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Number 346

March | April 2017

nitrogen + syngas

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Nitrogen+Syngas 2017 Conference, London

Innovative urea technology

European gas markets

New nitric acid process



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Process Technologies



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China's sea change



While the world has been focused on events in Washington over the past few months, and the possible implications for the future, over the past year momentous events of a different kind appear to have been occurring in China, and particularly among Chinese urea producers. Chinese urea exports dropped from 14 million t/a in 2015 to 'only' 8.5 million tonnes for 2016. The effective withdrawal of 5.5 million t/a from international markets has offset the impact of new capacity elsewhere, in the US, North Africa and Middle East, and has helped support prices towards the end of the year and into 2017.

Chinese coal prices still remain high compared to this time last year.

The chief culprit for the reduction seems to have been a rise in Chinese coal prices. China introduced production cuts in April 2016 which meant that coal miners were only able to operate for 276 days per year instead of 330. This caused shortages and increased imports from overseas and led to a doubling of thermal coal prices to \$110/t, and coking coal to more than \$300/t. Beijing eventually moved to ease the cutbacks to bring prices down, allowing miners to operate at 330 days per year again from March 2017, while demand cutbacks from power and chemical producers has allowed the pressure on coal prices to fall to an extent. However, Chinese coal prices still remain high compared to this time last year – anthracite coal, the main feedstock for Chinese urea producers, is at \$125/t. And now the Chinese National Development and Reform Commission (NDRC) has indicated that it is looking to close 800 million t/a of uneconomic coal capacity this year, against only 500 million t/a of new, lower cost production. China's coal production may rise to 3.9 billion t/a in 2020, but demand is forecast to be 4.1 billion t/a. China is also trying to wean itself off its coal dependency for environmental reasons, as it makes efforts to cut chronic pollution that blights the country's major cities as well as meet ambitious targets for reduction of carbon dioxide emissions per unit of GDP in the wake of the Paris Agreement.

All of this has pushed up costs for Chinese urea producers, leading to much lower operating

rates – down to about 50% at the start of 2017 as compared to over 60% at the start of 2016, and the consequent fall in urea exports. And in a recent market forecast Canada's PotashCorp says that it believes Chinese urea exports may fall still further in 2017, to between 5.0 and 7.5 million t/a, even though urea prices appear to be on the way back up again, following falls to below \$190/t in China last year, while the Profercy consultancy's estimate, at 5-5.5 million t/a, is at the lower end of that range. Chinese gas-based urea producers are also facing a squeeze from rising natural gas prices, which Integer Research now estimates have some of the highest production costs in the industry, at over \$270/t, due to Chinese gas prices floating towards market rates. This also means that the urea price floor, which has been set by marginal Chinese producers in recent years, is coming up along with Chinese feedstock prices.

In the 1990s, China was one of the largest importers of urea, but this changed as the country rapidly built new capacity to become by far the largest producer in the world, and from the turn of the millennium onwards the country has become a progressively larger exporter. This decade, the nitrogen industry has got used to having to deal with large volumes of Chinese urea exports, and the China has become in effect the global price setter in the way that the Black Sea was in the 1990s. Now, however, there are signs that this is changing, and perhaps more rapidly than people had expected.

Richard Hands, Editor



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Price trends



MARKET INSIGHT

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

NITROGEN

To say that the nitrogen market had a tough year in 2016 would be an understatement. Existing market weakness at the start of the year gave way to continued price decreases in light of chronic oversupply and lower energy feedstock costs, which improved the production economics of the industry's highest cost producers.

Delayed nitrogen capacity expansions became the new normal in 2016 globally, with only a handful of new plants coming online close to their original expected commissioning date, providing some relief in the market given the already oversupplied situation. Several overdue plant start-ups came to fruition in the final months of 2016, when a slight uptick in prices had already begun, buffering the impact of this new supply.

The global ammonia market saw an upward pricing surge from mid-November to late December due to shorter supply. Several plant shutdowns coupled with high natural gas curtailments in Trinidad led to higher global prices. Short-term supply restrictions boosted the Yuzhnyy f.o.b. benchmark to \$215 per tonne f.o.b. in late December, after it trailed below \$170 per tonne f.o.b. throughout Q4 2016. The reduction in supply was due to outages at plants in Africa, Asia, and in Trinidad,

where producers suffered from continued gas curtailments. Several producers switched from selling ammonia to urea in response to weak ammonia prices, including Algerian producer Sofert and Russian producer TogliattiAzot. The US Tampa contract price remained weaker than other international benchmarks and showed a marginal increase of \$15 per tonne to \$225 per tonne c.fr in December compared to previous prices in October and November. IncitecPivot's new \$850 million ammonia plant at Waggaman, LA in the US, which was commissioned in October produced 65,000 metric tonnes between mid-October and late November.

Short-term supply shortages seen in Q4 2016 had been expected to be resolved in early 2017, making a further substantial ammonia price recovery in January and February unlikely. But the ammonia market has been unexpectedly firmer ever since a dispute arose between Russian ammonia producer, TogliattiAzot, and its Ukrainian pipeline partner Ukrhimtransammiak over the shipment of ammonia to Black Sea ports, which has removed 130,000 tonnes of ammonia from monthly export availability. The dispute, which ended on 3 February, left ammonia supply from the region at a standstill, and aided inflation across all major global price benchmarks.

Table 1: Price indications

Cash equivalent	mid-Jan	mid-Nov	mid-Sep	mid-Jul
Ammonia (\$/t)				
f.o.b. Caribbean	215	175	195	245
f.o.b. Arab Gulf	195-221	175	165	305
c.fr N.W. Europe	345	245	230	295
c.fr India	230	187	225	340
Urea (\$/t)				
f.o.b. bulk Black Sea	251	219	190	176
f.o.b. bulk Arab Gulf*	260	238	181-193	173
f.o.b. bulk Caribbean (granular)	243	213	194	167
f.o.b. bagged China	265	236	196	197
DAP (\$/t)				
f.o.b. bulk US Gulf	329	323	339	340
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	169	145	137	135

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

Source: Fertilizer Week

The supply situation at Yuzhnyy has been compounded by the shutdown of OPZ since late December due to a lack of natural gas, which has continued without resolution into February.

The steep increase in ammonia prices in January more than offset higher energy prices in the US and improved the region's typical ammonia gross margins, which grew to \$85/tonne, up by \$36/tonne compared with December. In Russia, the typical ammonia gross margin improved by \$35/tonne to reach \$62/tonne, after gross losses were recorded between September and November 2016.

The urea market continued to firm in Q4 2016 as the Yuzhnyy urea price rebounded to \$218 per tonne in mid-December, up by around \$30 per tonne compared to October. The price gains were supported by strong demand in the US and Europe and limited availability in Yuzhnyy. This was despite the surprising cancellation of the Indian import tender in November, which prompted urea prices to fall marginally at the beginning of December. However, market fundamentals remained largely unchanged due to the supply shorts and Iranian tonnes destined for India were absorbed easily into the market.

China's role as a swing supplier remains the key influence. The Chinese government has put pressure on the coal industry to rationalise, which led to rising Chinese coal costs in October and November and continued to squeeze urea producers, which in turn, led to a higher Chinese urea export price floor. However, the government backtracked on its coal policy in late November and coal prices nudged downwards accordingly, which likely means a lower urea floor once again and downward pressure on urea prices moving forward.

Monthly average producer margins generally improved in Q4 2016, driven by higher urea prices and stable, if not lower, feedstock costs. Ukrainian producers continued to make gross losses in the final months of 2016, and with several plants down either for maintenance or due to gas supply issues, the country has returned to the position of swing producer.

Chinese margins remain thin despite recent urea price increases, although the reduced export-potential of Chinese producers is far more driven by plant closures as part of the wider industry consolidation and a stronger domestic market in the short-term as opposed to short-term production economics.

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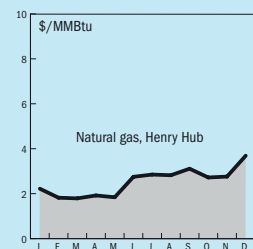
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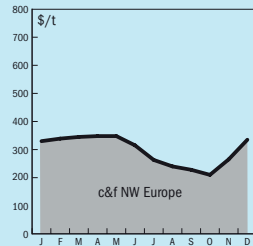
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END OF MONTH SPOT PRICES

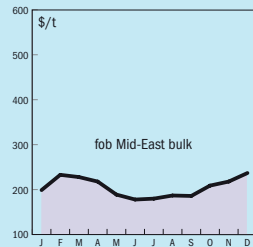
natural gas



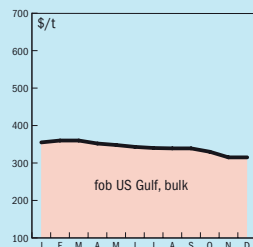
ammonia



urea



diammonium phosphate



MARKET INSIGHT

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

METHANOL

Methanol prices increased further in January, reflecting marginally higher crude oil prices as well as a tight methanol market with some supply constraints in the Middle East and North Africa and the start-up of two major MTO facilities at the very end of December resulting in lower inventory levels in China.

US reference prices for February were \$1.25/gal for Methanex (a rollover from January) and \$1.29/gal for Southern Chemical Co. (up \$0.10), equivalent to \$416/t and \$429/t respectively. IHS Chemical's contract net transaction price for February was officially posted at \$1.268/gal (nominal \$422/t). American methanol demand was seasonally slow and steady. Demand into construction applications should begin soon as producers build inventory and colder weather resulted in strong de-icer demand. Methanol demand for MTBE production in the US is lower, as is normal for this time of the year. Acetic acid demand was healthy, with all major units running at healthy rates ahead of turnarounds over the next few months.

In India, prices rose in line with the gains made in c.fr China prices, as Indian consumers and traders looked to compete with China for available volumes from Iran; coastal inventories were extremely low. Port prices started the month at \$322.5/t c.fr T1 and finished the month at \$362.5 c.fr T1; domestic prices increased from 26 Rs/kg to 31.5 Rs/kg during the month. Demand remained very weak and operating rates at formaldehyde units were at very low levels, partly due to higher methanol prices but also low consumer demand, amid the ongoing difficulty following the demonetization last year.

European spot prices (T2 f.o.b. Rotterdam) for January averaged €330/t over the month, up €28 over December. Methanex posted its 1Q 2017 West European Contract Price at €370/t, f.o.b. Rotterdam T2, an increase of €120 on the previous quarter's posted price. The ongoing suspension of duty on methanol arriving into the EU is likely to remain for the foreseeable future while a protest following the changes in GSP status is reviewed by the EC. The European

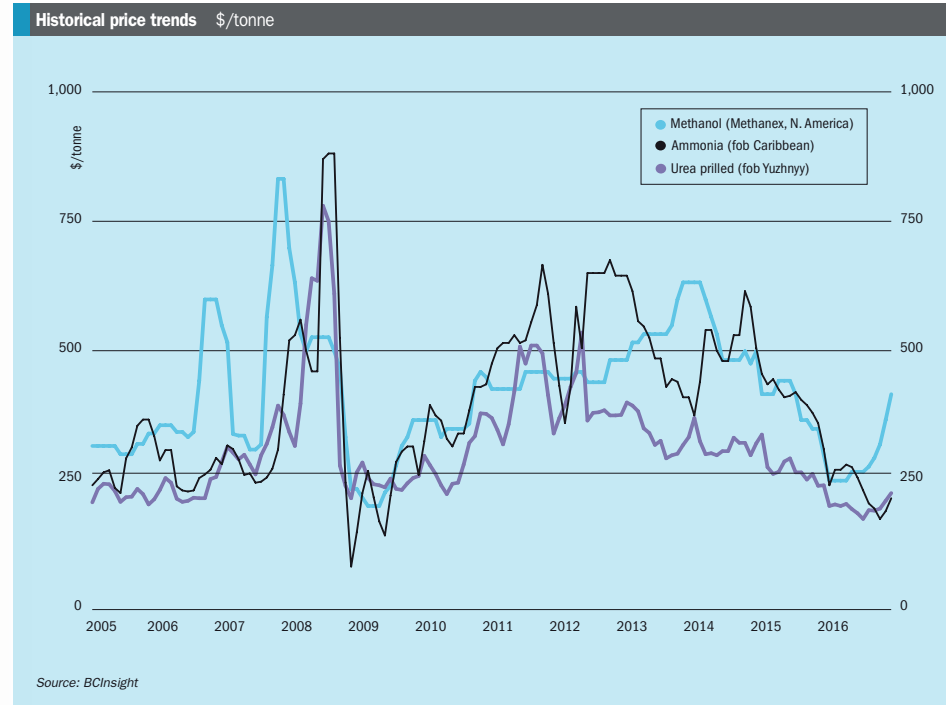
market was short on supply against stable demand. Operating rates at formaldehyde units in the Mediterranean was strong, with strong downstream demand into resins and adhesives. Demand for MTBE in Europe and West Africa has improved. Acetic acid demand was stable, with major units running at healthy rates.

Asian prices in January traded up \$22/t, in a range of \$328-365/t, c.fr; China prices rose \$19/t in a range of \$328-350/t, c.fr. Methanex's posted APCP for February is \$430/t, a rollover from January. In China, overall capacity utilisation was higher than December at around 54% of nameplate capacity, or around 68% of effective capacity. Increasing numbers of domestic coal mines have stopped production amid intensified safety concerns and slowing market activity. This may reduce January output by 20% from 320 million tonnes to 260 million tonnes, with production in February even lower at around 176 million tonnes.

Methanol demand in China was strong in the first half of January but fell away in the second half as the Lunar New Year holiday approached. Coastal inventory was at low levels. Two new MTO units started up in the last week of December: Fund Energy Changzhou (1.2 million t/a methanol) and Shenghong Group (Jiangsu Sailboat; 2.3 million t/a methanol). The larger of these two units came offline in early January, however, after only 10 days of production. This facility will re-start once its units downstream of ethylene (EVA and polyethylene) have started up, after the Lunar New Year holiday. Most middle to small formaldehyde producers had shut down before the holiday, although large formaldehyde units continue to produce normally. Methanol demand into DME remained bearish.

In Southeast Asia, the spot market tightened as a result of Petronas's production issues. Methanol demand was very stable across major downstream applications. In Korea, the market was stable with limited trade, and in Taiwan, end-user inventory remains at a middle to low level, as downstream production was stable and end-users have been purchasing exclusively on a spot basis, without an immediate need to purchase spot product.

Market outlook



Source: BCInsight

AMMONIA

- Global ammonia prices were expected to continue to increase through February due to a spate of unexpected supply shortages that allowed for a rally in pricing January.
- In particular, the outlook for the ammonia market will depend on how quickly and effectively Russian ammonia begins to be piped along the Ukrainian pipeline following the resolution of the dispute between Togliatti and Ukrhimtransamiak in early Feb.
- In the longer-term, however, ammonia capacity expansions in the US, South America and Asia are likely to alleviate any ongoing supply issues, and the global ammonia market remains oversupplied.

UREA

- Seasonal demand for spring application in the US and Europe is expected to drive higher price ideas in Q1 2017, and sentiment could remain firm beyond the first three months of the year amid delayed demand due to mild winters.

- Chinese urea producers are mainly focussed on the domestic season but international prices could come under threat as 2017 continues if coal prices to urea exporters fall and production rates increase.
- Dnipro is the only urea producer servicing the export market at press time and the OPZ and Cherkassy plants were down through February at least.
- Anticipated urea capacity expansions in the US will begin to displace imports.
- Anticipated urea capacity expansions in the US will begin to displace imports; up to 3-4 million tonnes is expected this year, at CF Port Neal, OCI Wever, Koch at Enid OK, Agrium Borger TX and Dakota Gasification.

METHANOL

- In Iran, Kaveh Methanol Co. (2.3 million t/a) will commence operations in January 2018, and expectations for Marjan, which is 85% complete, are also for the full 1.65 million t/a capacity to enter commercial production by 1 January 2018.

