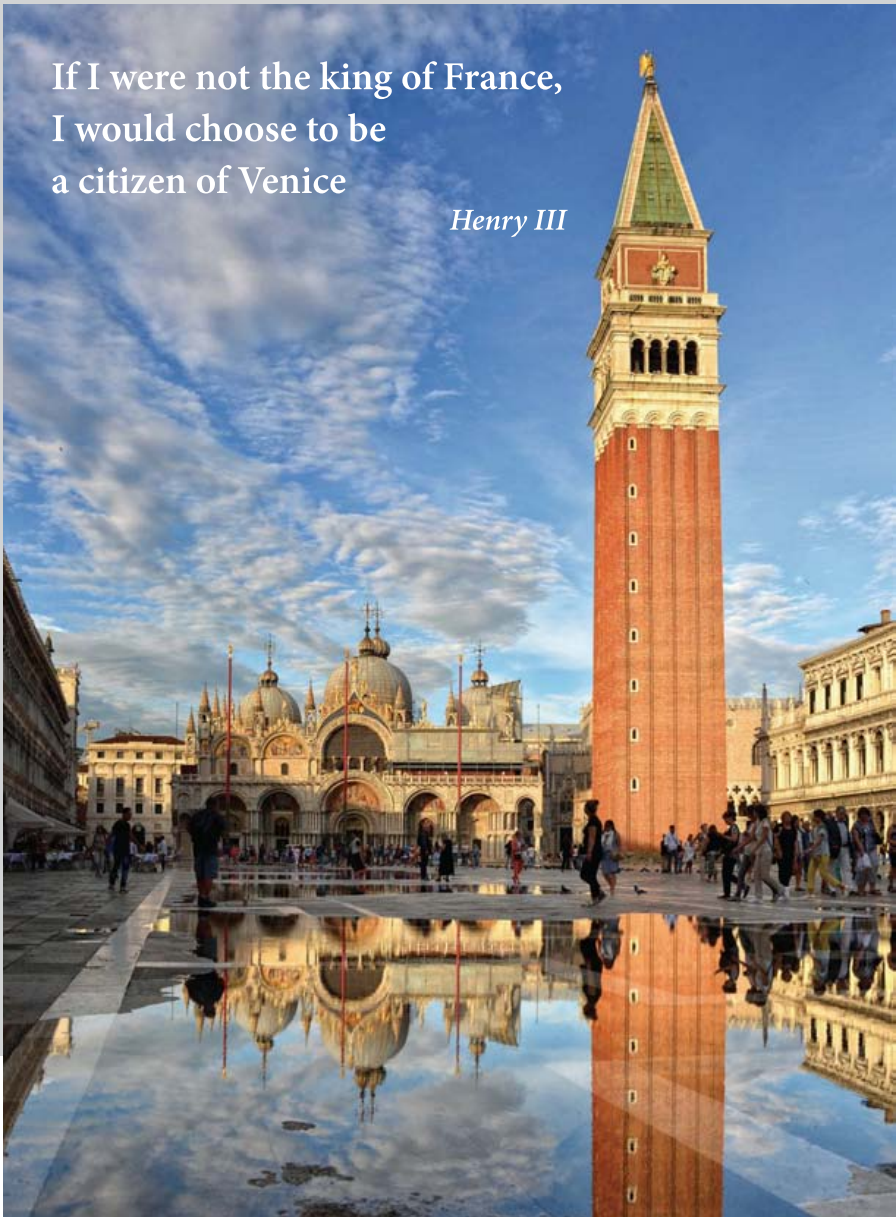
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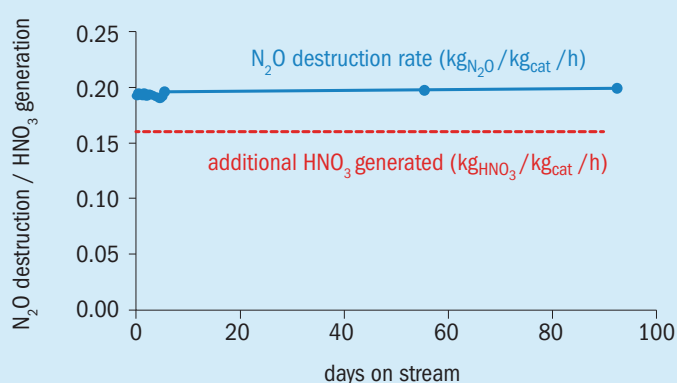




Improving yields with secondary N₂O abatement

Loading of EnviCat® N₂O-S catalyst at Huayangdier plant just before installation of Pt/Rh oxidation gauze.

Fig 1: Performance of EnviCat® N₂O-S at Huayangdier nitric acid plant



Over the past decades, significant developments have been made to reduce the emission of nitrogen oxides and nitrous oxide from nitric acid plants. Typically, one or more types of catalytic abatement technology are installed, each with their ability to efficiently and effectively remove these harmful emissions. Recently, however, Clariant's EnviCat® N₂O-S secondary catalyst was found to not only reduce N₂O emissions, but to also help improve nitric acid yield.

Three main types of emission control measures exist for nitric acid plants. These are: primary, secondary and tertiary abatement. While not new, secondary abatement technology is an area that has received much recent focus. Secondary catalysts in the nitric acid production process are installed inside the oxidation reactor following the primary Pt/Rh gauzes. This directly applied abatement technology gives plant operators the ability to effectively remove significant levels of N₂O emissions without negatively influencing the NO_x yield.

Recently Clariant, working with Huayangdier in China, has demonstrated that their new secondary catalyst, EnviCat® N₂O-S, not only effectively reduces N₂O emissions but also improves the efficiency of the ammonia oxidation process (Fig. 1). The positive impact on the process efficiency

was gauged over several months, and directly observed as a reduction in ammonia consumption for each tonne of produced nitric acid. The ammonia reduction is around 250 tonnes per year to achieve the same output – a saving of over \$70,000. This combined performance enhancement and abatement was achieved without additional process or engineering costs.

The nitric acid produced from Huayangdier easily meets the required quality standards and shows no significant impurities. Additionally, the catalyst shape is optimised for low pressure drop and robust mechanical strength. Over the course of the Huayangdier run, the overall pressure drop has not changed which demonstrates the high integrity of the catalyst during initial start-up and operation.

In addition to the improvement in product quantity and quality, another advantage

of Clariant's EnviCat® N₂O-S is that the producer can achieve high levels of N₂O conversion with less catalyst in comparison with other state-of-the-art catalyst options. In Huayangdier, the total loading of Clariant's secondary N₂O catalyst was less than half by weight and 20% less by volume compared to a competitor catalyst, while achieving conversion rates of > 85% N₂O destruction.

Based on these results, Huayangdier is optimistic about the benefits of this installation. Not only are they able to improve their production and see cost benefits, they are able to effectively reduce harmful emissions. Clariant is currently in the process of demonstrating the performance benefits of EnviCat® N₂O-S at a wider range of customer plants, with varying process conditions, and welcomes partnership inquiries to trial EnviCat® N₂O-S.

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Small-scale production of ammonia

B. Keil, and **K. Noelker** of thyssenkrupp Industrial Solutions and **J. Pach** of Johnson Matthey propose small-scale ammonia plants as a measure to minimise transport risk and cost of ammonia. The process of small-scale ammonia production is different to the usual ammonia process. Key equipment are described, advantages of this process are highlighted and reference plants are shown.

Eighty percent of anhydrous ammonia is used as fertilizer, either by direct injection to the soil or in the form of nitrogen fertilizers such as urea. Other direct consumers of anhydrous ammonia are phosphate fertilizer plants, nitric acid and ammonium nitrate plants, nylon intermediate manufacturers, some waste water treatment facilities, refrigeration plants and power plant pollution control systems. Many of these have a relatively small consumption and import their ammonia feedstock by railcar or truck. In 2007, 3.9 million tons of ammonia was shipped by railcar in the United States.

Accidental derailments of ammonia railcars have occurred in the past with serious consequences. As a result railroad companies are trying to avoid transporting ammonia. In addition railroad carriers have sought to raise rates to attempt to cover their risk exposure. Liabilities associated with the transport risk are increasingly being passed on to shippers and receivers of ammonia.

The best solution is to eliminate transportation risk by co-locating production and consumption facilities of ammonia.

Development of small-scale ammonia plants

There is increasing interest in smaller scale ammonia plants with capacities of less than 600 t/d. This is in contrast to the trend for ever larger capacities to exploit economies of scale. To address this demand, thyssenkrupp Industrial Solutions and Johnson Matthey have evaluated the best suitable technology for these facilities.