- Iran has been prevented from trading with Europe and the US during the period of sanctions so IHS Markit expects it will take time for the country to overcome this hiatus. As a result, there may be unexpected delays to the start-up of projects, due to more hurdles in access to technology, know-how and basic parts. Trading relations will also take some time to become re-established.
- In the US, the view is that an additional 10 million t/a of capacity will be added to North America by 2021 from 2014's level of just 3 million t/a. US Methanol announced in mid-August 2016 that the project they have slated for Institute, West Virginia will be based on a 150,000 t/a unit that they are disassembling in Brazil. Start-up is targeted for July 2017.
- Another step-increase in exports will occur when the 1.75 million t/a Natgasoline project starts up; this is currently expected on-stream in December 2017.

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Nitrogen Industry News

EGYPT

Commissioning for MOPCO plant

thyssenkrupp Industrial Solutions has recently commissioned Egypt's largest nitrogen fertilizer complex. Located in the Damietta free trade zone, 160 km north-east of Cairo, it will be operated by the Egyptian Nitrogen Products Company (ENPC), a wholly owned subsidiary of Misr Fertilizer Production Company (MOPCO). When running at full capacity, the plant will be capable of producing 2,400 t/d of ammonia and 3,850 t/d of urea. Greg McGlone, Managing Director of ENPC said: "We are elated to have continuous production at our new world-scale fertilizer complex in Damietta. Together with our partner thyssenkrupp we were able to successfully take this mega-project from start to completion, despite the extremely challenging political and economic circumstances in Egypt over the past nine years."

Ralf Richmann, CEO of the Fertilizer & Syngas Technologies business unit of

thyssenkrupp Industrial Solutions added: "This project demonstrates once again the immense trust of the major players within the fertilizer industry in our technological capabilities and experience gained in the construction of more than 130 fertilizer plants worldwide."

ENPC commissioned thyssenkrupp to build the new turnkey fertilizer complex including two ammonia and two urea plants as well as various offsite and related utility systems, product handling and storage facilities in 2007. The largest single fertilizer contract in the history of thyssenkrupp to that point, it included both basic and detailed engineering, supply of equipment, construction and commissioning. The ammonia plants are based on thyssenkrupp's proprietary ammonia process, while the urea plants use Stamicarbon's process. All comply with stringent Egyptian and European standards.

UNITED STATES

Agrium completes Borger expansion

Agrium says that it has successfully completed construction of the new urea plant at its nitrogen facility in Borger, Texas. Commissioning of the new 610,000 t/a urea facility is under way, and production is expected to commence in the first quarter of 2017. The new plant includes a Diesel Exhaust Fluid (DEF) production line which will consume 100,000 t/a of urea. DEF is used to reduce nitrogen oxide emissions in diesel vehicles and Agrium says that the product line will help further diversify the company's end-user markets.

"Achieving this critical milestone in our Borger nitrogen expansion project... is another example of our commitment to operational excellence at Agrium. The project creates shareholder value by refreshing the asset to ensure its future longevity, provides improved supply chain integration as well as product diversification and availability in this important agricultural region," commented Agrium's President and CEO, Chuck Magro.

CO₂ plant for ammonia facility

Praxair has signed a long-term contract to purchase by-product CO₂ from US Nitrogen

LLC. The company will build, own and operate a new CO₂ purification and liquefaction facility at US Nitrogen's ammonia plant in Tennessee, which is set for start-up towards the end of 2017. When complete, Praxair will own a total of seven sites of this kind throughout the Eastern USA..

SWITZERLAND

Casale renames Chemoproject Nitrogen

Casale Holding SA, the owning company of Casale SA, says that its Czech engineering subsidiary Chemoproject Nitrogen a.s., acquired in July 2014, has officially changed its name to Casale Project a.s. and is now fully owned by Casale Holding. The rebranding is part of a reorganisation of the two companies which, since Chemoproject's acquisition in 2014, have been realigning their organisations and, says Casale, underlines their common drive toward achieving greater scale, as a combined entity with a shared vision, in order to deliver a better and wider service to their customers.

"This name change better reflects the common future direction of Casale and Casale Project" says Giuseppe Guarino, CEO of Casale SA, vice chairman of Casale Holding and chairman and statutory director

of Casale Project a.s. "in which Casale's well-known technological leadership will blend seamlessly with the capabilities of Casale Project in project execution, allowing both Companies to provide their Customers with a full range of services required to successfully implement projects, including turnkey execution, for new units construction and large revamp of existing plants as well."

BELGIUM

New calcium nitrate fertilizer

Phosphate producer Prayon has added a new product to its *Hortipray*® range of fertilisers: Calcium Nitrate Extra (17-0-0 + 33% CaO) has a higher calcium oxide content than previous grades, which were 25% CaO. It also guarantees that at least 17% nitrogen will be available as nitrates.

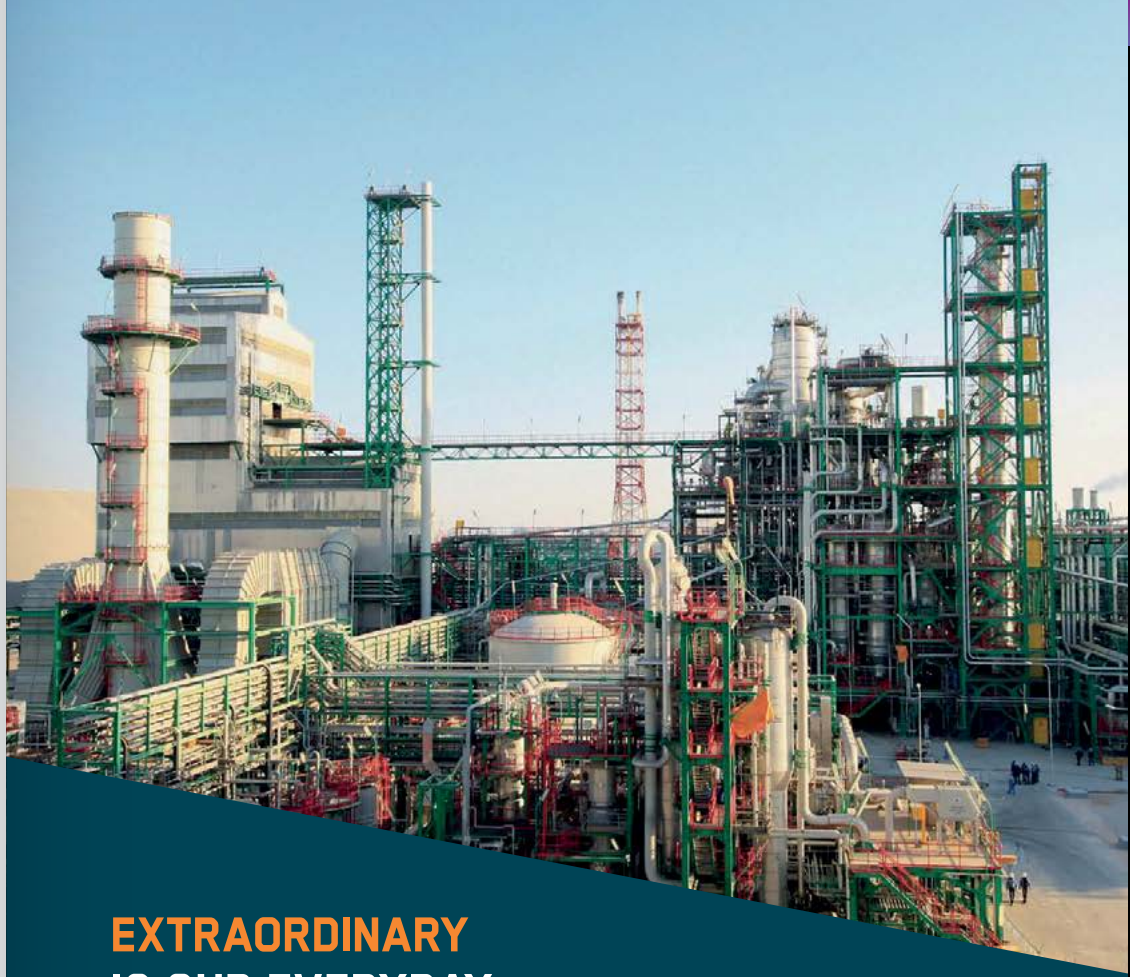
"Compared to standard products, the crystals in Calcium Nitrate Extra contain fewer water molecules, resulting in a higher concentration of nutrients", explained Kurt Verhelst, Prayon Northern Europe Horticulture Customers Coordinator. "The more concentrated product helps growers reduce their transport and storage costs. Specifically, five bags of standard fertiliser can be replaced by four bags of Calcium Nitrate Extra while maintaining the same amount of readily available calcium."

The new product also contains a negligible amount of ammonium, unlike the calcium nitrate fertilisers typically used. In some hydroponic crops, excessive ammonium can cause growing problems resulting in yield and quality losses.

FRANCE

Cooperation on nitric acid plants

Industrial software supplier ProSim has signed an agreement with Johnson Matthey Plc aimed at further enhancing the performance of nitric acid plants. The partnership will see Johnson Matthey actively market and support the sales of ProSimPlus HNO₃ software, while Johnson Matthey will become ProSim's exclusive catalyst supplier within the nitric acid industry. Both companies will collaborate in flowsheeting simulation work by applying their know-how and expertise in the nitric acid industry as a service for customers, aiming to resolve issues and optimise plant operations. Further joint developments in the catalyst modelling aspect of the simulation will also benefit operating firms and engineering companies.



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Caption: Signing of the Stamicarbon-SBN cooperation agreement. Table from left to right: S. Zwart, VP Licensing, Sales & Services, Stamicarbon; S. Christof, CEO Christof group; P. Djavdan, CEO Stamicarbon and M. Fuchsichler, CEO of J. Christof Apparatebau Beteiligungs GmbH.

NETHERLANDS

Stamicarbon signs cooperation agreement with SBN

Urea licensor Stamicarbon and equipment manufacturer Schoeller Bleckmann Nitec (SBN), part of the Christof Group, have signed a cooperation agreement related to the fabrication of high pressure equipment for urea plants. Both companies have been closely working together for many years in the field of designing, engineering, manufacturing and delivering of high pressure equipment, in particular reactors and heat exchangers made of stainless steels and operable under pressures prevailing in the synthesis section of Stamicarbon-design urea plants.

The scope of the agreement includes: delivery of HP equipment using *Safurex*[®] stainless steel based on Stamicarbon urea technology within 12 months of ordering and SBN keeping standardisation material and SBN keeping standardisation material and prefabricated parts as stock.

INDIA

RCF to take on Namrup project

In a move to resolve the impasse on reviving the Namrup fertilizer plant, the Indian government has decided to pass the project to Rashtriya Chemicals and Fertilizers (RCF), which will take a 52% controlling stake in the project, following the failure to attract private investors. Last year the government cleared a plan to set up an 864,000 t/a ammonia-urea plant at Namrup at a cost of \$660 million on the basis

of a public-private partnership (PPP) via a joint venture. Other partners include the Brahmaputra Valley Fertilizer Corp. Ltd and the government of Assam, with 11% each and Oil India Ltd, which holds 26% equity. The new proposal will now go before cabinet for approval. Also needing to be cleared will be an increased gas allocation. Although the new plant will be twice the size of the existing facility, it will only use an additional 0.62 million m³/d on top of the 1.72 million m³/d currently allocated.

BRUNEI

Work to begin on ammonia-urea plant this year

Brunei has indicated that work is due to begin this year on construction of a new 2,200 t/d ammonia and 3,900 t/d urea plant for the majority state-owned Brunei Fertilizer Industries Sdn Bhd (BFI). The BFI project is sited at the Sungai Liang Industrial Park at Siptang, next to well-established gas processing facilities in Lumut. Completion of the facility is targeted for 2020. All of the ammonia produced will be converted to granular urea, some of which will be earmarked for domestic use, but the bulk will be aimed at export markets. According to a government statement, Brunei hopes that the establishment of BFI will significantly contribute to the development of Sungai Liang as a world-class petrochemical hub which will be able to accommodate other downstream petrochemical projects in the future.

AZERBAIJAN

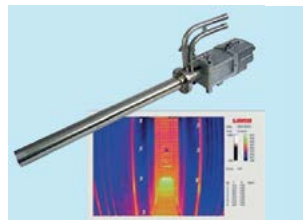
Loan agreed for urea plant

The Export-Import Bank of South Korea (EximBank) has arranged a €500 million loan facility for the construction of an ammonia-urea plant for Azerbaijan's state oil company SOCAR in Sumgait. EximBank says that the financial assistance will help to develop economic cooperation between Azerbaijan and South Korea and lay the foundation for the implementation of other large-scale projects in Azerbaijan. The cost of the new nitrogen plant is put at €700-750 million in total, with completion expected in 1Q 2018. The facility will produce 1,200 t/d of ammonia and 2,000 t/d of urea. The main construction contractor is South Korea's Samsung Engineering, while the licensors are Stamicarbon and Haldor Topsoe, with project management consultancy provided by Neste Jacobs Oy.

UNITED KINGDOM

AMETEK Land to showcase new borescope

Temperature measurement specialist AMETEK Land will launch its Near Infrared Borescope (NIR-B) 3XR to the international market at the Nitrogen+Syngas 2017 conference in London. The NIR-B 3XR delivers continuous, high-accuracy reformer tube wall temperature (TWT) measurement, furnace optimisation and monitoring, giving operators the ability to measure temperature point data and for storing and trending this data for future analysis, leading to increased productivity, greater asset protection and enhanced tube life. The NIR-B 3XR features a wide (90°) angle field of view and a high-resolution image, allowing multiple reformer tubes to be imaged and measured simultaneously. That capability is critical to extending asset life and maximising efficiency, as a -10°C measurement error over time can result in either 1% lost productivity, while a +10°C error can result in a 25% reduction in tube life.



JAPAN

GE and Toyo to work on digital solutions for chemical projects

General Electric Company (GE) and Toyo Engineering Corporation have signed a memorandum of understanding for a joint project to explore digital solutions for the fertiliser and petrochemicals industries. Under the MoU, GE and Toyo will jointly work to evaluate, define and confirm the technical and economic feasibility of the deploying of GE Predix, a cloud-based platform built exclusively for industry, and asset performance management (APM) software, to implement specific solutions for pre-FEED, FEED, EPC, commissioning, operation and maintenance phases of fertiliser and petrochemicals facilities.

INDONESIA

Clariant provides catalysts for new plants

Clariant says that it is providing catalysts for two new ammonia plants in Indonesia, in cooperation with its licensing partner KBR. The new projects will use Clariant catalysts across the whole of the ammonia production process, including *AmoMax*[®] 10 for ammonia synthesis, *ReforMax*[®] 330 LDP and *ReforMax* 210 LDP for reforming, as well as *ShiftMax*[®] 120, *ShiftMax* 217 and *ShiftMax* 210 for the high temperature (HTS) and low temperature shift (LTS) reactions. Awarded in 2015, the Indonesian projects are part of a strategic cooperation between Clariant's Catalysts business and KBR. Start-up of the plants is under way.

TURKEY

Ban lifted on sales of CAN

The Turkish government has lifted the ban on domestic sales of sodium and potassium nitrate which it imposed in June 2016, and has relaxed restrictions on the sale of calcium ammonium nitrate (CAN). However, the ban on sales of ammonium nitrate, imposed after several bomb attacks across the country, is set to continue permanently due to "security concerns".

ITALY

Pipes for urea service

Raccortubi Group will exhibit together with its partner Salzgitter Mannesmann Stain-

less Tubes GmbH at the Nitrogen+Syngas 2017 Conference and Exhibition in London from 27 February to 2 March 2017. Given the growing requirement for pipes, fittings and other piping components for urea production systems globally, Raccortubi and Salzgitter Mannesmann signed a partnership agreement in 2013 to combine each company's expertise in manufacturing and supplying to offer customers the most complete product packages with the shortest lead-times. It allows Raccortubi to stock urea grade pipes and to use them as raw material in the internal manufactur-

ing of butt weld fittings, via its integrated plants Tecninox and Petrol Raccord, enabling the Group to fulfil customer needs on demand.

The partnership covers the distribution of 316L UG (UNS31603) and 25.22.2 (UNS31050) piping and the supply of the relevant fittings and flanges. All the materials resulting from this synergy conform to the latest Urea Casale, Saipem (Snamprogetti) and Stamicarbon specifications, and the two companies aim to always be compliant with the highest standards in the sector.



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NIGERIA

Brass methanol plant signs off-take deal

The Brass Fertilizer & Petrochemical Company Ltd (BFPCL) says that it has signed a \$6 billion off-take deal with BP Oil International. The deal covers all methanol output from the plant for the first 10 years of production. BFPCL says that the deal is a "significant milestone" in the development of the project, and paves the way for financial closure on the \$4 billion project, which will be built at Brass Island, Bayelsa State. The first phase, which is targeting completion in 2020, will produce 1.66 million t/a of methanol and 1.3 million t/a of urea, and also includes a dedicated export jetty and

gas processing plant. A 25 year gas supply contract for 300 million scf/d of gas has been signed with Shell Petroleum Development Company of Nigeria Ltd from Shell's offshore OML33 field.

Executive vice chairman Ben Okoye said: "attracting a major international player like BP bears testimony to the tremendous support for the project by the current administration of the Federal Government of Nigeria (FGN), the Nigerian National Petroleum Corporation (NNPC) and the Central Bank of Nigeria (CBN), as well as the hard work and commitment of the project developers".

Haldor Topsoe has been responsible for design work and licensing ammonia and methanol technology for the complex, which is set to be the largest single foreign investment in Nigeria. Project management will be performed by Engineers India Limited (EIL), with the shortlisted EPC and O&M contractor to be selected in early June. Investors in include a subsidiary of DSV Group, a leading Nigerian provider of solutions to the local pipeline industry, Haldor Topsoe, Maj Invest, the Investment Fund for Developing Countries (IFU), Swedfund and the Bayelsa State Government.

UNITED STATES

Petcoke-based methanol plant secures loan guarantees

In late December the US Department of Energy (DoE) announced that it had made the "first ever offer for a conditional commitment" of loan guarantees under its Advanced Fossil Energy programme to Lake Charles Methanol, LLC, for a petcoke-to-methanol facility. The DoE's Loan Programs Office (LPO) has offered up to \$2 billion in loan guarantees to help finance the facility in Lake Charles, Louisiana. The plant is claimed to be the first methanol facility in the world to use carbon capture technology, and will become "the world's largest industrial manufacturing carbon capture facility."

Lake Charles Methanol says that it aims to begin construction in 2017, with completion likely around 2020. The project aims to purchase around 2.6 million t/a of petroleum coke from local Gulf refineries – the source of 58% of US petcoke – and gasify it to produce synthesis gas for conversion to 1.0 million t/a of methanol, as well as other recovered by-products, including sulphuric acid. It will also capture up to 90% of the carbon dioxide generated, estimated at up to 4.2 million t/a, which will then be piped to Texas to be used in enhanced oil recovery (EOR). The overall cost of the project is put at \$3.8 billion. A similar project was originally being developed by New York-based Leucadia Energy LLC, but that project was finally cancelled in 2014, leaving

the DoE with unallocated development funding for 'clean coal' and carbon capture projects. Using petroleum coke for a syngas project is unusual in the US, where projects, including another methanol project at Lake Charles, are all based on shale-derived natural gas. However, Lake Charles Methanol, which is using Fluor as its main contractor, says that its operations and management team have experience earned in the development of the Coffeyville petcoke to ammonia facility in Kansas.

Small scale LNG

Dresser-Rand, part of Siemens Power and Gas, has commissioned its first micro-scale natural gas liquefaction system at the Ten Man liquefied natural gas (LNG) facility in Pennsylvania. The modular, portable LNGo technology enables distributed production of LNG and can be installed in a short period of time to meet local demand for LNG. Developed by Dresser-Rand, it will allow the operator, Frontier Natural Resources, to monetise stranded gas assets at Tenaska Resources LLC's Mainesburg field, located in the Marcellus shale play. Frontier Natural Resources is an independent natural gas producer focused on developing conventional and unconventional resources.

The scope of supply included a standardized LNGo solution consisting of four different modules, each handling one step of the liquefaction process. The whole LNGo system can be transported on eight trucks. It is deployed directly at the gas field and has a footprint of approximately 508 m².

The Ten Man facility commenced production in four months from contract signing.

"This project demonstrates our unique capabilities to deliver innovative solutions for oil and gas applications that help our clients maximize the value of their assets," said Michael Walhof, sales director Distributed LNG Solutions for the Dresser-Rand business. "We are proud to provide Frontier Natural Resources with a reliable, robust solution to liquefy natural gas and cost-effectively move it to market."

The LNGo technology makes it possible to monetise stranded gas deposits due to its relatively low capital and operating costs. The micro-scale LNGo solution can be deployed in rough terrain or remote regions, eliminating the need to establish an expensive gas pipeline infrastructure or arrange for long-distance trucking of LNG from centralized plants to point of use. It can function as a decentralized solution where the requisite pipeline infrastructure is lacking, or as an onsite transformation solution to reduce or eliminate flaring of petroleum gas at, for example, oil rigs or producing gas fields.

ASU under construction for methanol plant

Air Liquide says that it will complete work on a state-of-the-art, energy efficient air separation unit (ASU) producing oxygen, nitrogen and argon by the second half of 2017, as part of a gas supply contract with Yuhuang Chemical, Inc. for the latter's new world-scale manufacturing complex in St. James Parish, Louisiana. The Yuhuang Chemical methanol complex will produce

approximately 5,000 t/d of methanol, making it one of the largest methanol production facilities in the US based on capacity. Air Liquide will supply Yuhuang Chemical with 2,400 t/d of oxygen from the new ASU.

Primoris Services Corporation has been awarded a \$30 million contract as part of the development, including site preparation work for the new plant facility, along with the supporting laydown areas, parking areas, and roadways. Work is scheduled to commence on the project in the first quarter of 2017, and this stage is expected to be completed late in 2017.

Auxiliary boiler contract for US methanol plant

Amec Foster Wheeler's Global Power Group (GPG) has been awarded a contract from Yuhuang Chemical Inc. for the supply of an auxiliary boiler for Yuhuang's new methanol facility, currently under construction in Louisiana. GPG will design and supply a shop-assembled auxiliary boiler that will provide the equivalent of approximately 60 MW of high pressure steam for the first phase of YCI's major methanol facility in St. James Parish, Louisiana. In addition to the natural gas fired auxiliary boiler, the scope of supply includes the fan, ductwork, combustion system, heat recovery and selective catalytic reduction equipment to meet emissions requirements.

UNITED KINGDOM

Gas from waste project launched

The launch of the world's first commercial-scale 'BioSNG' plant, making substitute natural gas (SNG) from gasified waste has been opened in Swindon, UK by project partners UK National Grid Gas Distribution, Advance Plasma Power, and Progressive Energy. It will produce 22GWh of substitute natural gas per year from 10,000 t/a of household waste. The low carbon BioSNG produced will be used to fuel heavy goods vehicles (HGVs) and supply gas to homes and businesses. When fully operational the plant will be able to reduce greenhouse gas emissions by more than 5,000 tonnes per year of CO₂.

David Smith, Chief Executive of Energy Networks Association said: "The UK's Gas Distribution Networks (GDNs) are working with industry partners to drive innovation in green gas technology which will provide clean, affordable and sustainable energy to meet the challenges of decarbonisation.

The use of green gas, such as BioSNG, biomethane and hydrogen, will also make efficient use of the UK's extensive gas network infrastructure meaning costs and disruption to customers are minimised.

We have the opportunity to become a world leader in green gas and low carbon network technology and today's launch demonstrates the progress that we are making in this increasingly important market."

National Grid Gas Distribution Chief Executive Chris Train, OBE, said: "National Grid Gas Distribution is delighted to be involved in this important project. Developing green technologies such as BioSNG means our customers can keep on using our network and their existing household appliances for affordable energy which will also be more sustainable and eco-friendly. Green gas fuelled vehicles also cause much less pollution than diesel and are particularly suitable for inner cities."

He added: "Making gas from household waste also reduces the amount of waste sent to landfill. As a long established player in the gas industry we're delighted to be at the forefront of this exciting new frontier in the sector."

IRAN

Methanol capacity may be delayed

Platts reports that up to 4 million t/a of new Iranian methanol capacity which had originally been due to start up this year has been delayed, which is expected to help support world methanol prices. The Kaveh Petrochemical Company's plant, with an output capacity of 2.5 million t/a at Bandar Dayyer is expected to start commercial production by the end of 2017 or the start of 2018, while the Marjan Petrochemical Company's 1.7 million t/a plant at Assaluyeh is now expected to start by early 2018. The 2018 start date for Marjan was also recently confirmed by the Iranian National Petrochemical Company (NPC) in its most recent statement.

QATAR

Shell signs EPCM deal with WorleyParsons

Qatar Shell has signed a five-year engineering, procurement and construction management (EPCM) services contract with WorleyParsons for the Pearl gas-to-liquids (GTL) project and associated facilities. The signing ceremony was held at Qatar Shell's offices in Doha, and was attended by Michiel Kool, managing director and chairman of Qatar Shell Companies; Chris Ashton, WorleyParsons managing director (operations – Europe, Middle East and Africa); and Sheikh Faisal bin Jassim Al Thani, WorleyParsons Qatar partner. Under the contract, WorleyParsons will provide EPCM services primarily for a portfolio of brownfield projects. The contract will be executed by WorleyParsons Qatar with sup-

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port from WorleyParsons Global Delivery Center in India. Pearl GTL is the world's largest producer of GTL products, capable of producing 140,000 bbl/d of products at the Ras Laffan site in the north of Qatar.

CHINA

Velocys signs MoU with Morimatsu

UK-based gas-to-liquids (GTL) developer Velocys has signed a memorandum of understanding (MoU) establishing a strategic alliance with Morimatsu Jiangsu Heavy Industry, a subsidiary of Morimatsu Industry Co. Velocys says Morimatsu will be its preferred supplier of module engineering and fabrication services for its plants, and that the agreement will drive down costs for gas-to-liquids and biomass-to-liquids plants based on Velocys technology, by optimising the design and fabrication of plant modules.

Velocys and Morimatsu have already been working together for the past 18 months on the modular design of the Fischer-Tropsch section for a range of plant sizes – a design that Velocys said will deliver targeted reductions in both capital cost and plant footprint. The two companies said they have identified “strategic synergies” that underpin an alliance where the partners shall collaborate with other strategic partners to further drive down costs across all areas of the plant, through innovative modularisation.

Velocys said it expects the terms of the MoU to be reflected in legally binding documentation within the next few months. It is the first strategic partnership that has been formalised since a review of Velocys’ strategy was completed in the fourth quar-

ter. A core theme of Velocys’ new strategy is to deliver, jointly with partners, a fully integrated and financed, cost effective and operations-ready plant solution, the board explained.

“The potential benefits of further modularisation of smaller scale GTL plants are significant in terms of reduced plant build schedule, reduced risk of delays, lower capex and opex,” said Velocys CEO David Pummell. “Morimatsu has a world-class team of engineers and impressive fabrication facilities in China. I am confident that together, Morimatsu and Velocys will continually improve the plant offer to our customers, underpinning both the economics and the delivery of an integrated solution in our renewable fuels and stranded gas markets.

Koei Nishimatsu, CEO of Morimatsu, said his company already has a track record of working in close collaboration preparing the groundwork for a range of modular low-cost plants. Nishimatsu added: “I am delighted that our companies intend to finalise this strategic partnership. Morimatsu is at the forefront of innovation and technical excellence and we look forward to continuing to work with Velocys as a route to accessing new markets for our engineering and fabrication expertise.”

Ningxia CTL plant delivers first shipment

A project to convert coal into liquid fuels in the northwestern Chinese region of Ningxia, the biggest plant of its kind in the world, delivered its first shipment of products on Wednesday, the official China Daily reported. The coal-to-liquid (CTL) project, which has an annual production capacity of 4 million tonnes of oil, was

built by the Shenhua Ningxia Coal Industry Group, a subsidiary of China’s biggest coal producer, the Shenhua Group. It took 39 months to build and cost 44 billion yuan (\$6.33 billion), China Daily said. The plant was first mooted in 2006 and initially involved the South African CTL developer Sasol. However, the firm pulled out in 2012 after the plant had still not been approved by regulators. The Shenhua Group launched its first CTL project in Inner Mongolia in 2010. The firm aims to boost total capacity at the Ningxia plant to 11 million t/a by 2020.

KENYA

Kenya considers CTL plant

Kenya’s Petroleum principal secretary Andrew Kamau says that the east African nation is considering converting a portion of its coal deposits to fuel as part of measures to cushion the economy from the volatile fuel import market. While he acknowledged the high up-front costs, he told local journalists that the coal-to-liquid (CTL) option remains open, and highlighted the success of South Africa in monetising its coal resources in that way. In recent years Kenya has discovered coal over 400 million tonnes of coal deposits in the Mui Basin in Kitui, although mining has yet to begin.

“We’ll first have to use the coal in power plants but the coal-to-liquid technology is still a possibility for us,” said Mr Kamau. Kenya gas an estimated 750 million barrels of oil reserves, a portion of which the country seeks to start exporting this year, but overall the country is a net importer, with oil accounting for around 20% of Kenya’s imports by value.

People

Waste-to-biofuels and renewable chemicals producer Enerkem Inc. has announced the appointment of **Dominique Boies** as executive vice-president and chief financial officer. Boies has over 20 years of experience in corporate and financial strategy, investment banking and operations. Prior to joining Enerkem, he was executive vice-president and chief financial officer at RONA where he was responsible for the financial and corporate strategy, investor relations, accounting, financing, treasury and legal affairs. At RONA, he led the company’s turnaround as well as the transaction that resulted in the acquisition of RONA by Lowe’s valued at C\$3.2 billion. Prior to this, he held various senior executive positions at RBC Royal Bank and at the Caisse de dépôt et placement du Québec (CDPQ), one of the largest institutional fund managers in North America.

“We are thrilled to welcome Dominique to Enerkem and to have attracted a financial executive of such high calibre,” said Vincent Chornet, President and Chief Executive Officer of Enerkem. “Dominique is a great addition to our seasoned team of executives and his experience is a great asset as we are now growing our commercial footprint around the world.”

Mr. Boies holds a masters degree in finance from the Université du Québec à Montréal (UQAM).

Grupa Azoty selected **Wojciech Wardacki** as its new president on 16 December and at the same time removed the previous president, Mariusz Bober, who had been in office for less than 10 months. Mr Wardacki previously served as the president of Zakłady Chemiczne Zachem and was a board member of Ciech. He has been president of Grupa Azoty Zakłady Chemiczne Police since April. He has also served as a member of the Sejm, the lower house of the Polish Parliament. “My mission is to complete the integration of the

group, comprising four companies, while ensuring that they remain independent, and to enhance the group’s market position,” said Wardacki.

Ma’aden’s president and CEO **Khalid Al Mudaifer** has been appointed to the board of the International Fertilizer Association (IFA). “For many years the IFA has been the voice of the global fertilizer industry,” said Khalid Al-Mudaifer. “We have been growing our relationship with IFA for a number of years now, while continuing to establish our own credentials in the global phosphate fertilizer market.” Mr Al-Mudaifer has been president and CEO of Ma’aden since 2011 and has decades of experience as a mining sector executive. He led on the early development of the Ma’aden Phosphate Company and the master planning of Ras Al Khair industrial city.