For a number of reasons, the small-scale process differs from the conventional large-scale process. Main thoughts during its development were:

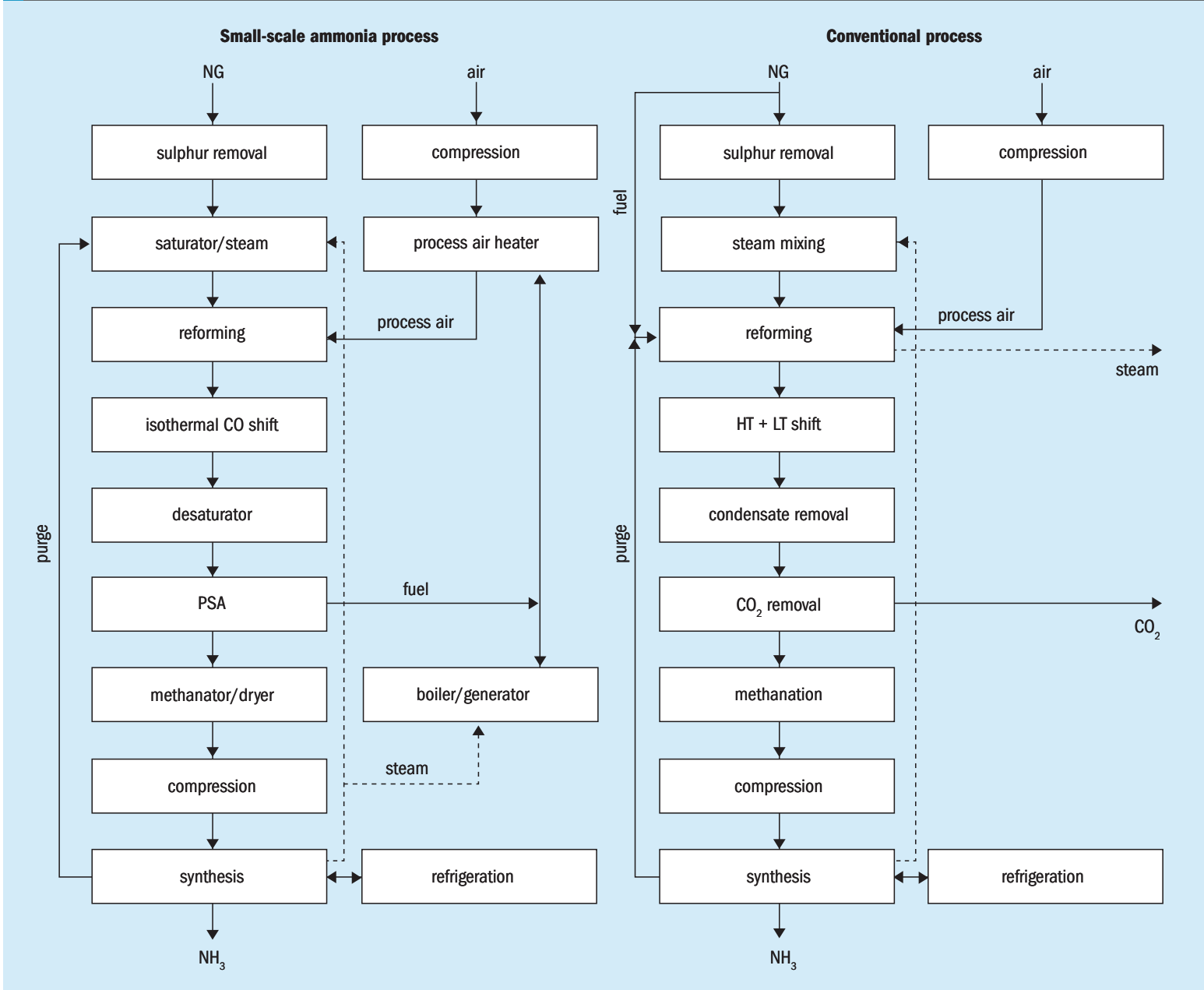
- **Cost-effectiveness:** Some unit operations are not economic on flowsheets of less than 600 t/d – the capacity of the smallest conventional ammonia plant built by thyssenkrupp Industrial Solutions (formerly known as Uhde) in recent years. For example, although the number of reformer tubes scales linearly with plant capacity, associated equipment such as the furnace box, the inlet and outlet manifold, the burner system, the waste heat recovery and the combustion/flue gas systems, do not scale linearly with plant capacity. As a result, the capital cost per t/d of capacity of a reformer on a smaller plant is higher than that on a larger plant. This problem is overcome with the use of a gas heated reformer (GHR), a different type of reformer without external firing, without associated waste heat recovery and without a combustion air/flue gas system.

- **End use:** The target market for the new process is not ammonia for mass production of urea. Therefore, it is not necessary to recover the CO₂ separated from the synthesis gas at high purity. Thus, instead of a wet CO₂ removal system a PSA (pressure swing adsorption) has been selected. A wet scrubbing system is ideally suited for large capacities and where CO₂ is required at high purity. Small plants without this requirement are more economic with a PSA system.
- **Compressor type:** Centrifugal compressors have been used for synthesis gas compression since the 1960s. As plant capacity is lowered the volumetric flow through the compressor falls, and efficiency of centrifugal compressors drops sharply due to internal leakage. Reciprocating compressors are not a desirable alternative as they are less reliable and require more maintenance. The synthesis loop pressure has therefore been reduced to less than 100 bar. This increases the volumetric flow rate and allows a centrifugal compressor to be used.

Table 1: Main features of the small-scale ammonia process

Problem	Solution
Scale-down of steam reformer not cost-effective	Gas heated reformer (GHR)
Wet CO ₂ removal expensive	Pressure swing adsorption (PSA)
Low volumetric flow rates impede use of centrifugal compressors	Low synthesis pressure to allow for centrifugal compressors
Machinery with low shaft power	Generator turbine for consumption of excess steam, electric motor drives for all process compressors

Fig 1: Block diagram of small-scale ammonia plant and conventional process



- **Energy balance:** Whilst steam turbines are state of the art for compressor drivers in large plants, they are not the first choice for small plants due to lower efficiency and to higher cost of turbines and their accessories such as the condensate system. Therefore, for the small plant all surplus steam is converted to electricity in a generator turbine, and all other machinery is driven by electric motors. Further, if the ammonia product is used for manufacture of a high-value chemical, the cost-pressure on the process might not be as high as it is for large scale urea production, and it might be acceptable that the process efficiency is slightly below that of a large plant.

The resulting main features of the process are summarised in Table 1.

Small-scale ammonia plant process

The small-scale ammonia process consists of the process steps illustrated in Fig. 1. Natural gas is compressed to front-end pressure. Sulphur-bearing components are poisonous for reforming and shift catalysts and have to be removed from the feedstock. They are converted with H₂ at a lower temperature than in a conventional process using a high activity PURASPEC_{JM}[™] 200 catalyst from Johnson Matthey so that the preheating of the feed can be achieved by saturated medium pressure steam. The H₂S which is formed is removed over ZnO beds. The desulphurised gas is mixed with purge gas from the synthesis loop and enters the saturator. The saturator is a packed column in which hot and already partially evaporated process condensate heats and saturates the feed to the gas

heated reformer. Roughly 80% of the required process steam is generated in the saturator. The desired steam-to-carbon ratio of 2.5 is adjusted by adding saturated medium pressure steam to the saturated feed. The reactants to the GHR are heated by the hot gas leaving the GHR shell side. The preheated natural gas and steam mixture enters the GHR (Fig. 2) and flows through catalyst filled tubes in which the reforming reaction takes place and which are heated by the stream leaving the secondary reformer. The reformed gas leaving the GHR enters the secondary reformer. Like the secondary reformer of the conventional ammonia process, the secondary reformer is a refractory lined vessel with a catalyst bed. In the upper zone compressed and preheated air is mixed with the effluent from the GHR above ignition temperature so that some part of the

Fig 2: Gas heated reformer (GHR) and secondary reformer

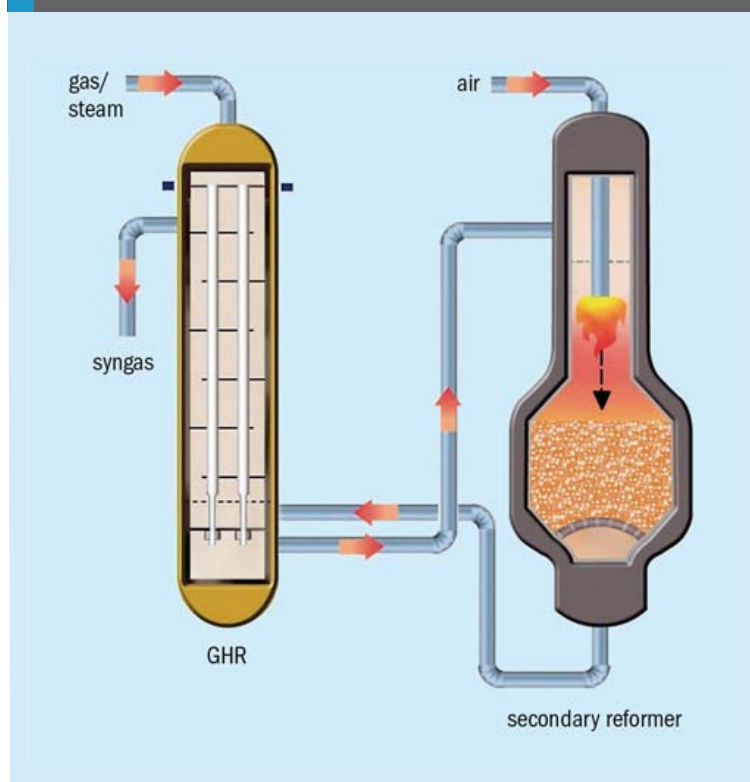
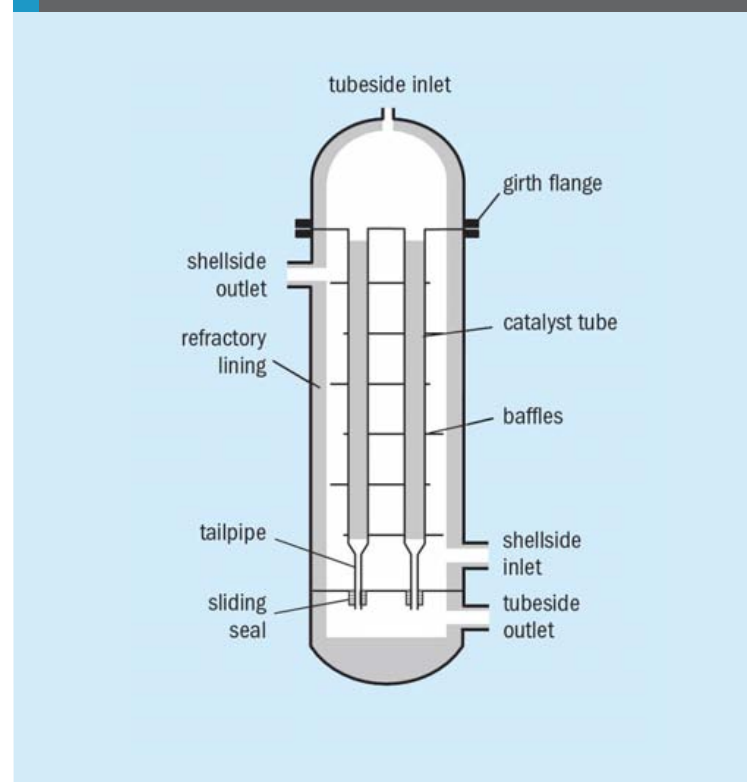


Fig 3: Gas heated reformer



residual methane is burnt with the oxygen from the process air, supplying heat for further endothermic reforming reaction which reduces residual methane content to low levels. The hot effluent from the secondary reformer provides the heat for the endothermic reaction in the GHR tubes and also heats up the reactants.

The process air is preheated in a gas-fired process air preheater. PSA off gas serves as fuel for the burner. The amount of nitrogen introduced by process air is higher than required for the ammonia synthesis loop.

The raw synthesis gas with a high CO content enters the isothermal CO shift converter. The CO shift converter is designed as tubular reactor. The tubes are cooled by boiling water on the shell side of the CO converter. The gas at the exit of the CO shift converter heats up the process condensate to the saturator and is further cooled down in the desaturator by cooled, recirculated water.

The raw synthesis gas mostly contains hydrogen, nitrogen and carbon dioxide, but also carbon monoxide, methane and argon in small quantities. CO and CO₂ have to be removed because they poison the ammonia catalyst; surplus nitrogen has to be removed in order to adjust the desired stoichiometric ratio of H₂ and N₂ in the make-up gas. This separation is achieved by a PSA unit in which molecular sieves are used to split the synthesis gas into a high

pressure product stream with high hydrogen content, and a low pressure off-gas stream with high carbon dioxide content. Most of the hydrogen is recovered and roughly the half of nitrogen is separated. The PSA off-gas is used as fuel in the process air preheater and the auxiliary boiler.

The gas leaving the PSA unit still contains levels of CO and CO₂ which are too high for ammonia synthesis. These are converted back to methane in the methanator. The gas is then cooled down and passed through a dryer to remove residual traces of moisture.

The make-up gas is compressed to 80 bar in a two-stage centrifugal compressor and is mixed with recirculated synthesis gas downstream of the recycle compression stage and heated up in a loop exchanger before entering the ammonia converter in which ammonia is synthesised. The converter is an Uhde 3-bed radial ammonia converter with indirect cooling. The hot, reacted cycle gas leaves the ammonia converter and raises medium pressure steam in the Uhde waste heat boiler. It is further cooled down in a series of heat exchangers and condensers to a temperature of -8°C. The condensed, liquid ammonia is knocked out in a separator and sent either to the consumer or to storage in a bullet tank at ambient temperature. The low temperature in the separator is achieved by evaporation of liquid ammonia in the intermediate and low pressure chillers. The evaporated

ammonia is recompressed and condensed in the refrigeration unit.

In order to control the inert concentration in the loop, some of the recycle gas is purged to the inlet side of the saturator. This eliminates the need for an elaborate ammonia recovery system that would be otherwise required to recover hydrogen. The remaining cycle gas is recompressed to make up for the pressure losses in the synthesis loop.

Table 2 summarises the features and advantages of the small-scale ammonia production compared to a conventional process.

The process is commercially available and is currently being offered in a capacity range of 270 to 550 t/d in a couple of on-going projects.

Special equipment

Gas heated reformer (GHR)

The GHR is a refractory-lined vessel with an external water jacket. It is in principle a shell and tube heat exchanger with catalyst inside the tubes (Fig. 2). The tubes are filled with KATALCO_{JM}™ 23-4Q which catalyses the strongly endothermic reforming of methane with steam. The secondary reformer consists of an open space for the combustion of methane and a bed of KATALCO_{JM} 23-8Q catalyst bed in which the endothermic reforming reaction further proceeds. Fig. 3 shows a schematic draw-



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Table 2: Features and advantages of the small-scale ammonia production process

Unit	Small-scale process	Conventional process
NG purification	Low-temperature, NG preheated by steam	Higher temperature, NG preheated in coil
Process steam	NG is saturated with recycled process condensate	Direct steam addition to NG, process condensate stripper required
Primary reforming	Reforming by convection (GHR)	Externally fired primary reformer and elaborate waste heat recovery system
Secondary reforming	No air separation unit required, operated with excess air	Secondary reformer operated with stoichiometric amount of air
CO conversion	Single-stage isothermal CO-shift converter	HT and LT shift converter
CO ₂ removal	Pressure swing adsorption	Wet scrubbing columns and associated chemicals handling
Synthesis pressure	80 bar, low pressure in synthesis allows use of centrifugal compressors even at low plant capacity	190 bar
Steam system	Medium pressure (60 bar), all steam to generator, maximum use of motor drives	High pressure (112 bar), steam drives
Ammonia and hydrogen recovery	Not required	Ammonia absorber, membrane unit
Start-up	Faster than conventional process	

ing of a gas heated reformer. Feed gas enters the top of the vessel and flows down through catalyst-filled tubes. The tubes reduce in diameter to a slightly flexible tail pipe, which passes through the lower tube sheet. The gas from the tail pipes collects in the lower section of the GHR and then flows to the secondary reformer. Whilst the tubes pass through the lower tube sheet, they are not fixed to it. As a consequence

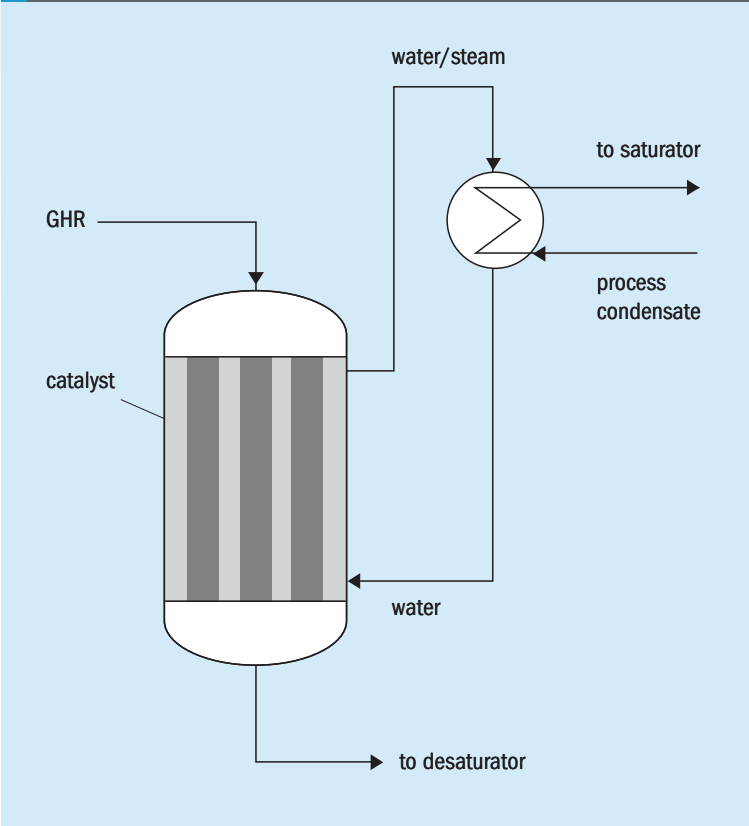
each tube can expand and contract through the tube sheet without imposing stress upon either the tube or tube sheet. A seal system is provided between the tube and the lower tube sheet. The design of the seal is unique and ensures that it is not possible for leakage to occur from the tube side to the shell side of the GHR, even if the seal wears during operation. Long-term operation without seal leakage can there-

fore be assured. The system has been the subject of an extensive research and development program and has been proven on the Coogee plant over many years (Fig. 4). Unlike a conventional steam reformer in which the reformer tubes need to be designed to withstand full process pressure the reformer tubes of a GHR only have to be designed for the process pressure drop across the reformers.