The chairman of Abu Qir Fertilizer Company **Saad AbulMaaty** has been made chairman of the Arab Fertilizer Association (AFA). Mr AbulMaaty said he would put all his experience and expertise at the disposal of the AFA and would strive to make the Arab fertilizer industry the most innovative and competitive globally.

Mark Sopp will join Houston-headquartered KBR Inc. as its Chief Financial Officer (CFO) on the retirement of its current CFO, Brian Ferraoli. He previously served as CFO and executive vice president for Leidos Holdings from 2005 to 2015. Prior to this, Sopp held various executive positions with Titan Corp, another firm involved in government contracting and commercial business.

“We look forward to Mark joining KBR,” said Stuart Bradie, KBR president and CEO. “Along with his extensive financial and capital markets expertise, Mark’s long-time experience in the government contracting sector, including knowledge of the government services investment community, will be immensely helpful as KBR expands our Government Services segment to achieve better balance between our government and hydrocarbons businesses.” Bradie also paid tribute to Brian Ferraoli: “We greatly appreciate Brian’s fiscal leadership during his time at KBR.

He has made many significant contributions, overseeing all the financial affairs of the company, helping strengthen our financial management and reduce our overall cost structure, and his sage advice has been a great help to me personally. We thank Brian for his service to the company and we wish him the very best in his well-deserved retirement.”

Calendar 2017

FEBRUARY

27-30 IFA Global Safety Summit, AMMAN, Jordan
Contact: IFA Conference Service, 28 rue Marbeuf, 75008 Paris, France.
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

27-March 2 Nitrogen+Syngas 2017, LONDON, UK
Contact: CRU Events, Chancery House, 53-64 Chancery Lane, London WC2A 1QS, UK.
Tel: +44 (0)20 7903 2444
Fax: +44 (0)20 7903 2172
Email: conferences@crugroup.com

APRIL

24-27 SynGas Association Meeting 2017, TULSA, Oklahoma, USA
Contact: SynGas Association
Tel: +1 225 922 5000
Web: www.syngasassociation.com

MAY

22-24 85th IFA Annual Conference, MARRAKECH, Morocco
Contact: IFA Conference Service, 28 rue Marbeuf, 75008 Paris, France.
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

JUNE

29-30 International Fertiliser Society Technical Conference, LONDON, UK
Contact: International Fertiliser Society, PO Box 12220, Colchester, CO1 9PR, UK
Tel: +44 (0)1206 851819
Email: secretary@fertiliser-society.org

JULY

9-12 IMTOF 2017, LONDON, UK
Contact: Sue Appleton, Johnson Matthey Plc, PO Box 1, Belasis Avenue, Billingham, Cleveland, TS23 1LB, UK.
Email: sue.appleton@matthey.com

SEPTEMBER

10-14 62nd AIChE Annual Safety in Ammonia Plants and Related Facilities Symposium, NEW YORK, USA.
Contact: AIChE Customer Service
Tel: +1 800 242 4363 / +1 212 591 8100
Fax: +1 212 591 8888
Email: xpress@aiche.org

OCTOBER

1-6 Ammonium Nitrate/Nitric Acid Conference, AUSTIN, Texas, USA
Contact: Hans Reuvers, BASF
Karl Hohenwarter, Borealis
Email: johannes.reuvers@basf.com
karl.hohenwarter@borealisgroup.com

NITROGEN MARKET OUTLOOK
Who will suffer and who will prosper?
Integer are delighted to give you free access to a recording of our outlook for the nitrogen market, which covers:

- The next phase of nitrogen pricing: what has changed?
- Developments in China: Integer’s previous forecasts and how they have been validated and proven correct
- Production costs or the supply-demand balance, which is more important going forward?
- Medium term outlook: who will suffer and who will prosper?

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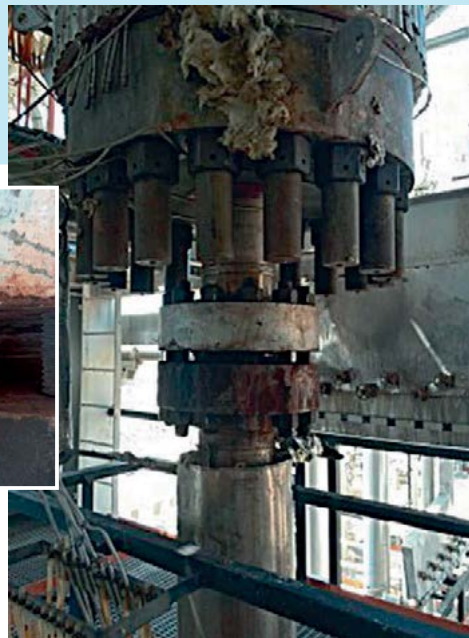
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Plant Manager+

Problem No. 41 Leakage of a high pressure flange connection

Among the many problems that threaten the daily operation of a urea plant, fluid leakage is perhaps the most common, especially the leaking of high pressure flanges in the urea synthesis section. A high-velocity jet emerging from a flange due to a failed gasket, a pinhole in an elbow, corroded threads of a level transmitter, etc., are familiar scenes that the maintenance crew encounters and must rectify.



Isa Norozi from Khorasan Petrochemical Company, Iran initiates this roundtable discussion: We are experiencing corrosion on the bolts of the high pressure flange in the HPCC liquid line to the urea reactor. 3 out of 12 bolts were corroded and we are going to replace these with new ones. The corrosion happened via a small leakage from the flange inside the insulation sheet. The process pressure inside the pipe is 145 bar and HSE groups have not given permission to replace the bolts. The bolts are close together. Does anyone have any experience or recommendations for replacement of this type of bolt during normal operation?



Mark Brouwer from UreaKnowHow.com, The Netherlands replies: There is only one course of action – stop the plant and replace the lens ring and bolts.

Prem Baboo from National Fertilizers Ltd, India offers his advice: It is not possible to replace the corroded bolts while the plant is running, it is very risky. It may be possible to stop the leak by clamping and applying a cold weld. Mechanical problems in early satellites have sometimes been attributed to cold welding. Our stripper bottom manhole cover flange has had leakages on many occasions and they were stopped by applying cold weld material. Furmanite is the worldwide innovator and leader in comprehensive on-site and on-line plant and pipeline maintenance. The Furmanite seal has been invaluable in keeping our unit up and running, please don't take any risk.

Isa Norozi from Khorasan Petrochemical Company, Iran provides more information: For your information, the very small leakage happened inside the insulation sheet but there is no longer any leakage from the flange. As you see in the pictures, one of the bolts was severely corroded and the others were slightly corroded. Can we continue in this way or do we need to replace them with new ones?

Mark Brouwer from UreaKnowHow.com, The Netherlands shares more experience on this topic: The fact that the leak has stopped does not mean the problem has been solved! On the contrary, carbamate will be present in the crevices between the lens ring and flange and as oxygen will be depleted, active corrosion will start. Only time is needed to cause a potential deadly failure. Please note that active corrosion occurs in stainless steel materials at rates of > 50 mm/y. The application of cold clamps and/or Furmanite on carbamate leakages is very risky for the same reason. One can never ensure that there will be no crevices where carbamate can be present causing active corrosion to stainless steel parts. I repeat, there is only one course of action recommended: Stop the plant and repair the leak.

Yudhistra Perdana Putra from PT Pupuk Kaltim, Indonesia shares his advice: The leakage may have stopped due to solidification of the urea carbamate solution. It may seem to have stopped but corrosion may still be occurring at the flange face of the HPCC. It is much too risky to keep the plant running.

Isa Norozi from Khorasan Petrochemical Company, Iran provides more information: Now that the leakage has stopped we have

seen small bubbles of gas escaping from two points of the flange, but not continuously. The insulation of the flange is open and the leakage is under visual check by operators and inspection groups and hasn't shown any sign of change up to now.

Mauricio Medici from M&M-CT Company, Argentina also shares his experiences: I agree with Mark and other colleagues here, leakage of HP equipment or lines, are always under discussion. Nobody wants to shut down the plant, especially plant managers, but although the leak appears to have stopped, corrosion may continue, as you mention this gas leak indicates that crevice corrosion in the lens rings/flanges is occurring (oxygen depletion), on the other hand carbon steel bolts are in great danger, and it's difficult to check the back side or the inner area of nuts.

The recommendation of performing a shut down soon is the best option, to avoid injuries and major loss. Try to keep the area clean of solid carbamate. Never replace bolts while the plant is running!

M Hassan from a fertilizer plant in Pakistan provides more advice: Keep the area clean on a daily basis. Apply steam at the location of the leakage so that build of carbamate does not occur

and you are not blinded. Maybe try slightly tightening if the leakage rises may help.

Don't replace the bolts while the plant is running. The condition of the bolts does not look too bad from the pictures (maybe close up it is a different story).

Never go for cold box up on this service and pressure. Whoever did it was very lucky to avoid a disaster.

Isa Norozi from Khorasan Petrochemical Company, Iran provides an update: Thank you for all your recommendations. We had a short shut down because of a gas compressor failure in the ammonia plant. During this time we have changed the bolts. Only one bolt was corroded on its outer face.

Syed Ali Salman Bokhari from Pak-American Fertilizers, Pakistan also shares his opinion: I must say "Nip it in the bud". Although it may be a painful decision, it is better to stop the plant and take the corrective actions as per standard operating procedures. A little production loss is much better than huge man and equipment loss.

Khalid Khattak from FFC Goth Machhi, Pakistan also comments: Box up is to be avoided in HP equipment. Don't do it.

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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Nitrogen+Syngas 2017

LONDON

CRU's Nitrogen+Syngas 2017 International Conference and Exhibition takes place in London at the Hilton London Metropole Hotel from 27 February to 2 March. As global nitrogen prices remain under pressure, the commercial programme will focus on the challenges and opportunities for the market. The technical programme will cover the full nitrogen value chain, including syngas, ammonia, urea, nitrates and finished fertilizers, with a particular focus on improving operational efficiency and enhancing performance and output.

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All urea melt and granulation licensors will be invited to present their latest innovations and revamp technologies, plus UreaKnowHow.com will present its top ten revamp tools.

Johnson Matthey is inviting operators to tour its state-of-the-art materials technology and catalyst development centre in Sonning, UK, where they will be able to discover more about Johnson Matthey's technologies in areas such as emission control, low carbon technology, fuel cells and electrochemistry, platinum group metals refining and advanced characterisation.

New for 2017, there will be 14 technical showcase presentations featuring advanced technologies and proven ways to improve operations.

Commercial programme

The commercial sessions of the conference will be held in the morning on Tuesday 28 February. CRU's Nitrogen team and invited guest speakers will provide insight and analysis, outlooks and price predictions for global gas, nitrogen costs, the European nitrogen market, as well as opportunities for nitrogen producers to address changing farmer needs for fertilizers, the effect of China's market-oriented transition in the fertilizer industry on Chinese producers and Euronext's nitrogen fertiliser solution UAN 30 futures contract.

Technical programme highlights

The technical programme takes place over 2½ days, from 28 February to 2 March. A selection of some of the topics that will be presented is highlighted below:

Syngas generation

Johnson Matthey Process Technologies will discuss the latest developments in gas heated reforming. Recent changes, especially in the energy sector, have prompted many to relook at the benefits of gas heated reforming when electrical power is increasingly being generated by renewable



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energy. Similarly where water resource is scarce, the use of a gas heated reformer can cut the raw water use by half. Johnson Matthey, building on the work of ICI, has continued to develop the gas heated reforming technology to the point where it is now beneficial in multiple areas of synthesis gas generation.

Three practical examples will be presented:

- Leading Concept Ammonia plant for the Midwest USA
- Ultra low emissions methanol plant for the North-West USA
- Syngas plant revamp for extended capacity in Far East Asia

Ammonia plant safety and reliability

Over the last two decades, mechanical integrity of rotating and process equipment has improved tremendously. Also the reliability of instrumentation and control systems has improved exponentially with better DCS and field instrumentation and by adopting SIL-2/SIL-3 redundancy.

Most plant incidents and accidents can be attributed to human-machine interactions or human errors. By incorporating the latest developments in IT, this gap can be filled effectively.

Fitiri has designed a secure and user friendly system that has been incorporated in a number of ammonia and methanol plants around the world using state of the art context-aware mobile technology. This system imposes discipline, uniformity in thinking and makes available the required technical information on-demand into the hands of a smart operator. Fitiri will explain how the system works and discuss routine and non-routine operations, on-demand technical information, improved plant safety with soft alarms, communication of operation and implementation

Secondary reformer incidents

Engro Chemical Pakistan and Johnson Matthey will be reporting on the robustness of a secondary reforming catalyst despite a series of major secondary reformer incidents that have taken place at a 1960s vintage ammonia plant. During plant start-up the process air compressor experienced a surge event, resulting in many repeated uncontrolled explosions within the secondary reformer. A detailed investigation was carried out and it was decided to unload the secondary catalyst to find the source of the problem. The observations were analysed and after catalyst inspection, unloading and screening the reloaded catalyst charge has proven to be in good condition in operation.

Within a year of the catalyst being reloaded, the catalyst bed was again removed and reinstalled, as refractory of the secondary reformer required complete replacement. More recently during 2010, due to a speed control issue in the air compressor gas turbine, excess process air was admitted causing over-heating, but still the catalyst bed continued to work fine in 2016.

Ammonia plant commissioning

KBR has commissioned six world scale purifier based ammonia plants over the past two years and will discuss the challenges and lessons learned from these recent plant start-ups, as well as technology options used to meet the energy and utility needs of the site complex. This includes the use of a gas turbine to drive the process air compressor versus the use of a steam turbine. Significant care must be given to the design of the steam system and how it affects the start-up and operation of the plant. There are many items to consider when designing an ammonia plant and the associated steam system including steam import and export options, the use of motor drives, steam header pressure and temperature, start-up boiler requirements and utility options. Another important topic that will be covered is the increasingly difficult environmental regulations and how they affect the overall design of the reformer and process condensate recovery system.

Emissions management

thyssenkrupp Industrial Solutions will be presenting experiences of the start-up of a new kind of scrubbing system in its first commercial application in a large urea granulation unit designed by Uhde Fertilizer Technology. The new design is a two-stage scrubbing system, installed in a common casing. The design avoids some drawbacks of vertical two-stage scrubbers, has the advantage of low pressure drop on the gas side and achieves lower than ever emission values. The paper describes the technology and gives some insights into what to consider with the handling of acid and spent scrubbing solution. It presents some complications brought to light during initial operation in 2015 and 2016, their solution in the plant and the lessons learnt for future projects.

Urea plant incidents

Fatima Fertilizer Company has explored data collected from major catastrophic accidents in urea plants worldwide over

the past 50 years and will present their analysis of the data. For each accident the root cause and lessons learned have been identified. Major incidents included:

- explosion in scrubber vapour line;
- reactor rupture;
- HP pump failure;
- HP piping failure;
- explosion in ammonia water tank;
- rupture of stripper bottom.

Nitric acid technology

Messer Group will be introducing "Oxyboost Technology", a new concept for improving the absorption efficiency of nitric acid plants. This concept uses pure oxygen for the oxidation of nitrous acid (HNO₂) and nitrous gases in the liquid phase and/or gaseous phase. Ten industrial test runs at five different nitric acid plants have been carried out and led to the conclusion that the appropriate choice for introduction point and entry system is decisive for its successful application.

Advantages of Oxyboost technology include:

- reduction of NOx emissions;
- less shut-down time;
- additional production (proportional to the improved absorption);
- less ammonia needed for the DeNOx;
- DeNOx will be easier to operate because of smoother operation;
- low investment costs;
- Messer Group has all the equipment needed for trials and delivers a full custom-made package for fixed installations after proving the viability;
- capacity increase of nitric acid plants (up to 10% possible).