Fig 4: Gas heated reformer (GHR) and secondary reformer at Coogee, Australia



Fig 5: Isothermal CO-shift converter and water circuit



Isothermal CO-shift converter

The process uses a single, isothermal shift reactor which recovers heat into a circulating water system (Fig. 5). It is a tubular reactor in which catalyst filled tubes are cooled by water on the shell side of the reactor. The system dispenses with the requirement for an HTS catalyst. Instead, KATALCO_{JM} 83-5 of Johnson Matthey is used. This makes it possible to operate the reformer at a low steam-to-carbon ratio without fear of over-reducing conventional HTS catalyst. The water circuit allows near isothermal operation, leading to a lower catalyst volume.

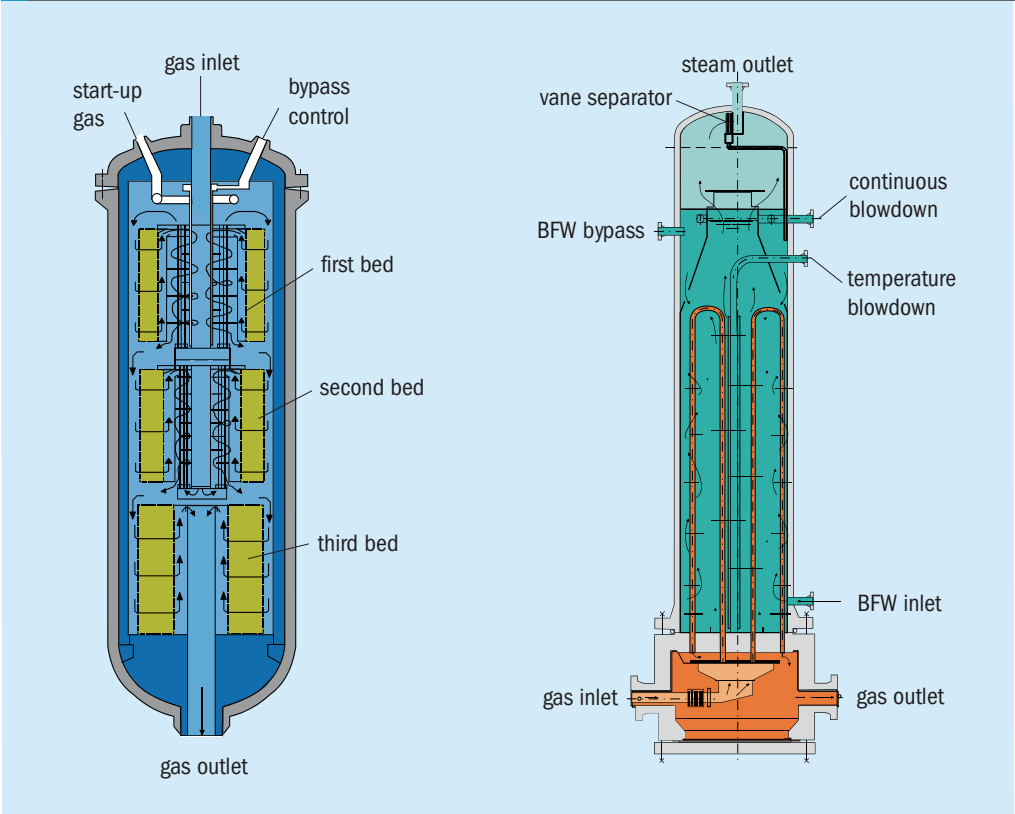
Ammonia converter

The ammonia converter is an Uhde 3-bed radial ammonia converter with radial flow from the outside to the inside of all three catalyst beds and indirect cooling by two heat exchangers between the catalyst beds (Fig. 6). The catalyst, KATALCO_{JM} 74-1, was developed specifically to achieve a high activity at the low synthesis pressure of 80 bar. It is iron based and contains a small amount of cobalt in addition to the promoters found in conventional synthesis catalysts (alumina, potassium and calcium). Sufficient references exist from other applications at low pressure.

Waste heat boiler

The Uhde waste heat boiler (Fig. 6) has a vertical design with the process gas passing through a U-tube bundle. In the upper part of the shell steam and boiling water can separate so that no additional steam drum with connecting piping is needed and less floor space is required.

Fig 6: Uhde 3-bed radial ammonia converter (left) and waste heat boiler (right)



Steam system

Steam is generated in the waste heat boiler of the synthesis loop and in the auxiliary boiler. The steam pressure is 60 bara and the temperature of the superheated steam is 460°C. Some of the saturated steam from the synthesis loop is used as process steam and to heat various streams. The rest is superheated in the auxiliary boiler. The remaining PSA off gas which has not been consumed in the process air preheater is combusted in the auxiliary boiler. The combustion chamber is equipped with special burners which can handle low calorific value PSA off gas. All of the superheated steam

generated in the auxiliary boiler is used to generate electricity in a turbo alternator. The electrical power is used to drive natural gas, process air, synthesis gas and refrigeration compressors. In addition to that a net import of about 4 MW electric power is required for a 325 t/d plant.

Layout

The plant has a compact layout. In order to lower the construction cost, a design using pre-fabricated modules has been developed. A snapshot of the plant with modularised design is shown in Fig. 7. The decision on stick-built or modularised

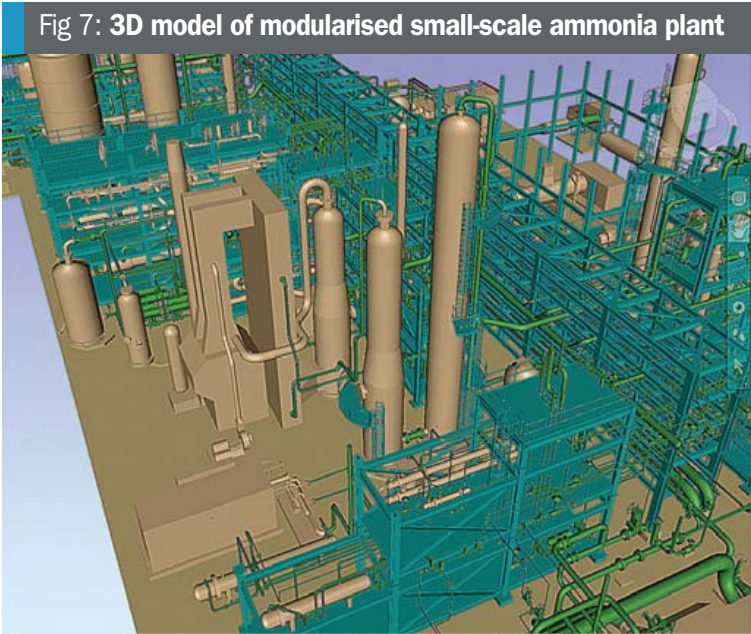


Table 3: Reference small-scale plants with GHR

Location	Product	Design capacity	Operation
Sevenside, UK	ammonia	2 x 450 t/d	1988 – 2008
Yazoo, USA / Moranbah, AUS	ammonia	450 t/d	1998 – 2004 2012 – today
Laverton, AUS	methanol	162 t/d	1994 – today
New Zealand / Trinidad	demonstration plant (methanol)	36 t/d	2002 – 2004 2011 – 2013

construction can be made depending on the site and the cost of local labour. Both alternatives are ready for the market.

Reference plants

Table 3 gives an overview of the reference production facilities. Sevenside Works near Bristol in the UK was a highly integrated fertilizer complex capable of producing ammonium nitrate (500,000 t/a) and granulated compound fertilizers (200,000 t/a). Ammonia was initially supplied by two plants built in the 1960s. In the 1980s it was decided to replace these less efficient ammonia plants with two new plants using ICI's Leading Concept Ammonia (LCA) design (Fig. 8). The design capacity was 450 t/d each. The two ammonia plants were commissioned in 1988 and operated continuously until 2008. The plants were closed in January 2008 due to poor fertilizer market conditions in the UK.

A third plant with a production capacity of 450 t/d of ammonia was constructed for Mississippi Chemical at Yazoo City, USA. It was commissioned in 1998 and shut-down in 2004 due to a downturn in the US ammonia industry. The plant was relocated to Moranbah in Queensland, Australia, and was recommissioned by Dyno Nobel, a subsidiary of IncitecPivot, in 2012. The feedstock is coal seam methane gas originating from mines in the neighbourhood.

A GHR can also be operated with pure oxygen instead of air so that it can be used as a synthesis gas generator for methanol production, in which synthesis gas free of nitrogen is required. A GHR is installed in Coogee's methanol plant in Laverton, Victoria, Australia. Although the design capacity was 165 t/d, the plant is now operated at rates in excess of 225 t/d of methanol. It has been in operation since 1994.

Materials for the GHR have also been tested in Johnson Matthey's materials demonstration unit (MDU). The GHRs are fitted with full-size tubes; each coupled to a secondary reformer and associated

equipment. The MDU was initially erected in New Zealand and operated from 2002 to 2004. It was then relocated to Trinidad in 2011 and operated until 2013. The experimental results proved the suitability and stability of catalyst and materials that are resistant to carbon at very low steam-to-carbon ratios.

Economic considerations

Most of the design features mentioned above are aimed at reducing the inherent disadvantages in the economics of scale which smaller plants (300 to 600 t/d) face compared to larger plants. The following analysis shows, however, that a Johnson Matthey/thyssenkrupp Industrial Solutions small-scale ammonia plant can be competitive with a modern world scale plant of 2,000 to 3,300 t/d. It has to be kept in mind that the ammonia produced on site in a small-scale plant is not meant for sale but serves as an intermediate for other products (in particular non-fertilizer products). It thus replaces ammonia which would otherwise have to be purchased from other production sites and transported to site. As a consequence, not only production costs but also transportation costs have to be taken into account.

A comparison is made for the example of a conventional 2,200 t/d plant and a small-scale plant of 325 t/d. Capex is estimated for a typical North American location. Capital service is calculated for a payback period of 10 years with 5% interest rate.

The operating costs (opex) are determined using a natural gas price of \$4.0/MMBtu LHV. The same gas price is used for both plants as it does not vary to any great extent across North America (other than the ammonia price). Further contributions to opex are manpower (western hemisphere wages), maintenance costs (1.5% of capex) and consumption of catalysts and utilities. Intentionally a gas price is selected which is believed to be a realistic

long-term value for North America. It should not be compared with spot market prices which are often lower but which cannot be used when analysing economic feasibility.

The resulting production costs (capex plus opex) are compared in Fig. 9. They are normalised to a basis of 100 for the large-scale plant. As expected, they are higher for the small plant, the main reason for this being capex which, due to economies of scale, works in favour of the larger plant. However, opex is quite similar for both plants as the specific energy consumption of a small plant is only marginally higher than that of a large plant.

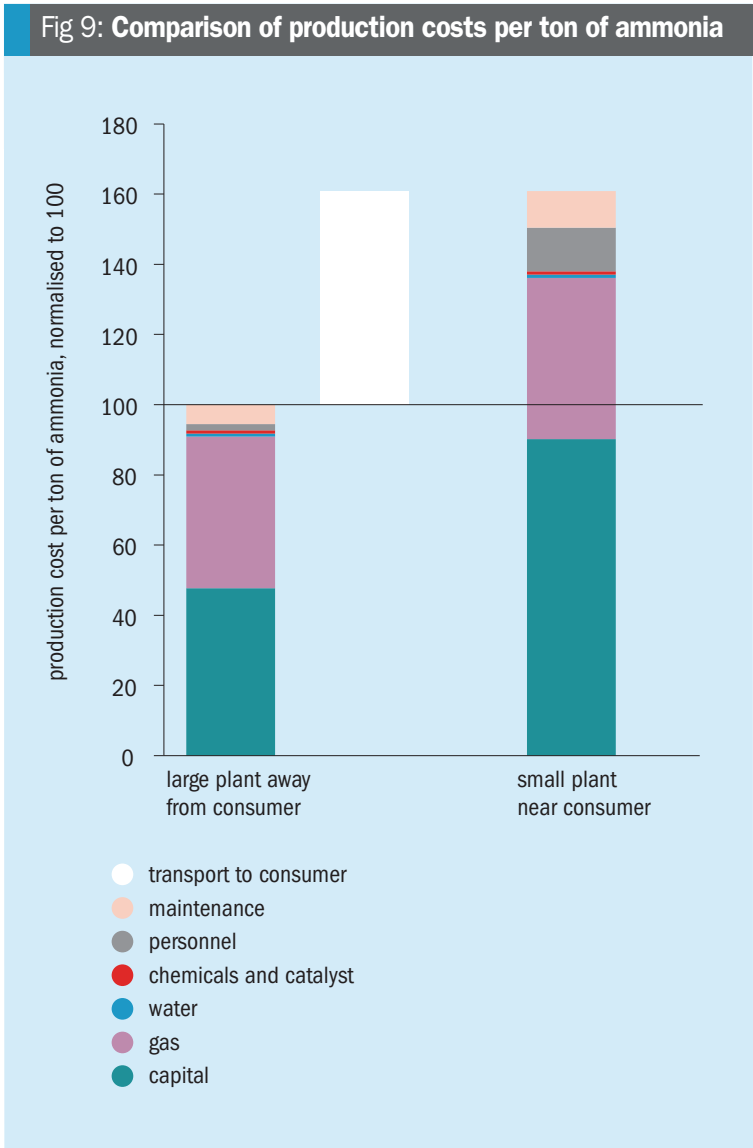
Fig. 9 shows that the local, small-scale ammonia plant becomes competitive if transportation costs exceed 60% of the production cost of the large plant. This value is fairly insensitive to the energy price which is the main contribution to opex.

If, as an example, the Gulf Coast ammonia price is \$300/t, a 60% premium corresponds to \$180/t. In fact, freight rates of \$180/t of ammonia from US Gulf Coast to local consumers in the North have been reported. This means that production at higher cost in a small, localised plant is feasible in order to avoid them.

There may be additional factors, not accounted for here, which would make local production even more cost effective. These could include integration of the ammonia plant with the ammonia-consuming facility to avoid the need for an ammonia unloading and storage facility or to reduce their size. It is also likely that freight rates will increase at faster rate than the energy prices, due to increasing safety standards and increasing insurance costs. Finally, for some locations capex savings are expected as a result of modularised construction.

In addition to that, the economic evaluation does not include "soft factors" such as secure supply from an owned nearby facility along with independence from market shortages and from fluctuating ammonia prices.

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Conclusion

Anhydrous ammonia is a key feedstock for many industrial and farming applications. A significant quantity is transported by rail. In the past several accidents occurred with serious effect on people and the environment. As a result restrictions and regulations on transport are becoming more onerous and freight rates are increasing.

Product substitution and co-location of ammonia production and consumption sites can mitigate the transport risk. To address this problem Johnson Matthey and thyssenkrupp Industrial Solutions have developed a competitive small-scale ammonia plant based on a gas heated reformer, pressure swing adsorption and low pressure ammonia synthesis loop.

The technology has been well proven in plants which have been in operation for 20 years. It is now offered in a capacity range of 270 to 550 t/d.

As it is unlikely that restrictions on the transport of anhydrous ammonia will become less onerous and that freight rates decrease, the demand for small ammonia plants will increase, as will their competitiveness. The small-scale ammonia process may also be of interest for the exploitation of stranded gas of medium size.

Currently, thyssenkrupp Industrial Solutions and Johnson Matthey are working on improving the concept to further lower its cost. The latest development is a module-based design, aimed at reducing on site construction costs.



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Syra 4: A nitric acid project overview

Casale and Chemoproject Nitrogen (CHPN) have been awarded a contract by Yara for the construction of a new nitric acid plant in Köping, Sweden. The Yara contract is based on state-of-the-art technology, improving energy efficiency and further reducing greenhouse gas emissions in the Köping plant. **I Cerea** of Casale discusses the project under execution, the roles of the companies involved and the technology applied.

In 2014, Casale made two important acquisitions, namely the Czech contractor Chemoproject Nitrogen (CHPN) and, from Borealis, the complete process technology portfolio related to nitric acid/nitrates and phosphates, formerly owned by GPN.

In 2015, CHPN was awarded the contract as EPC contractor to build a new 685 t/d 58 wt-% nitric acid plant based on Casale technology for Yara's Syra complex in Sweden.

Casale technology and know-how, combined with Yara's plant skills and operational experience and CHPN's project management and engineering strength provide a strong base for a future successful project.

Nitric acid plant design

The new Syra 4 nitric acid plant has been designed according to exacting requirements with safety being a top priority for project design and execution.

The major project goals are:

- overall raw material consumption (as NH_3) has to be kept as low as possible but with a sound compromise in term of investment cost;
- plant must be able to export a high specific amount of LP steam and in the meantime generate electrical power;
- plant heat recovery has to be maximised and further heat used for district heating during winter;
- plant emissions levels are extremely strict;
- plant overall noise levels shall be contained at minimum level;
- no compromise on ease of operation.

Dual pressure plant arrangement

A major concern for today's nitric acid plants is the energy cost and thus most design efforts are focussed on reducing plant specific consumptions and optimising the energy balance. Several design

choices can be made but the major challenge for the designer is to make them economically justified and cost effective.