Urea granulation technology

Uhde Fertilizer Technology will be discussing the benefits of a newly developed, formaldehyde-free additive for urea granules. The new additive shows a product quality and a granulation performance which is at least as good as the benchmark urea formaldehyde (UF) but is not harmful to health or the environment, since it consists of components which are biodegradable and are allowed to come into contact with food. Additionally the application of the alternative additive makes it possible to utilise the same urea granules for fertilizer, technical and DEF applications. This extends the range of application of urea granules and drastically reduces the efforts with regard to logistics for all producers of multiple urea grades.

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Sourcing gas in Europe

Lower gas prices have eased the cost burden on European ammonia producers, and while Europe remains dependent upon imports from elsewhere, creeping liberalisation of gas markets is continuing to promote gas on gas competition and remove long term contracts linked to oil.

Europe's ammonia and methanol industry has been through some tough times over the past couple of decades, facing continually increasing competition from lower gas cost locations overseas at the same time that European gas prices tended to be among the highest in the world. However, in the wake of the oil price collapse, changes that had already been working their way through European gas market seem to have been accelerated, leading to a very different gas price environment for producers.

Production

Europe has been producing natural gas for many years. Most of the continent's supply used to come from the Netherlands and fields in northwest Germany and extending offshore, joined from the 1970s onwards by fields in the UK North Sea, and gradually moving northwards during the 80s and 90s into the northern North Sea and Norwegian Sea. However, these gas reserves have progressively become exhausted over the years, as demand has grown, and today only Norway is left with significant gas reserves, at around 1.9 trillion cubic metres (tcm). As a result, Europe's largest gas producer by some way is still currently Norway, with output of 117 billion cubic metres (bcm) in 2015, according to BP figures. Within the EU, the Netherlands produced 43 bcm the same year and the United Kingdom (which is at least for now in the EU – more on that later) 39.7 bcm. Other producers, like Romania, Germany, Italy and Denmark, are responsible for only 5-10 bcm each. UK gas output has been in long-term decline for many years, in spite of technological advancements which have prolonged the life of some fields, and UK gas output halved from 2005-2015, from 88 bcm to 40 bcm. It actually bottomed out in 2013 at 36.5 bcm and there has been a slight uptick since then, but with investment levels low in the wake of the

current decline in oil and gas prices, lower production is forecast for 2017-20. In the Netherlands, gas output has been relatively stable for some years, but dropped precipitately after 2013 from 69 bcm to 43 bcm in 2015, and most recent figures indicate Dutch output halved again in 2016, lowering EU gas production by 24% overall in spite of some increases in the UK and Ireland (the new Corrib field). In the case of the Netherlands, production is not falling for technical reasons, but rather a government decision to cap production from the main Groningen field at 27 bcm in 2015 and 24 bcm in 2016 out to 2020 (with a possible 6 bcm increase during cold snaps) because of increasing seismic activity associated with the field's depletion.

Overall, EU gas production has been on a long slow slide for many years. Potential sources of new production are relatively few. There is some new production in Ireland, but the Corrib field will only produce about 3 bcm per year, and there is exploration and development under way in the Black Sea offshore Bulgaria, Romania and Turkey, where the Neptun Deep for example has an estimated 42-84 bcm of gas in place. In the Eastern Mediterranean, there have been new gas discoveries off Cyprus, at the Aphrodite Field, but most of the gas is in areas owned by Lebanon, Israel and Egypt. Nevertheless, IHS has suggested that the region as a whole may have as much gas as offshore Norway.

Poland has drilled 70 or more shale gas wells, but the expected bonanza there failed to materialise as the geology proved much more difficult than expected. Shale gas exploration has slowed down; major operators have left, and there are only three national companies left exploring for shale gas. Only two shale gas wells were drilled in 2015. Within the EU, where many countries have banned fracking, only the UK is left as a major proponent, and there, in spite of government enthusiasm, there

Table 1: European gas market 2015, billion cubic metres

EU gas production	138
Of which:	
Denmark	5
Germany	7
Italy	6
Netherlands	48
Poland	4
Romania	10
United Kingdom	40
EU gas consumption	445
Imports from outside EU	307
Of which:	
Algeria	33
Nigeria	6
Norway	108
Qatar	25
Russia	123

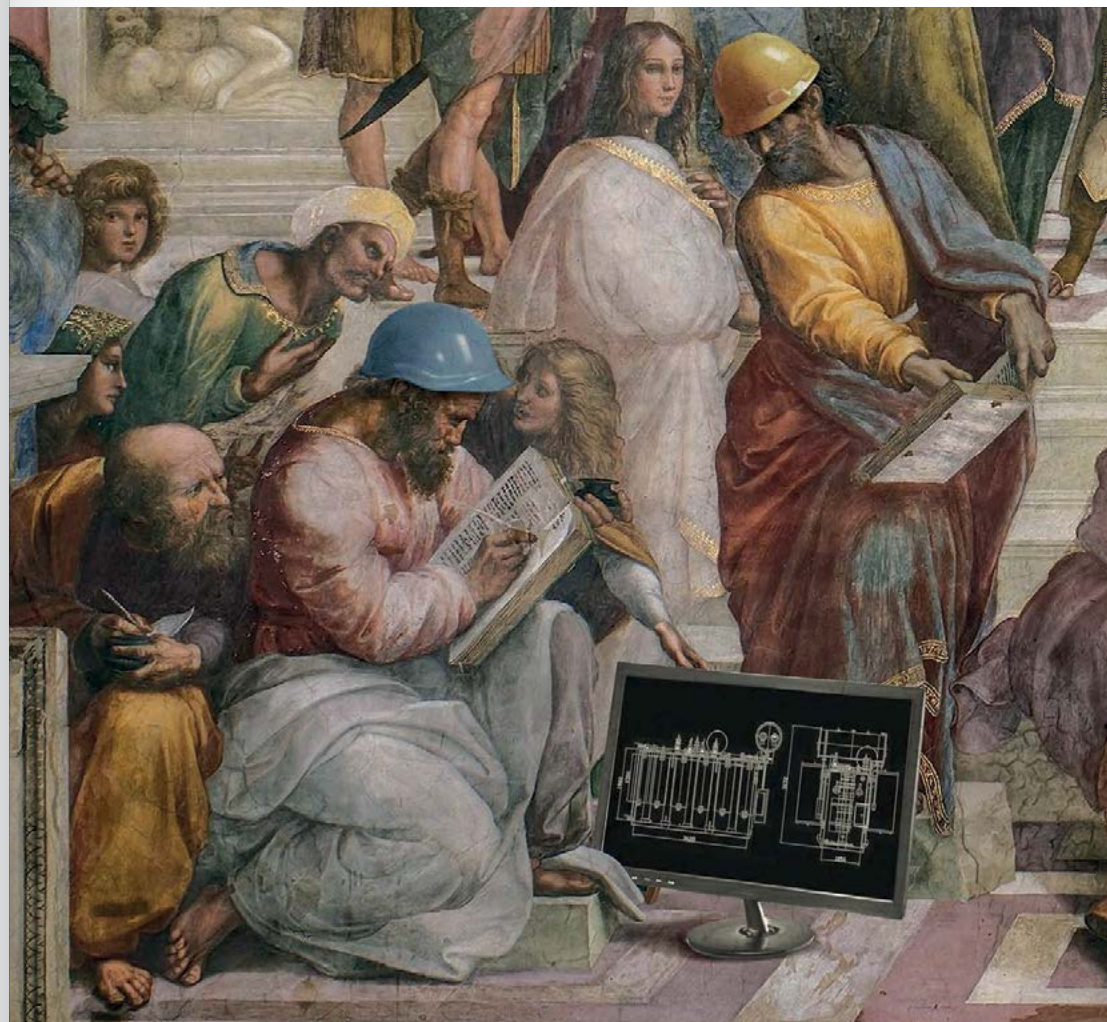
Source: BP

has been considerable local opposition and long and arduous planning and permitting processes, and a moratorium from 2011-16 due to seismic activity from the first wells. Although there is now renewed licensing activity, the low gas price environment will probably make UK shale gas uneconomic for the time being.

As to Norway, production has plateaued at around 115-120 bcm per year, and is forecast to remain at around that level for the foreseeable future, at least out to 2025.

Consumption

European gas production is in decline, but consumption continues to be variable. It had been increasing steadily, driven mainly by gas use for power production, as restrictions intensified on coal-based capacity due to its higher CO₂ output, and there was a lack of enthusiasm for replacing ageing nuclear plants because of concerns over



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waste disposal. In spite of heavy competition from renewables, especially wind power, gas-based electricity production continued to increase. However, high oil and gas prices and a flood of cheap US coal knocked onto the world market by US coal-fired power production switching to cheaper shale gas meant that for a few years coal-based power production was favoured, and EU gas consumption fell from 2011-2014, to a low of around 405 bcm. Since then, however, the global fall in the price of oil and gas, and more coal-based power plant closures for environmental reasons have boosted gas demand once again, up to 447 bcm in 2016 for the EU-28. Demand in France also rose sharply towards the end of 2016 as French nuclear power stations were taken offline for safety checks.

Gas demand is relatively price insensitive outside the power sector, but within the power sector the main switching tends to be between gas and coal, where there is up to 50 bcm of capacity which can switch between the two, depending on price. Demand is also not evenly spread across the EU; 80% comes from seven western European countries: Germany, UK, Italy, France, Netherlands, Spain and Belgium. Just 12% of gas demand comes from seven Central and Eastern European countries (Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia). This means that the majority of Europe's gas demand occurs in countries with strong energy efficiency and renewables programmes in place, which may further decrease demand in future.

Imports

The growing disparity in gas production and consumption means that the EU currently imports just over two thirds of its gas requirements. Natural gas dependency in EU-28 was 69.3% in 2015, slightly up from 67.4% in 2014. Virtually all countries are net importers – only Denmark and Netherlands are net exporters. In 18 Member States, energy dependency is higher than 90%.

Traditionally, the largest supplier has been Russia. However, this has always been a fractious relationship, mainly due to Russia's ongoing dispute with Ukraine, which has continued pretty much since the breakup of the former Soviet Union.

Ukraine was the transit point for most Russian gas reaching Europe, and Russian-Ukrainian gas disputes over gas siphoned from pipelines or not paid for by Ukraine led to supply interruptions in the 1990s, and again in 2005-6, 2007-8 and 2008-9 – the latter three all leading to European supply disruption. These gas crises led to responses by both Russia and Europe – on the Russian side, new supply pipelines were constructed which by-passed Ukraine, including Nord Stream across the Baltic and Blue Stream across the Black Sea. On the European side, meanwhile, it led to an attempt to diversify sources of supply away from dependence on Russian gas. The chief beneficiary of this has been Norway, which has seen its share of EU gas supply rise to 30% in 2015, as compared to 40% from Russia's Gazprom (some of this direct, some via Belarus or Ukraine).

The situation has been exacerbated by the "Orange Revolution" in Ukraine in 2014, which saw pro-Russian president Victor Yanukovich forced into exile and a pro-western government installed. Russia's reaction was to encourage separatists within Ukraine, leading to a low-level civil war in the east of the country and Russian annexation of the Crimean peninsula. Gas became a critical weapon in the dispute, with gas supplies from Russia to Ukraine cut off in 2014 and again in 2015.

Other major suppliers to the EU include Algeria, which supplies about 15% of Europe's gas, most of it by pipeline to Spain and Italy, but also some as liquefied natural gas (LNG). The EU has begun to import increasing volumes of LNG as part of its diversification strategy, with supply in 2015 coming mainly from Qatar, but also from Algeria, Nigeria, Trinidad and even Peru. The United States joined these countries in 2016, with a cargo to the UK.

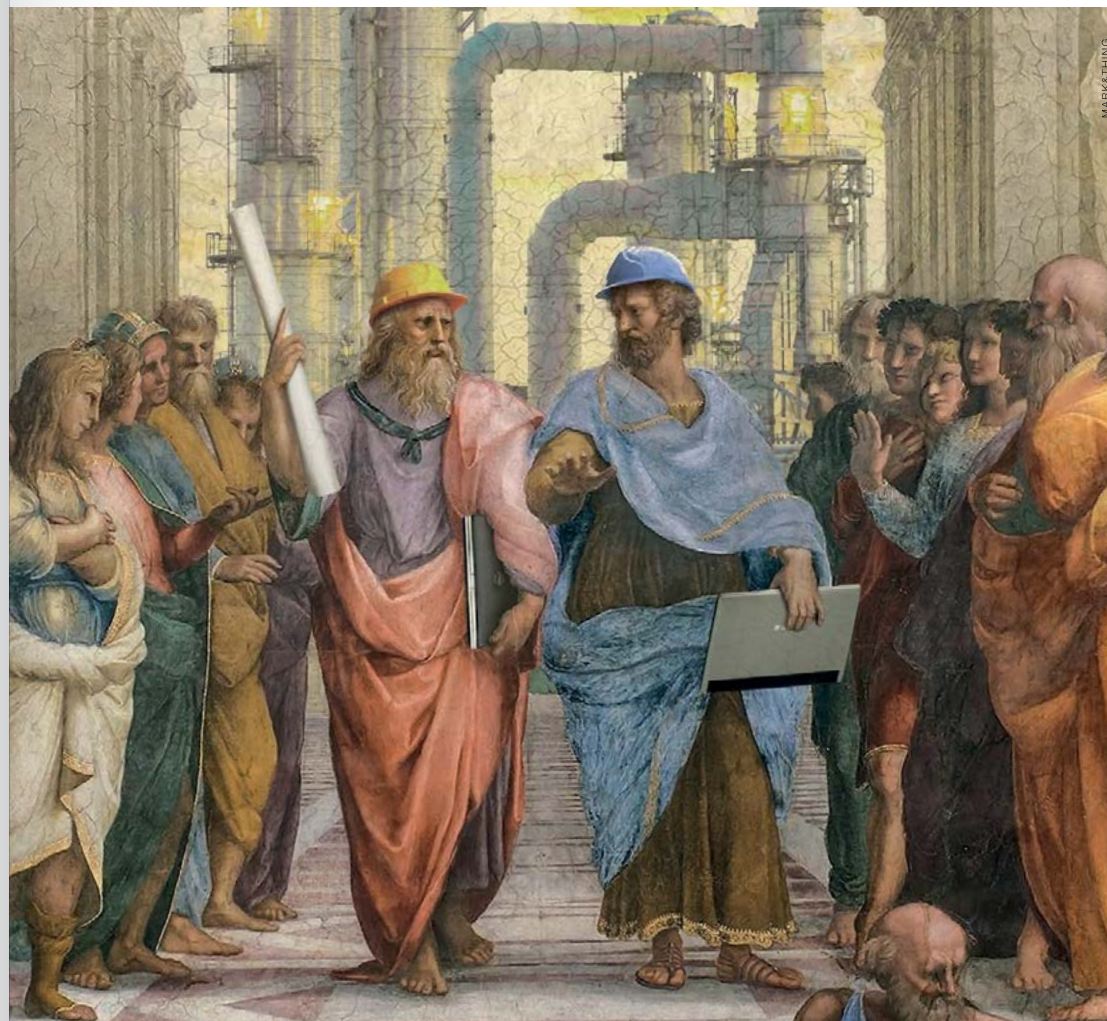
The LNG market has been in surplus for a couple of years, a factor which has helped drive down LNG prices and reduce the incentive to sign up to long-term, fixed price contracts, and 2017 is set to be no different. Global LNG supply increased by 23 bcm in 2016 and there are considerable new volumes of LNG supply due to come on-stream from the US and Australia, with a total of 35 bcm of new capacity due to start up this year. Even though liquefac-

tion plants can take up to six months to ramp up to 90% capacity, and there have been delays at some projects like Gorgon and Sabine Pass, the high volumes of LNG on the market will be a boon for European customers who are seeking to diversify sources of supply. Regasification capacity in the EU and Turkey now comprises 25 terminals with 216 bcm of capacity, representing potentially up to 40% of EU demand or 55-60% of EU imports, and this has been a game changer for negotiations with other suppliers like Gazprom. Additional flexibility has been added by increasing interconnectivity between European pipelines, which allows for reverse flow options (such as the EU gas flow back into Ukraine in 2014-15 when Gazprom supplies were cut).