The dual pressure scheme has been selected in view of the fact that this is the most effective arrangement available to achieve low $\text{NH}_3/\text{t HNO}_3$ specific consumption.

The operating pressures of the low pressure (LP) and high pressure (HP) sections have been selected to minimise equipment size and design pressure and to balance the turboset shaft power.

The dual pressure plant has been designed with the LP section operating at 5 bara and the HP section operating at 11.5 bara. An air compressor delivers primary and secondary air and a nitrous compressor compresses nitrous gas to the HP section. An expander is then used to recover power by expanding the tail gas down to atmospheric pressure, before discharging it to the atmosphere.

Fig 1: Plant power balance

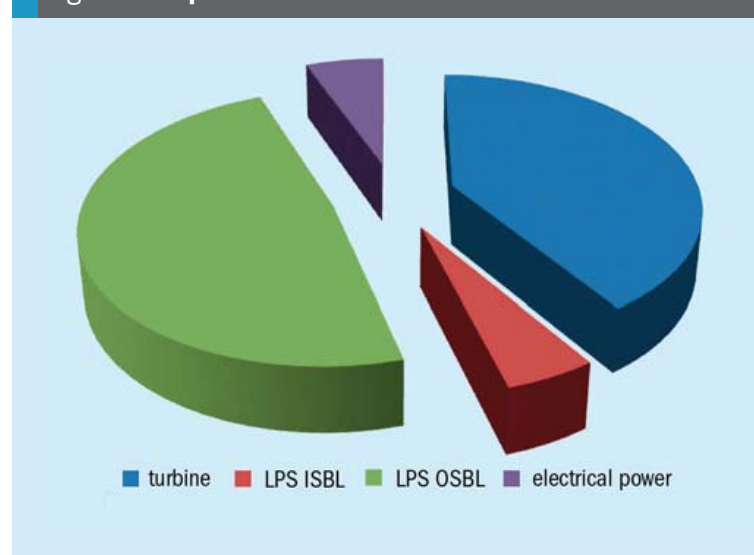


Fig 2: Power consumption: Air vs NOx compressor

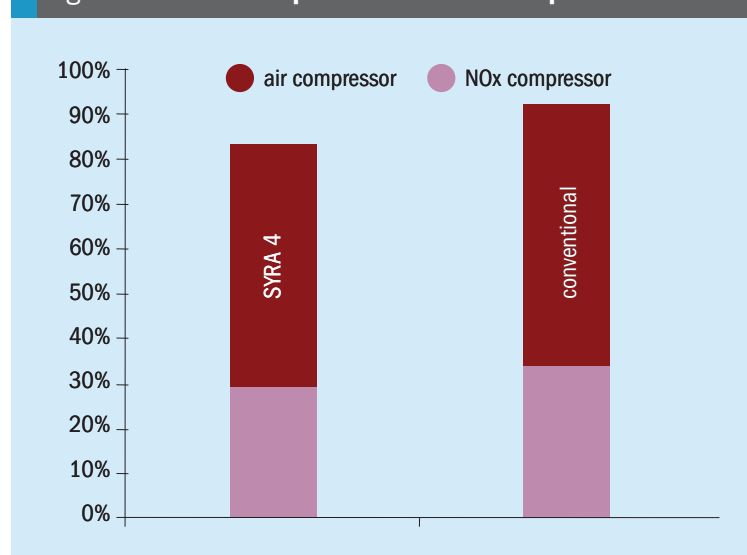


Fig 3: MHI compressor train arrangement

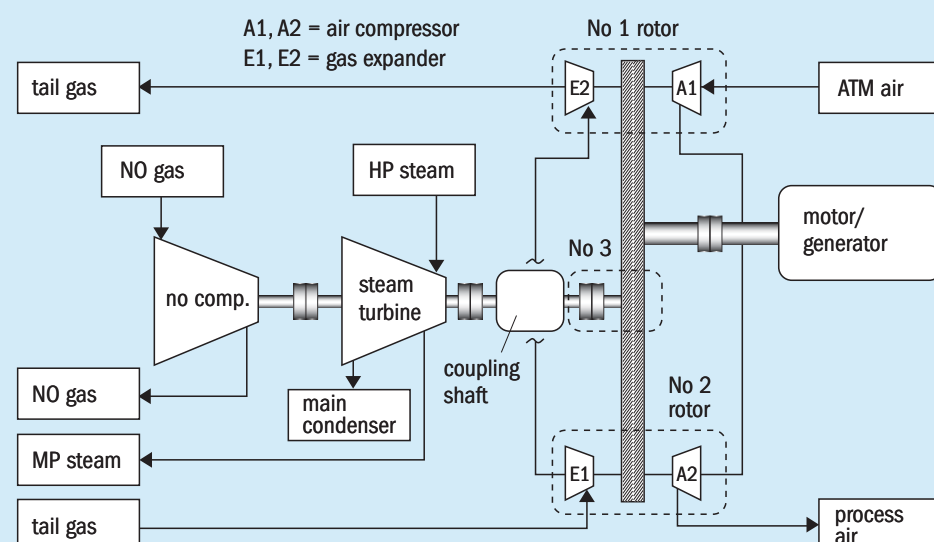
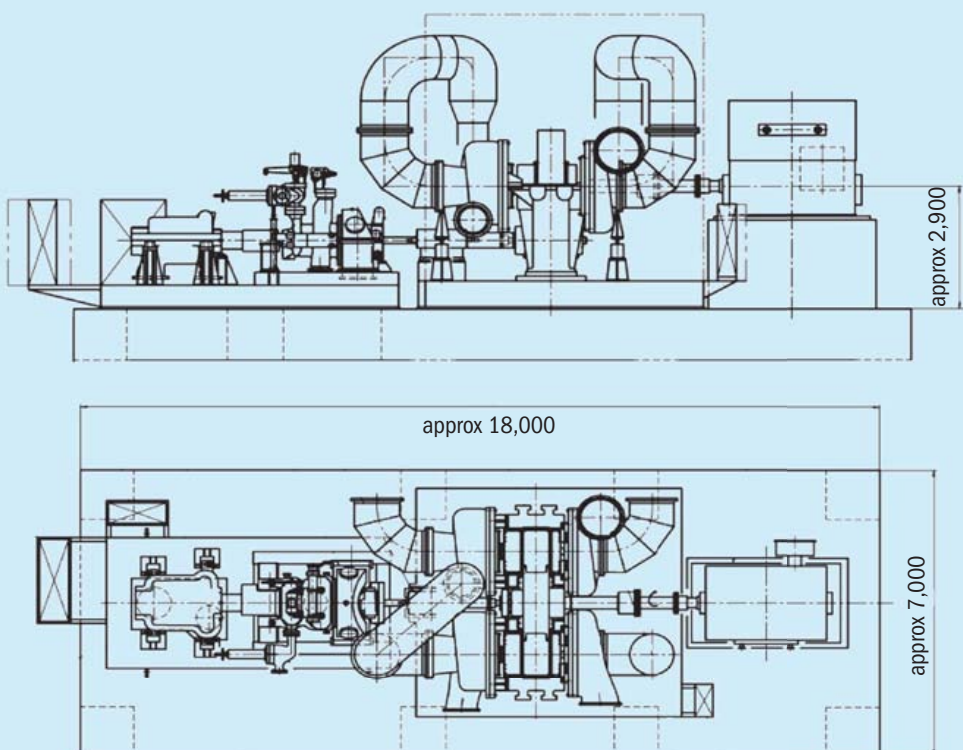


Fig 4: MHI compressor train layout



Steam and electricity power export

Yara's requirements are to have from 11 t/h to 20 t/h of LP steam (6 bara) export at battery limits (BL) depending on BL external request and no HP steam (60 bara) export to BL.

The plant has been designed to cope with these constraints while ensuring maximum flexibility. All HP steam generated in the steam drum is fed to the turboset compressor steam turbine.

The excess power from the steam turbine not used for compression work is

used to generate electricity in an induction type motor coupled to the turboset machine. The steam turbine is a condensing type turbine with LP extraction to be exported to BL. This enables the plant to operate with extended flexibility in terms of electrical power export or LP export.

The amount of power expected to be generated by the induction motor is about 55 kWh/t HNO_3 , while export of LP steam is more than 750 kg/t HNO_3 .

More than half of the available plant power is made available at the battery limits both as steam or electric power (Fig. 1).

Low pressure drop

To further improve energy savings, a detailed study has been carried out on the lay-out and pressure drops along the plant ducts and equipment, resulting in expected reduction of about 10% compared with a conventional nitric plant of the same size. As shown in Fig. 2, the energy consumption of the two major machines (air compressor and nitrous compressor) benefits from the lower pressure drop in the LP and HP sections.

Casale equipment design overview

Most of the equipment was originally developed by Borealis/GPN and has already been applied and proven in several nitric acid plants.

Turboset compressor

The turboset machine plays an important role since it is designed with large flexibility to deliver LP steam to BL and generate electric power.