Contracts and pricing

In Europe, prices used to be mainly set via oil price escalators, but GoG is spreading as the EU liberalises its internal gas markets. The International Gas Union calculated that in 2015, 60% of European gas was traded as GoG, with trading hubs like the UK National Balance Point (NBP) and Zeebrugge now setting prices across the continent. Oil price-linked contracts by contrast now account for only 30% of gas bought in Europe, with GoG steadily spreading from the more liberalised markets of northwest Europe into central and even eastern Europe. The main holdout for oil-linked contracts is now in Mediterranean countries. Gazprom's supply contracts have traditionally been oil-indexed, 'take or pay' contracts at fixed volumes, with very little flexibility to respond to changes in price or demand, and LNG has likewise often in the past been supplied via long-term, oil indexed contracts. However, the growth of a spot LNG market and European gas trading hubs, especially at the UK National Balance Point (NPC) and the Dutch Title Transfer Facility (TTF), have increased the proportion of gas traded as 'gas on gas' competition, and Norwegian gas, increasingly important to Europe, also tends to be more flexible both in terms of volume and pricing.

Energy industry consultancy Timera Energy have argued that 2016 saw a "tipping point" in terms of pricing and availability which has encouraged switching out of oil-indexed contracts towards more gas on gas competition. A combination of strong Norwegian production and rising LNG



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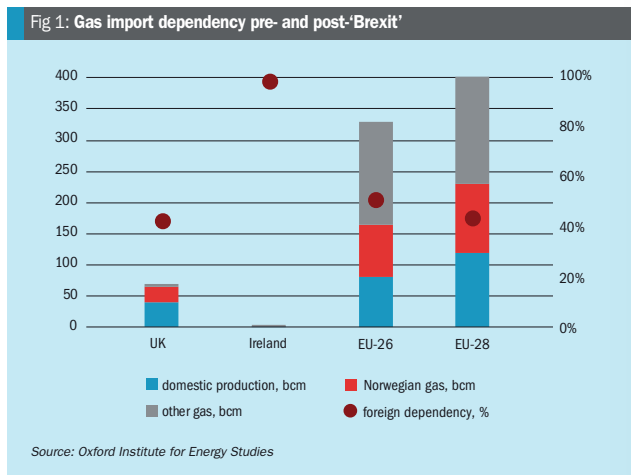
imports have pushed oil-indexed contract prices away from their traditional price-setting role, as increased supply at hubs has let hub prices (around \$4.00/MMBtu) fall below oil-indexed contract benchmarks (\$4.50+/MMBtu). With hub prices at a discount to contract prices, suppliers are incentivised to reduce contract volumes to take or pay levels. Timera suggest that price support may only come once hub prices drop so low that it is no longer worthwhile for US LNG capacity to be sent to Europe, and once there is large-scale switching from gas to coal by power producers. With coal prices at around \$3.80-3.90/MMBtu, coal is no longer the attractive option it was a couple of years ago.

This could see European hub prices converge towards Henry Hub prices – a novel situation for Europeans, who have got used to high gas prices. Not since deregulated UK gas prices in the 1990s dropped to \$2.00/MMBtu has there been such a situation in Europe, and at the time those low prices led to the so-called “dash for gas” by the UK power industry and even proposals for a methanol plant to be built at Grangemouth in Scotland.

Increased interconnectivity has also led to a gradual erosion of price differentials across the continent. Natural gas prices in the Czech Republic have already converged with German gas hub prices and this trend is expected to continue with the development of interconnectors in other less connected nations in southeastern Europe. In 2014, for example, Czech wholesale gas prices were 28% higher than Dutch TTF trading hub prices, but in 2016 this differential was less than 1%.

Gazprom

The other major variable for European gas prices is its largest supplier, Russia’s Gazprom. In spite of the uneasy relations between Europe and Moscow, Gazprom’s supplies to European consumers have in fact been increasing recently, and set a new record in 2016. In 2015, Gazprom delivered 158 bcm of gas to Europe and Turkey, and in 2016 this rose by 12% to almost 180 bcm, of which the EU-28 represented 153 bcm. This also accounted for 75% of Gazprom’s overseas sales. This clearly shows that European customers are not afraid to buy from Russia if the price is right. While Gazprom does not disclose the prices it charges its European clients, it did reveal that its average European gas price was

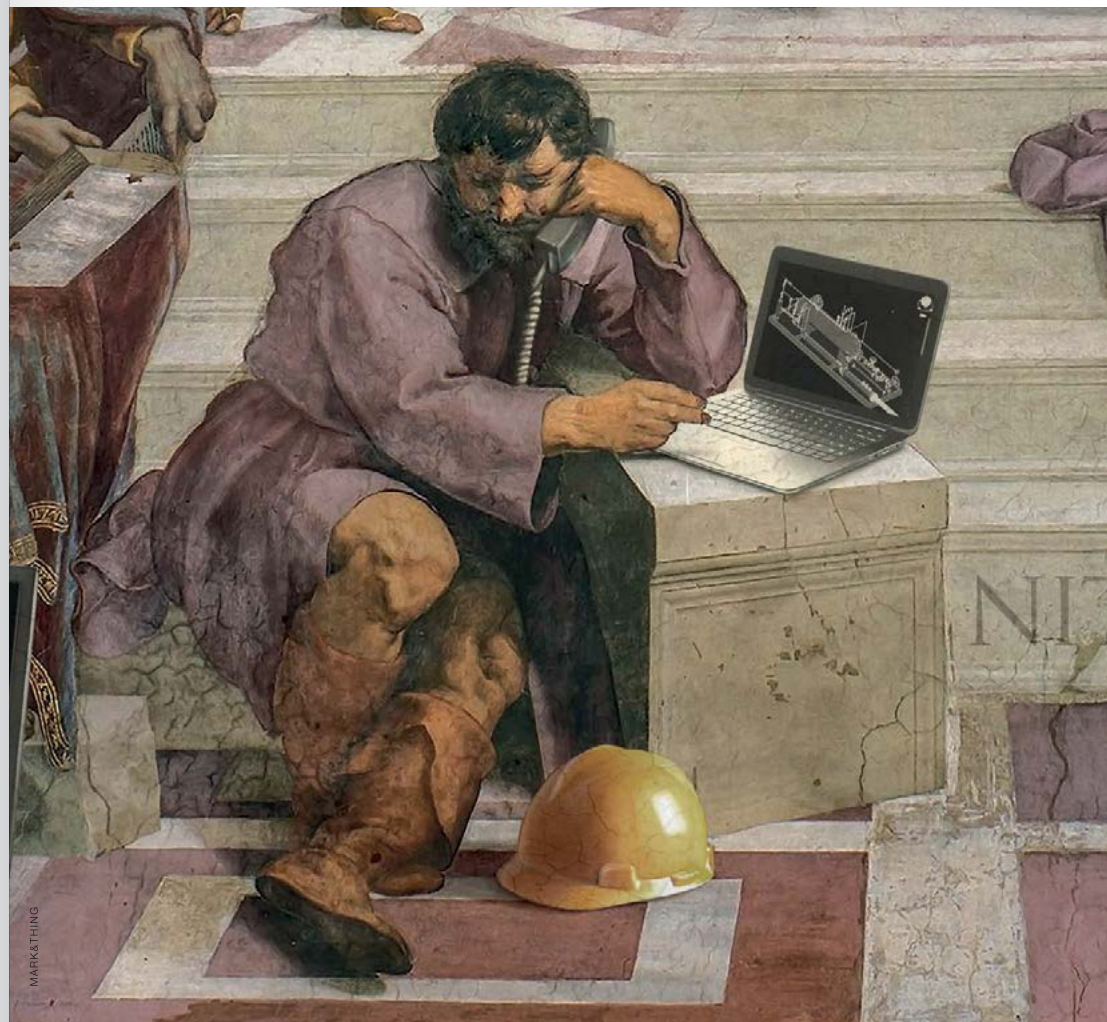


\$5.00/MMBtu in the first half of 2016, and its average price for the whole of 2016 is estimated at around \$4.55 – 4.70/MMBtu; comparable to or even lower than European spot prices. In May 2016, the German border price, which is heavily dependent on Gazprom supply, went as low as \$4.00/MMBtu, or around 20% below UK NBP prices the largest gas trading hub in the EU. Compare this to NYMEX prices of \$3.33/MMBtu at the same time, and it seems clear that, once regasification and transportation costs are included, there is little room for US LNG in the European market at such prices. It also seems to indicate that Gazprom has given up on its strategy of trying to force up European prices and keep oil-indexation and instead has been prepared to drop to prevailing market rates in order to keep market share. The company has also shown a willingness to bend to EU market regulators – in December it submitted proposals to settle a long-running anti-trust case with the European Commission. Although the nature of the offer was not disclosed publicly, Gazprom said that the proposal addressed EU concerns “to the extent it is reasonable and possible”. These concerns have centred on three issues: contract terms preventing cross-border gas sales; tying gas supply to pipeline investment; and unfair gas pricing to Bulgaria, Estonia, Latvia, Lithuania and Poland. Gazprom has already removed contract restrictions on re-selling gas and linkages to gas pipelines, leaving gas pricing to central and eastern Europe as the main outstanding issue.

Brexit

The other major variable for Europe’s gas industry and markets is what happens once the UK leaves the European Union, probably some time in 2018. Figure 1 shows EU and UK/Ireland gas import dependency. While Ireland will remain in the EU, in spite of new production from Corrib its gas is and will be almost exclusively supplied by the UK, which in turn imports gas from Norway and from continental Europe. While Brexit does not make much difference for the EU in terms of gas dependency – comparing the EU-26 and EU-28 columns in Figure 1 – the difference for the UK is a considerable one, and will very much depend on the kind of relationship that the UK is able to negotiate with its former EU partners – so-called ‘hard’ or ‘soft’ Brexits. A ‘hard’ Brexit could for example turn the NBP into a minor ‘offshore’ regional hub rather than the important international trading hub that it is now, with price setting moving to the Dutch TTF hub. The UK also has quite low storage capacity compared to demand, with Centrica’s Rough facility accounting for 70% of UK storage, which can hold only 4.5% of UK annual demand, and whether it has easy access to EU gas storage is an important question. Whether the UK has to pay additional transit or border charges for example could also significantly impact upon gas prices. At the moment there are no clear indications which way the negotiations will go – both sides have, perhaps unsurprisingly, talked tough in advance of

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them, but until talks begin later this year it is difficult to predict how much of this is posturing/pre-positioning.

However, the UK also has four operational LNG terminals – South Hook and Dragon at Milford Haven in west Wales,

the Isle of Grain in the Thames Estuary, and Teesside Gasport in the northeast. Two other terminals exist but have been closed down or converted. The two largest are South Hook and Grain, each with about 15 million t/a of capacity, while Dragon

can handle about 4 million t/a. Teesside can take floating storage and regasification vessels, but is rarely utilised. In 2015 the UK imported 10 million tonnes of LNG, 20% up on 2014, and accounting for 13% of UK gas supply, but it has the potential to import up to 45% of its supply as LNG, or about 80% of its imports. There is also talk of increasing LNG capacity at the Isle of Grain by another 6 million t/a. The UK is already Europe's largest LNG importer, and this flexibility could help with negotiations and the country's gas situation in the future as North Sea supplies continue to dwindle.

Methanol and ammonia

While there are only five methanol plants left in Europe, most of which operate on non-gas feedstocks (e.g. petroleum coke at Leuna or glycerine at Delfzijl), as Table 2 shows, Europe – the birthplace of the modern ammonia industry – still has a considerable number of ammonia plants, with a combined capacity of just over 19 million t/a. Actual production runs slightly below this – in 2014 it was 16.8 million t/a according to IFA figures, for a highly creditable on-stream factor of 87%. While there are still a number of smaller units, the combination of years of higher gas prices and increasing environmental regulations has shaken out the less profitable units and left those who have invested in cleaner and more efficient production, integrated into larger chemical complexes where price risk can be spread over several products. Proximity to end use markets also leads to more competitive transport costs. The current fall in European gas prices towards US levels has eroded the relative competitiveness of regions like the Middle East, and European producers currently seem to be well placed. ■

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Table 2: European ammonia capacity

Country	Company	Site	Capacity
Austria	Borealis	Linz	500,000 t/a
Belgium	EuroChem	Antwerp	590,000 t/a
	Yara	Tertre	400,000 t/a
Bulgaria	Neochim	Dimitrovgrad	410,000 t/a
Croatia	Petrokemija	Kutina	450,000 t/a
Czech Republic	Chempetrol	Litvinov	350,000 t/a
Estonia	Nitrofert	Kohtla-Jarve	165,000 t/a
France	Borealis	Grand Quevelly	380,000 t/a
	Borealis	Grandpuits	380,000 t/a
	Borealis	Ottmarsheim	215,000 t/a
	Yara	Le Havre	400,000 t/a
Germany	BASF	Ludwigshafen	800,000 t/a
	Ineos	Cologne	300,000 t/a
	SKW Piesteritz	Piesteritz	1,100,000 t/a
	Yara	Brunsbüttel	750,000 t/a
Greece	ELFE	Nea Karvali	165,000 t/a
Hungary	Nitrogenmuvek	Petfurdo	545,000 t/a
Italy	Yara	Ferrara	600,000 t/a
Lithuania	Achema	Jonavos	990,000 t/a
Netherlands	OCI	Geleen	1,100,000 t/a
	Yara	Sluiskil	1,900,000 t/a
Norway	Yara	Porsgrunn	500,000 t/a
Poland	Anwil	Wloclawek	500,000 t/a
	Grupa Azoty	Police	1,200,000 t/a
	Grupa Azoty	Kedzierzyn	180,000 t/a
	Grupa Azoty	Pulawy	280,000 t/a
	Grupa Azoty	Tarnow	380,000 t/a
Portugal	Amoniac de P	Lavradio	250,000 t/a
Romania	Amonil	Slobozia	300,000 t/a
	Azomures	Targu Mures	470,000 t/a
	Interagro	Donau	330,000 t/a
Serbia	HIP Azotara	Pancevo	300,000 t/a
Slovakia	Duslo	Sala Nad	430,000 t/a
Spain	Fertiberia	Palos	370,000 t/a
	Fertiberia	Puertellano	200,000 t/a
UK	CF Fertilizers	Billingham	500,000 t/a
	CF Fertilizers	Ince	350,000 t/a
	Yara	Hull	300,000 t/a
Total:			19,330,000 t/a

Source: BCInsight

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Carbon reduction and the nitrogen industry

In the wake of the Paris Agreement on climate change, is it possible for there to be a level playing field for energy-intensive industries like ammonia production?

In spite of some very notable sceptics, such as President Trump and many in his new administration, the escalating risk posed by man-made climate change has focused minds worldwide on trying to limit emissions of carbon dioxide and other greenhouse gases. Nearly a third of the world's energy consumption and 36% of carbon dioxide (CO₂) emissions are attributable to manufacturing industries. The large primary materials industries, i.e., chemical, petrochemicals, iron and steel, cement, paper and pulp, and other minerals and metals, account for more than two-thirds of this amount, and within the chemicals sector, the nitrogen fertilizer industry has attracted particular scrutiny because of the energy-intensive nature of ammonia production.

Kyoto

Moves to tackle man-made sources of carbon dioxide culminated in the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). This set a series of binding targets for 2008-2012 and 2013-2020 for the reduction of CO₂ emissions relative to the baseline year of 1990. Although the Protocol has been criticised for leaving out international shipping and aviation (because of difficulties in managing where the emissions occurred) and focusing on developed rather than developing countries where emissions were rising fastest, it was nevertheless the first global agreement to limit emissions.

Three main 'flexibility mechanisms' were identified for controlling emissions: emissions trading schemes (ETS), the Clean Development Mechanism (CDM), and Joint Implementation (JI). CDM and JI projects make the developer eligible for UN Certified Emission Reduction (CER) credits

('carbon credits'), which can count towards their emission reduction limits, be sold to companies to comply with their limits, or be traded on accredited emissions trading schemes. CDM projects were in effect those that took place in 'Annex 1' (more developed) countries which were signatories to the Protocol, while JI projects were in developing nations not bound by the Protocol. Examples within the nitrogen industry have been the installation of CO₂ recovery systems at ammonia plants to capture and feed extra CO₂ into downstream urea or methanol production.

Emissions trading schemes, or so-called 'cap and trade', were intended as a way to bring a market incentive to reductions in carbon emissions by putting a price on each tonne of CO₂ emitted. Governments allocated carbon credits to the scheme, with a decreasing cap on their number, and emitters could then purchase a 'right to emit' above a baseline level, in theory giving them a financial incentive to reduce emissions. The largest such scheme was implemented by the European Union. The EU Emissions Trading Scheme covered 11,000 major emitters across all 28 member states, representing the most intensive 45% of EU greenhouse gas emissions. However, the scheme attracted criticism by setting the number of credits too high, meaning that the price of a tonne of CO₂ equivalent – which had been envisaged at around €30/tonne – fell to only a few euros (<€3/t at one stage), and the incentive for polluters to reduce emissions was far smaller than intended. Over the past few years there have been various EU attempts to reform the scheme, and prices have briefly spiked towards €10/tonne of CO₂ equivalent before falling back to €5-6/t. The market remains oversupplied with carbon credits and is likely to do so for several more years.

Carbon taxes

An alternative to the complications of an emissions trading scheme is to simply tax the number of tonnes of CO₂ produced. This was initially the method favoured by the EU, and it only moved to the ETS after attempts to enact a 'carbon tax' failed to gain the required unanimous approval among member states. A similar scheme was also proposed in the US but again has failed to win the support of lawmakers. The major issue with such a tax is where responsibility for the emissions is allocated – on the producer or the consumer? Some carbon taxes have nevertheless been imposed, for example on flights through EU airspace, or on EU vehicle fuels. Some EU states like the UK have also imposed carbon taxes on power generation, and Sweden taxes consumers on the carbon value of goods. Other nations which have imposed carbon taxes include Chile, Ireland and – between 2012 and 2014 – Australia.

Some economists recommend a hybrid model that combines a cap on emissions (to regulate the quantity of pollution), with adjustment mechanisms such as a carbon price floor or ceiling, to keep the price of a permit within acceptable bounds. Hybrid schemes have their own problems, however, such as greater complexity and more intervention by the regulator in the permit market.

Carbon leakage

The fear which has led to over-allocation of permits and the failure of the EU emissions trading scheme has largely been driven by concern over the potential for so-called 'carbon leakage', whereby high prices for carbon credits in one region drive the industry to move to another region where there is no such restriction; in the

case of Europe, driving it to, for example North Africa, the Middle East or CIS. The effect of the policy would therefore not have been to reduce overall global emissions of CO₂, merely to shunt them from one place to another. Indeed, Fertilizers Europe have argued that, as European ammonia plants are some of the most energy-efficient in the world, the net effect could be to increase global CO₂ output; a 2015 study¹ showed that the fertilizer industry was one of those most at risk of carbon leakage because it has both high intensity of emissions and high intensity of trade, making it difficult to pass on costs to end-users (as they could simply buy in fertilizer from elsewhere).

Paris Agreement

With the Kyoto Protocol only scheduled to last until 2020, as that date approached there was considerable pressure to negotiate a successor to it, based on new knowledge that had been gained since Kyoto had been signed, as well as new realities, such as China becoming the world's largest emitter. Chinese moves to limit its own GHG emissions and a willingness by the Obama Administration in the US to compromise on some key issues helped the agreement of a global agreement at the 21st Conference of Parties ('COP 21') to the United Nations Framework Convention on Climate Change (UNFCCC), which was held in Paris in November 2015. The framework agreement was formally ratified on November 4th 2016, one month after the date that the required 55 signatories to the agreement, representing more than 55% of global carbon emissions, had individually ratified the treaty. The current ratification status is 128 out of 197 signatories to the agreement.

According to the UN: "the Paris Agreement builds upon the [1992 Rio] Convention and – for the first time – brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects, with enhanced support to assist developing countries to do so... [its] central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C. Additionally, the agreement aims to strengthen the ability of countries to deal with the impacts of climate change. To reach these ambitious goals, appropri-



The converter from BASF's first ammonia plant, built in 1913.

ate financial flows, a new technology framework and an enhanced capacity building framework will be put in place, thus supporting action by developing countries and the most vulnerable countries, in line with their own national objectives."

The Paris Agreement sets nationally determined contributions (NDCs) for all of the signatory states to reduce carbon emissions, and all parties must submit strategies for tackling this. Unlike the Kyoto Protocol, the Paris Agreement is not considered to be legally binding, which allowed the US to ratify without going back to Congress for approval, as part of a joint declaration with China last year. However, the future of the agreement under a Trump presidency remains open to doubt.

The nitty gritty of the agreement comes in Article 6, which outlines the methods and approaches that signatories can take in achieving their NDCs. It establishes a framework to govern international transfer of 'mitigation outcomes', allowing signatories to use emissions reductions outside of their own jurisdiction toward their NDC, in a system of carbon accounting and trading. In effect it requires the linkage of various ETS

systems to avoid double counting – transferred credits must be recorded as a gain of emission units for one party and a reduction of emission units for the other. There is also what has become known as the 'sustainable development mechanism' (SDM) as a successor to the CDM after 2020 "to contribute to the mitigation of greenhouse gases and support sustainable development". The SDM will resemble the Clean Development Mechanism, but will focus on sustainability as well as GHG emission reductions.

NDCs

The nationally determined contributions are the backbone of the agreement and set the targets that each country has voluntarily agreed to reach. China has agreed to achieve peak CO₂ emissions by 2030 at the latest, and to lower CO₂ emissions per unit of GDP by 60-65% below the 2005 level at that time (by 2014 it had already achieved a 33% reduction). It has also agreed to increase its non-fossil fuel share of energy consumption to 20%. The USA has set a target of a 26-28% reduction in emissions compared to 2005 by 2025. Courtesy of its switch from coal to gas-based power generation due to cheap shale gas, the US is already well on course to achieving its interim target of a 17% reduction by 2020. India declared a voluntary goal of reducing emissions intensity of its GDP by 20-25% over 2005 levels by 2020, and by 30-35% by 2030. The EU has committed to reducing its GHG emissions to 20% below 1990 levels by 2020 and 40% by 2030. However, there are notable holdouts – Russia for example, although it is a signatory to the Paris agreement, has not ratified it, nor has it so far submitted its NDC targets.

The nitrogen industry

What does this mean for the nitrogen industry? As noted earlier, the nitrogen industry comes under scrutiny as a GHG emitter via two main processes – the production of ammonia, and the conversion of ammonia to nitric acid. Ammonia production is an energy-intensive process which generally involves generating hydrogen from the partial combustion of fossil fuels – natural gas, coal, naphtha or petroleum coke. It represents the vast bulk (ca 90% according to IFA) of the 1.2% of global energy consumption represented by the fertilizer industry. The nitric acid industry, meanwhile, has been under scrutiny

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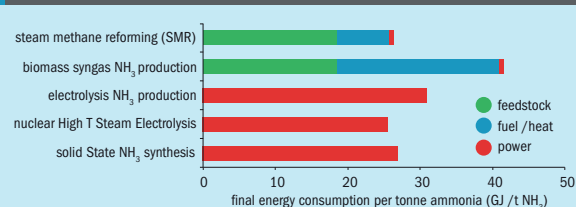
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Fig 1: Final energy consumption of steam methane reforming compared to potential substitute technologies



Source: CEFIC (2013)

because of the release of nitrous oxide (N₂O) in the production of nitric acid from burning ammonia, since N₂O has a global warming potential up to 300 times that of CO₂. While low carbon prices did have a knock-on effect on CDM and JI projects based around N₂O reductions, a price of around €5/tonne is just about sufficient to make an N₂O reduction scheme viable, as N₂O is relatively easily abated via catalytic systems either at the point of production or as tail gas treatment clean-up, and from 2003-2014 N₂O emissions from nitric acid plants in the EU fell by 87%, and the carbon equivalent emissions from nitric acid plants dropped to a fraction of that from ammonia production. The focus is thus likely to move toward curbing emissions from ammonia production in the years ahead.

But some have argued that this focus on the production process rather than the life cycle of fertilizers ignores other effects, posi-

tive and negative. Nitrogen fertilizer application and conversion into plant nutrients also releases N₂O and, in the case of urea, CO₂, and nitrogen applied in excess of crop needs is particularly susceptible to loss. Optimising use efficiency is the best way to prevent such emissions, and nitrogen use efficiency (NUE) has increased by 45% in Europe since 1985, according to Fertilizers Europe, though there is still scope for improvement. The International Fertilizer Industry Association (IFA) and partner organisations around the world are focusing on reducing emissions at the field level by encouraging the so-called '4R' strategy – applying the right fertilizer source, at the right rate, right time, and right place.

Finally, set against all this is the CO₂ removed from the atmosphere by increased plant growth, although this is temporary as the plant is then harvested and used. Nevertheless, Fertilizers Europe

has shown that CO₂ removed due to the use of fertilizers on grain can be a factor five to seven larger than the greenhouse gases emitted due to the production and use of these fertilizers.

Remediation techniques

An updated report prepared by Ecofys in 2015² looked at ways of reducing carbon emissions in the ammonia industry, focusing on three main areas; efficiency improvements, alternative feedstocks, and carbon capture and storage (CCS). The report concludes that CCS holds the best promise of large-scale reductions in CO₂ emissions, but admits that this assumes that cost-efficient techniques can be developed. Carbon dioxide is an acidic gas, requiring corrosion-resistant steels to handle it at high pressure, and scale-up of the amine solvent-based systems used for its capture is also problematic. For the moment, aside from some success in enhanced oil recovery (EOR), CCS remains an unproven and expensive technology.

The report also examined alternative feedstocks, but did not find them substantially better than natural gas-based steam reforming. For syngas produced from biomass, for example, energy use is higher than for steam methane reforming, as shown in Figure 1, as well as being less economically viable. If sufficient biomass-derived methane (biogas) was available, this would be an improvement. Electrolysis of water likewise relies on breaking hydrogen-oxygen rather than hydrogen-carbon bonds, and hence has a much higher energy use, and again

Table 1: Regional production, energy consumption and carbon emissions for the ammonia industry

Region	Ammonia emissions (million t/a)	Average plant production (GJ/t NH ₃)	Total energy use (TJ/a)	Carbon energy use (million t/a CO ₂)
Western Europe	11.0	35.8	393	23.0
North America	14.7	37.9	557	31.3
CIS	21.0	39.9	838	47.0
Central Europe	5.2	43.5	226	12.9
China	49.7	49.1	2,440	220.1
India	14.0	37.7	528	31.9
Other Asia	10.9	37.0	403	22.6
Latin America	9.9	36.0	356	20.0
Africa	6.3	36.0	227	12.7
Middle East	12.7	36.0	457	25.6
Oceania	1.9	36.0	68	3.8
World	157.3	41.3	6,495	451

Source: IETD, IEA. Based on 2010 production

tends to be more expensive than gas-based reforming. However, if ammonia production were used in conjunction with renewable power generation, for example at times of low electricity demand, as a form of 'storage' of electricity.

This leaves us with efficiency improvements. Here the industry has made and continues to make considerable strides, but faces an increasing hurdle in terms of the thermodynamics of the process. In steam methane reforming, for example, two thirds of the carbon dioxide emitted comes from the methane molecules which provide the hydrogen for the process – something which is in effect unavoidable – and only one third comes from heat and power and can be mitigated. Over the decades, this proportion has steadily shrunk, roughly halving over the past 30 years, and the best modern ammonia plants can achieve an energy consumption of 28-33 GJ/tonne ammonia, equivalent to as little as 1.6 tonnes CO₂ per tonne NH₃. While this is still some way above the thermodynamic limit of 22.7 GJ/t, it is considered to be approaching a 'practical limit' in terms of economic plant design.

There is still progress to be made, however. Table 1 shows the results of a 2010 benchmarking survey of ammonia capacity⁴, indicating that the global average plant for most regions had an energy consumption of 35-37 GJ/t ammonia, and some regions as high as 50 GJ/t ammonia. Given that China represents the largest single producer of ammonia, and many of its plants are older, coal-based plants, there is plenty of scope for reducing the contribution to global warming caused by the ammonia industry.

Two steps back

The question, of course, is whether the Paris Agreement is likely to deliver these improvements. Although it is the region that already has some of the most efficient plants in the world, the enthusiasm of the European Union for reducing CO₂ emissions is likely to place increased pressure on the European ammonia industry. In a recent position paper⁵, Fertilizers Europe notes that the EU ETS has a diminishing cap on free emissions allowances which falls by 1.74% per year to 2020, and from 2.2% per year after that, meaning that the industry will be paying progressively more and more in order to keep operating. Unless this is matched by similar moves elsewhere, there is a significant risk that capacity will be forced overseas, leading to carbon leakage. There are moves to cut emissions in other jurisdictions, it is true. China has gone so far as to try and arrange a cap on ammonia production capacity and the progressive replacement of older, less efficient plants with newer, larger scale ones. However, given the current absence of a major ammonia producer like Russia from the Agreement, and the potential withdrawal of the United States from it, it seems that the burden will inevitably fall asymmetrically, and for the ammonia industry it is a question of one step forward and two steps back.

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Africa natural gas and fertilizer outlook

Nelly Mikhael, Senior Consultant, Nexant, and Priyanka Khemka, Consultant, Nexant, look at the prospects for gas-based fertilizer production in Africa over the coming years.



Africa's gas potential: production at the Bouri field, off Libya

Africa's burgeoning population, economic growth potential, and rich endowment with energy resources combine to render the region a hotspot for significant global gas supply and demand growth. Just 17% of the world's population lived in Africa in 2015, but according to United Nations projections, more than half of global population growth between now and 2050 is expected to occur there. To feed, clothe, and transport the additional 1.3 billion people that will be added in Africa through 2050 will take vast amounts of energy; to increase their standard of living to the levels currently enjoyed by developed Western economies will require more still. Today, the region's energy use – particularly natural gas – is fairly modest relative to the size of its population. Uneven wealth distribution, a lack of creditworthy off-takers to support large-scale gas-based projects, political instability, and the uneven distribution of indigenous energy resources are just some of the factors which have hampered the uptake of natural gas in the region's energy supply mix. Improved gas supply availability is essential for Africa to develop economically and produce a higher standard

of living for its inhabitants, but political and regulatory stability are critical for the development of additional gas supply outlets in the region, including fertilizer projects.

Gas production

Africa's gas production, shown in Table 1, is quite small in light of its proven reserves base. Despite having more than 14 trillion cubic meters of proved reserves as of end-

Table 1: African gas production/consumption, 2015, billion cubic metres

Country	Production	Consumption
Algeria	83.0	39.0
Egypt	45.6	47.8
Equatorial Guinea	6.5	1.6
Libya	12.8	5.8
Mozambique	5.6	1.8
Nigeria	50.1	18.8
South Africa	0.9	5.0
Tanzania	0.6	0.6
Others	6.6	15.0

Source: BP

2015 (almost 500 trillion cubic feet; 8% of the global total), output in 2015 was just over 210 billion cubic meters (bcm), or less than 6% of world output that year. The bulk of regional output originates in North Africa (70%), thanks largely to Algeria and, to a lesser extent, Egypt. West Africa is the next-largest regional producing region, with the credit going largely to Nigeria. In recent years, Africa's gas producers have experienced marked supply fluctuations owing to a myriad of factors: security concerns (Algeria, Libya, and Nigeria); technical issues (Angola); and a lack of investment partly attributable to an uncompetitive commercial/regulatory environment (Algeria, Egypt, and Nigeria).