Major design engineering efforts have been devoted to minimising the energy consumption by selecting a higher efficiency machine.

The selected manufacturer for the turboset compressor is MHI.

The Turboset compressor comprises the following machines:

- air compressor to provide air to the LP section at about 5 bara both to the ammonia burner and to the HNO_3 bleacher (rated power 10.8 MW);
- nitrous compressor to compress nitrous gas from the LP to the HP section at about 11.5 bara (rated power 5 MW);
- tail gas expander to let down tail gas from DeNO_x reactor to plant stack and recovery
- energy (rated power 11 MW);
- extraction and condensing steam turbine for LP extraction to 8 bara (rated power 6.5 MW).

Fig. 3 shows the MHI compressor train arrangement.

Major components of the MHI train machines are as follows:

- air compressor and tail gas expander are radial type combined in a "compander", an integrally gear combined machine with a two stage compressor and two stage expander;
- NO_x compressor is a centrifugal, single shaft, horizontally split machine;

Fig 5: CFD velocity profile on Casale burner hood

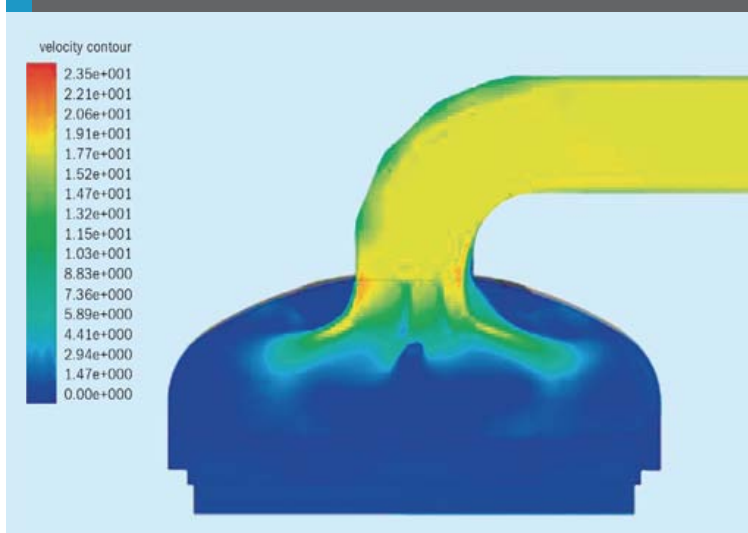
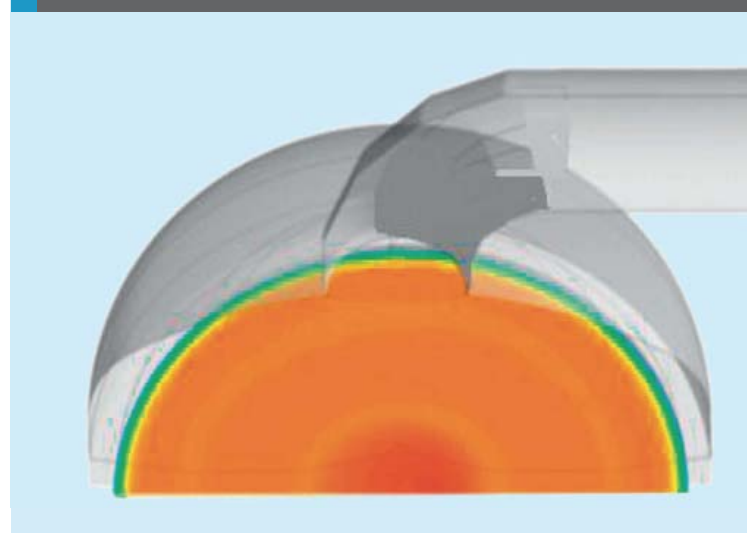


Fig 6: Burner hood CFD: flow distribution on gauzes



- steam turbine is an extraction and condensing steam turbine with double extended shaft ends to drive the “com-
pander” and NOx compressor;
- electric motor/generator is an induction type (3 phase, 6,300 V, 5,200 kW)

Due to the compander arrangement that combines two major machines (air compressor + expander) the turboset footprint is relatively compact.

Fig. 4 shows the MHI compressor train layout.

Burner hood

The burner hood is a critical item for nitric acid plants since uniform flow distribution is essential to guarantee the long-term utilisation of the platinum gauzes and a high conversion efficiency, avoiding undesired by-products.

The Casale burner hood is made of perforated deflectors, placed at different heights to ensure a uniform gas air-ammonia mixture distribution on the platinum gauzes.

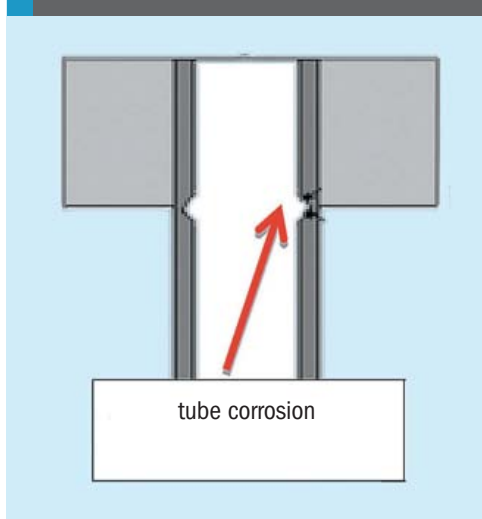
CFD studies have been carried out and the resulting velocity contours are shown in Fig. 5.

The gas is uniformly distributed above the platinum gauzes. Properly designed deflectors allow the distributor pressure drop to be minimised for an even distribution on the gauzes.

Fig. 6 shows the gas velocity and flow distribution just above the platinum gauzes. The burner hood has also been designed to ensure proper sealing to avoid bypass of gauzes.

Bypasses both reduce the ammonia conversion rate and could lead to dangerous formation of ammonium nitrate/

Fig 7: Tube corrosion in cooler condenser



nitrite in downstream equipment; for this reason they need to be strictly avoided.

The mechanical design of the catalyst basket support needs to take into account the thermal expansion due to the large temperature gradients between the burner shell and the gauzes/catalyst support basket.

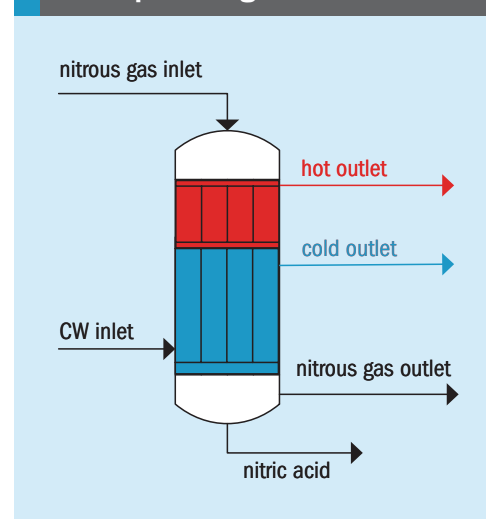
The mechanical design of the support basket is normally validated through FEM analysis in order to optimise the geometry and to reduce the thermal stresses to minimum.

The basket design is also tailored to meet specific client's requirements. For example in the burner hood for Syra 4 the basket is designed with the provision to install deN₂O secondary catalyst.

Water cooler condenser

The water cooler condenser in the nitric acid plant plays an important role but is also a critical item as regards corrosion and thus reliability. Fig. 7 shows tube

Fig 8: Cooler condenser CW hot cold split arrangement



corrosion in a cooler condenser.

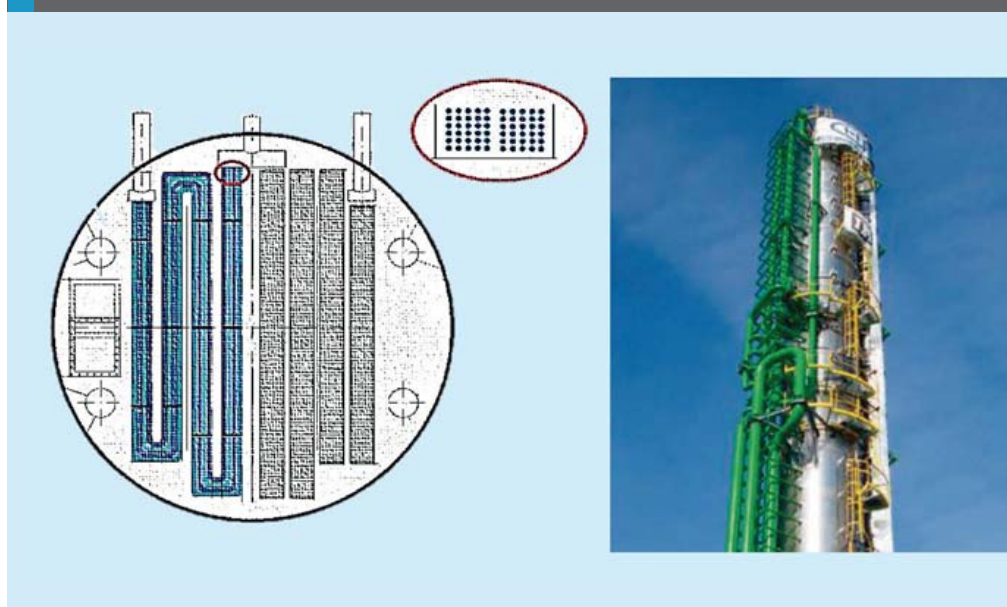
Corrosion normally takes place in the region of the tube inlets on the gas side, just after the end of the tubesheet or on the inlet tubesheet. Corrosion is caused by nitric acid reboiling once condensed.

The major cause of corrosion is when the exchanger tube and tubesheet wall temperature is lower than the inlet nitrous gas dew point, which facilitates local nitric acid reboiling and tube corrosion.

Furthermore, in a nitric cooler the heat is normally removed by cooling water (CW) and this heat is lost in the cooling water towers. Even if this heat is low temperature grade energy it is nevertheless dissipated and hence not effectively used in other plant sections.

To minimise corrosion and make effective use of the reaction and condensing heat, Casale has adopted a special design where the water condenser CW side is split into hot and cold sections as shown in Fig. 8.

Fig 9: Detail of absorber exchanger plate and absorption tower



Reboiling at the tubesheet and in the first part of the tubes is avoided by keeping the cooling water outlet temperature above the nitrous gas dew point. This design is applied to both the LP and HP cooler condensers but with different operating temperatures on the CW side to keep a safety margin on inlet nitrous gas dew point.

Cooling water is a closed loop fed with demi water and kept at enough pressure to ensure a proper operating temperature with enough margins to prevent boiling.

Once CW has left the cooler condensers, hot streams are used to pre-heat demi water from battery limits to the deareator through a series of plate exchangers. Finally, the hot stream CW is also used to heat district water (district water) for household heating in the neighbourhood. This makes the reaction and condensing heat more profitable and effective.

In the Syra 4 project, the expected heat recovery from the hot CW is more than 0.75GJ/t accounting for both LP and HP cooler condenser and available recovery on district water.

Exchanger materials selection

The tubes are made of AISI 310L whilst the top tubesheet is in AISI 304L with AISI 310L weld overlay.

Selected material of construction is based on Yara's experience and proven technology in different plant installations.

Casale nitric acid absorption column

In the past, ammonia was quite cheap compared to nowadays so the concentration of NO_x in the tail gas leaving the absorption tower was not very critical compared to the

extra investment cost required to recover it. However, now that environmental limits are becoming more and more severe, plants are required to achieve low ammonia specific consumptions. Considering that for each mole of NO_x leaving the column one mole of NH₃ has to be fed to the burner to produce it and another mole of NH₃ is needed to destroy it in the SCR, for each mole of NO_x exiting the top of absorption tower two moles of NH₃ are lost.

Assuming that 1,000 ppm of NO_x are in the tail gas leaving the absorption tower, 3 kg of ammonia/tonne of HNO₃, will be fed to the plant and not making any nitric acid so this is an equivalent decrease in yield of 1.1%. For a 685 t/d plant, this represents a loss of about 850 tonnes of ammonia per year.

For this reason, the design is increasingly focused on ensuring a low NO_x level leaving the absorption tower.

The absorber consists of a series of sieve trays and cooling coils to remove the reaction heat. Thanks to this feature, the absorber performance can also be improved by proper design of the absorption trays, thus limiting their number and reducing the investment cost of the equipment.

Different cooling water temperatures are used to remove the heat from trays: the top part of the absorber uses chilled water while the bottom section uses cooling water. In this way, the top section of the absorber is working at low temperature, boosting nitrous reaction and reducing the NO_x content at the absorber outlet.

Fig. 9 shows the absorber tower and details of the absorber exchanger plate.

Casale Denox reactor

NO_x and N₂O emissions are an environmental issue nowadays and the emission limits for the Syra 4 plant are extremely severe. The requirements in normal operation are:

N₂O: 0.1 kg/t HNO₃

NO_x: 25 ppm.

The plant has been designed from the outset to incorporate all possible means for emissions reduction. The reactor is designed to accommodate abatement catalyst with a special feeding and control arrangement to achieve the emission targets.

Casale has a long experience in the design of catalytic converters and the integration with Borealis' knowhow leads to:

- reduced pressure drop across reactor;
- optimal gas distribution within catalyst;
- low emissions level.

CHPN project management execution

As the main contractor, CHPN is responsible for all project activities such as project management, engineering services, procurement, commissioning and start-up activities all with the application of first class quality and safety standards applicable in this field of design and construction.

CHPN has completed a number of engineering projects in the chemical sector focused on the complex engineering activities and turn-key projects in the areas of nitric acid, urea, ammonium nitrate, UAN and aniline. This turn-key experience has resulted in designs that minimise plot area and optimise structural design. All these aspects contribute to produce a design that is cost effective to build without compromising on operability or quality.

Project management and engineering services for Syra 4

The project management is performed from the home office in Prague and the works include mobilisation to the project, engineering coordination between disciplines, preparation of a project execution plan, elaboration of internal and external co-ordination procedures, planning and establishing project controls – progress monitoring, progress reports and cost control using in-house information system and methods, document control using MS 365 SW and SharePoint webpage for the project documentation control as well as for the sharing of engineering documentation with the client. An in-house system is being used for

Fig 10: Hydrorested absorption tower dressed in one piece



Fig 11: Preliminary layout of nitric acid plant and utilities



vendor documentation control, certified by Lloyd's Quality Assurance Register.

The scope of the engineering consists of process design performed mainly by the licensor Casale with participation of CHPN process engineers resulting in production of the process book package, basic design as well as detail design documentation produced entirely in the CHPN home office in Prague. During the engineering phase the licensor is involved in the review of the key process documentation and key equipment specification. Basic and detail design will cover all disciplines involved i.e. process, mechanical, piping, instrumentation and control, electrical and civil.

During the engineering phase the design reviews are held for 30%, 60% and 90% completion of the plant model where inputs of the company can be discussed and upon mutual agreement incorporated as well as HAZOP procedure with participation of contractor, licensor and company to verify all safety aspects of the design as a first priority.

Procurement

CHPN is experienced in the procurement of equipment for nitric acid plants, which will be selected from a list of preferred first class equipment suppliers mostly in Europe and certainly from Sweden in compliance with company requirements, Sweden authority rules and for logistical purposes. CHPN will cover the purchasing, expediting and inspection services in order to assure all deliveries, site services, third party inspections and certification required for implementation of the project to meet European standards and for specific company requirements. CHPN is responsible for the full scope of the procurement.

Fig. 10 shows the absorption tower delivered hydrotested dressed in one piece

Construction and construction management

CHPN is experienced in construction management and provides a full suite of professional construction services to support project delivery. The construction services approach is structured around construction planning and strategies, construction execution and completion. These distinct services have established work processes, procedures and guidelines that provide consistently high performance in construction execution. This approach allows CHPN to focus on key phases in the project delivery process and apply specific resources, experience and knowledge at each point.

CHPN recognises that involving construction personnel during the early phases of the project results in a design that is easy to build from the start avoiding costly rework later in the project.

As a result, input for construction will be required throughout all phases of the project. CHPN proposes to include construction personnel in the design and engineering team from early in the project. They will be actively involved in constructability reviews on a daily basis as the design progresses. This will allow the team to seek and obtain construction input without waiting for milestones, mitigating potential delays in the design process.

Once the project moves to site the on-site team will execute the construction plans, manage the overall construction process, focus on safety, quality assurance, undertake field procurement, contracts management, project controls and material handling. The construction management suite of tools will allow accurate assessment of actual progress and productivity as well as realistic forecasting of a well controlled schedule and cost outcomes.

HSE supervision

CHPN targets zero safety incidents during execution of the project. To achieve this it will need to manage the subcontractors to ensure safety requirements according to the project HSE plan. The plan will incorporate CHPN safety standards in addition to local regulations and standards valid at the Köping plant.

Commissioning

The commissioning including start up, trial operation and performance test run will be managed by CHPN. CHPN will also provide all necessary testing, cleaning and preparative works, including putting the utilities into operation in order to have the plant ready for start-up and trial operation. The scope of commissioning includes training of the company's personnel at the site.

Start-up and trial run

CHPN will manage all testing and tuning procedures after introduction of the raw material in the system in order to prepare the plant for test performance guarantee. The activities will be performed with assistance of the licensor, commissioning managers of the turboset train and other main equipment suppliers and DCS and SIS commissioning engineers. Once the plant has successfully passed the trial run operation, the guarantee test is performed. When the guarantee test has been successfully completed the plant is provisionally accepted and can be commercially operated by the company.

Fig. 11 shows the preliminary equipment layout of the nitric acid plant and utilities.

The first phase of the project is under implementation and the project completion certificate is scheduled to be issued in July 2017.

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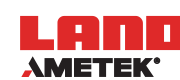
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