Regional output is projected to grow by 60 bcm through 2025, as new production centres emerge in West Africa and East Africa. Capacity additions are expected in parts of North Africa, but even with forecast Algerian and Egyptian production increases, North Africa's share of regional output falls on the back of gains elsewhere on the continent. Algeria keeps its position as Africa's premier producer on the back of its existing large production base and conventional and unconventional gas production gains, but Egypt, Mozambique and Nigeria have the most buoyant prospects over the forecast period. In Egypt's case, some of these gains will in effect be "spent" on recovering the footing lost between 2010 and 2014. For Nigeria's part, forecast production gains will require the establishment of a bankable commercial structure for Nigeria's gas sector. Price reforms, improvements in regulatory arrangements, a redefinition of the role of public companies in the gas sector and an alternative to the current Nigerian National Petroleum Corporation (NNPC) joint venture financing model are urgently needed. Failure on this front will adversely affect the supply outlook. Finally, Mozambique's outlook is predicated on the start-up of at least two individual LNG export projects in the 2020s. In the longer term, East African production rises further as export capacity is commissioned in Tanzania, but this occurs beyond the scope of the forecast period.

Gas consumption

Natural gas accounted for just 28% of the region's primary energy mix in 2015, coming in a distant second to oil. North Africa dominates regional gas use, with Egypt and Algeria accounting for over two-thirds of regional consumption in 2014, followed by West Africa. This is, of course, attributable to these countries' access to gas: although Algeria, Egypt, and Nigeria are large gas exporters, they used their export sectors as springboards for domestic gas sector development and growth. In recent years, however, domestic needs have superseded export commitments in countries like Egypt, whereas domestic unrest has affected gas deliveries to Algeria and Nigeria's export sectors. The governments of these three key regional gas producing centres face the dual challenge of ensuring affordable energy for their populations while offering sufficient incentives for upstream investment, which in the past have been sorely lacking.

Looking ahead, Nigeria and Algeria have the most robust consumption outlooks, followed by Egypt. However, the pace and trajectory of Nigerian demand growth is hostage to the formation of a coherent government policy regarding upstream and downstream energy investment, whereas Egypt's growth is predicated on the ability of the military government to retain public support in the face of intense social pressures. To that end, Egypt's priority will be focused on procuring sufficient gas to feed the domestic sector, utilizing existing gas-based projects more fully and supporting the establishment of new projects, in the hope that doing so will bring growth and stability to the troubled country.

Today, Africa's power sector dominates regional gas consumption, at over 50%, with the energy sector coming a distant second. By 2025, power generation's share of regional gas use rises to about 55%. The power sector provides a solid foundation for the "gasification" of African countries where gas plays little to no current role in the primary energy mix: as a large and more credit-worthy consumption base, the power sector is the favoured mechanism for initial African "gasification" initiatives, but the right regulation and prices are essential for success. Throughout Africa, robust population growth outlook is a key driver, as well as growing access to gas in areas with no or limited previous prospects (e.g., East Africa and South Africa). Despite demand gains by the energy industry on the back

of rising regional hydrocarbon output, the industrial sector supplants it as the region's second-largest end-use sector by the end of the forecast period. This is shown in Figure 1.

Looking ahead, even countries dependent on the export sector need to realise that ambitious production plans will benefit from an influx of competitively-priced gas to the domestic sector. Meanwhile, African countries with little to no resources of their own are in a position to benefit from the development of new upstream gas reserves in neighbouring countries, by accepting pipeline gas or even LNG deliveries (where the distance is too large to justify pipeline construction). The "gasification" of more African countries is a driving force behind increased employment and infrastructure development. For countries with undeveloped upstream resources as a supply base, it is also the means to achieve higher state revenues.

Nitrogen fertilizer outlook

The fertilizer sector consumes less than ten percent of Africa's natural gas. Africa uses relatively small amounts of ammonia, especially considering the size and population of the region, consuming an estimated 5.8 million t/a in 2016. Urea demand in Africa is estimated to be close to 4.6 million t/a in 2016, with around 90% utilised in direct fertilizer use for food production. Compared to other global developing regions, fertilizer consumption in Africa has increased only marginally over the past four decades. The low use of fertilizer

results in low crop productivity and, in turn, widespread food shortages and the rapid conversion of natural habitats to farming.

In order to address this challenge, African leaders adopted the Abuja Declaration in 2006, calling for increasing average fertilizer use in sub-Saharan Africa (SSA) from less than 10 kilograms per hectare (kg/ha) to at least 50 kg/ha by 2015. However, this goal was missed by a considerable margin: by 2014, the application rate was less than 20 kg/ha in Africa. Fertilizer application rates per hectare in SSA are the lowest in the world, at an equivalent of three percent of Asia's and nine percent of North America's application rates. The consumption of fertilizers is two to three times lower than required in order to meet the needs of the agricultural sector in Africa, resulting in soil nutrient depletion, low agricultural productivity, increasing population and declining arable land per capita and climate change. However, Nexant believes that fertilizer demand growth is inevitable in light of forecast population increases and higher gross domestic product (GDP) growth rates, which translate to higher crop demand. The vast availability of potential farming land also bodes well for an increase in domestic crop production. Africa's urea requirements are expected to grow at an average annual rate of 2.5% during the next decade.

Ammonia capacity in Africa stands at about nine million t/a, while urea capacity stands at about 8.5 million t/a, with Egypt alone hosting more than 50% of regional capacity. Despite being self-sufficient in

Fig 1: African gas demand by sector, 2015 and 2025

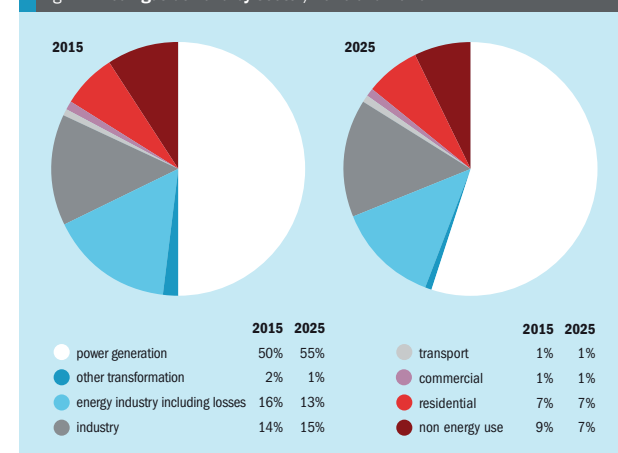


Table 2: New Ammonia/Urea Projects in Africa

Company	Location	Capacity, t/a	Status	Start-up/Expected Start-Up
Misr Oil Processing Co.	Damietta, Egypt	400,000 ammonia	Operating	June 2015 (MOPCO 1)
		650,000 urea		
Indorama Eleme Fert & Chem	Port Harcourt, Nigeria	400,000 ammonia	Operating	December 2016 (MOPCO 2)
		650,000 urea		
Indorama Eleme Fert & Chem	Port Harcourt, Nigeria	820,000 ammonia 1.4 million urea	Operating	March 2016
Brass Fert & Petchem Co.	Brass Island, Nigeria	790,000 ammonia 1.3 million urea	Construction	Post-2020
Riaba Fertilizers*	Riaba, Equatorial Guinea	1.5 million ammonia/ urea	FEED completed Technology not selected	Post-2021
Chemical Ind. Holding (Kima)*	Aswan, Egypt	430,000 ammonia 576,000 urea	Feasibility study	Post-2021
Egypt Basic Industries (EBIC)**	Sokhna, Egypt	720,000 ammonia	KBR technology selected	Post-2021

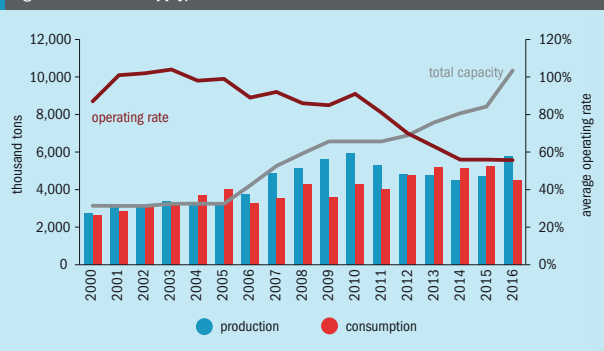
* Likelihood of completion is low due to gas issues. ** Gas shortages in Egypt may delay project

area, as shown in Figure 2, Africa is likely to add new capacity in countries with access to plentiful sources of gas supply, most likely in North Africa and West Africa. On Africa's east coast, which is a frontier hydrocarbon province, there is growing interest in monetising new gas finds and increasing the continent's fertilizer consumption.

However, new projects in Africa develop slowly due to political and security uncertainties, an onerous bureaucracy, limited access to finance, and in some cases, concerns about access to feedstock. For example, several fertilizer ventures have been announced in Egypt and Equatorial Guinea over the past year, but the timing and success of these endeavours is predicated on access to competitively-priced natural gas. In countries like Egypt, which has resorted to importing liquefied natural gas (LNG) to augment supply until new fields enter service, project development is ultimately contingent on the resolution of ongoing supply issues. Looking ahead, Nexant expects Africa will add about 1.2 million t/a of ammonia and urea capacity over the next ten years. The bulk of Africa's new capacity (over 70%) will be located in Egypt, whose current gas supply issues will be mitigated by the start-up of the Zohr gas field. Recent African fertilizer project activity (based on publicly available information) is listed in Table 2.

Egypt serves as an interesting case study for Africa's fertilizer sector. Like many countries in the region, it is endowed with rich gas resources, but the mismanagement of these resources, coupled with political instability and surging domestic demand

Fig 2: Africa urea supply/demand balance



bolstered by subsidised prices, resulted in a growing mismatch between indigenous supply and consumption over the last decade or so. A lack of incentives for upstream producers affected the scope of exploration in the country, whereas the political instability engendered by the Arab Spring acted as a further deterrent for upstream investment. The resultant gas shortages induced the cessation of Egyptian pipeline gas and LNG exports; indeed, Egypt was forced to start importing LNG in 2015 to bridge the gap between supply and demand. However, the outlook for Egyptian gas supply is fairly robust, thanks to the re-establishment of political stability and greater investor confidence. The 2015 discovery of the 30 trillion cubic feet Zohr gas field provided a much-needed boost for the

country's upstream sector; undoubtedly, it is hoped that additional discoveries will provide further security of gas supply. The possibility also exists for Egypt to augment domestic production with imports from neighbouring Israel and even Cyprus, thereby diversifying and broadening the country's supply base.

While new gas supplies for Egypt could be used to develop new ammonia/urea plants, existing end-users will most likely have priority for the allocation of incremental volumes. Given the growing volume of urea available for global trade, it will remain a challenge to secure financing for new ammonia/urea projects in Egypt until the market and prices recover. Hence, Nexant maintains a conservative outlook towards ammonia/urea capacity additions in Africa over the next decade. ■

Nitric acid catalysts and process plants ...

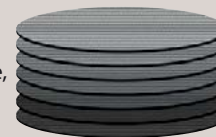
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Strategies for hydrogen production

A look at the production options open for hydrogen generation in refineries and elsewhere.

The main producers and consumers of hydrogen at present (discounting ammonia plants, where syngas generation is built into the process), are oil refineries, where it is used primarily in hydrodesulphurisation units/hydrotreaters, which remove a substantial amount of the sulphur present in the petroleum products. Hydrogen can be added to the tail gas treating unit (TGTU) of a sulphur plant when the streams to be treated are leaner (i.e., have a lower H₂S content). It is also used in hydrocracking, to upgrade heavy gas oils into more valuable streams such as gasoline and diesel. The hydrogen demand from these processes is increasing due to several factors, including more stringent environmental regulations for fuels, higher demand for lighter fuels and the need for refiners to process heavier and sourer crude.

KT Kinetics Technology estimated in 2015 that there were – in addition to 39 new refineries then under construction – a further 69 expansions or upgrades of existing refineries, adding a total of 49 new hydrodesulphurisation, hydrocracking, hydrotreating or delayed coking sections, all of them requiring additional hydrogen feeds.

Steam reforming

Steam reforming has generally been the preferred option for refinery hydrogen generation, with natural gas the preferred feed. While these can be relatively small scale compared to world scale ammonia or methanol reformers, the generation of export steam and integration into the refinery steam system can help improve overall operating efficiencies. Furthermore,

the push for larger refineries and more hydrogen for upgrading is leading to larger installed units, while in the US Gulf refiners have been able to take advantage of economies of scale via over the fence hydrogen supply from large plants which feed several end users. Where expansion is required, additional capacity has been generated from heat exchange reformers using process steam.

Gasification

Another option, where feedstock is available, is gasification of heavy feedstocks, often petroleum coke, produced elsewhere in the refinery. Three major refinery gasification applications are under construction; Reliance Industries in India has 95% completed its petcoke gasification project at Jamnagar, the world's largest refinery, and aims to eliminate high cost LNG imports using 3 million t/a of its own petcoke and 3.5 million t/a of imports. Meanwhile, at Saudi Aramco's Jazan refinery, an integrated gasification combine cycle (IGCC) complex is under construction to convert vacuum residue from the 400,000 bbl/d refinery into 50 million m³/d of syngas to produce purified hydrogen for the refinery as well as generating power for local use and export to the grid. Finally, in Alberta, Canada, the Sturgeon refinery being developed by the North West Redwater Partnership (NWR) is an oil sands upgrader using integrated gasification of refining residuals which will process 78,000 bbl/d of diluted bitumen.

The projects illustrate the potential synergies between refinery waste or low value residual streams and badly-needed hydrogen generation, as well as paying

dividends in terms of higher value products and power export credits. While all three projects were the outgrowth of the era of high oil and gas projects, the fall in oil and gas prices has not so far slowed their development.

Refinery off-gas

Refinery off-gases can contain anything from 10-90% hydrogen, depending on the refinery flow scheme. Historically this was often burned via the refinery fuel gas system, but where available it can be purified via pressure swing adsorption (PSA) systems or cryogenic or membrane separation techniques. The residual off-gas stream will still contain combustible fractions and can still be fed to the refinery fuel gas system. However, where the hydrogen content of the off-gas stream is very low, these may not be economical options. Linde have proposed instead integration into a steam reforming plant, again where available – the hydrogen content will obviously not justify the construction of a new reformer, but the refinery off-gas stream can act as a supplemental feed to a reformer, generating additional hydrogen from hydrocarbons in the stream.

Power to gas

Finally, hydrogen can of course be generated by electrolysis of water. This is generally prohibitively expensive using electricity directly from the grid, as breaking hydrogen-oxygen bonds is a very energy intensive process – this is the reason that steam methane reforming has been the dominant way of producing hydrogen for decades. However, where renewable power is available, use of this to generate hydrogen can be a cost-effective process where there are sufficiently significant incentives to do so, as hydrogen storage can be an effective way of dealing with excess power from renewable generation at times when there is insufficient local demand. Financial incentives can help. In Europe, for example, the EU fuel quality directive (FQD) sets a target of 6% reduction in greenhouse gas emissions from refineries by 2020, and carbon taxes and renewable fuel credits may also help ameliorate the cost. Nevertheless, this would probably only be an option where there was a government push that allowed or incentivised the integration of local power generation with refining feeds. ■

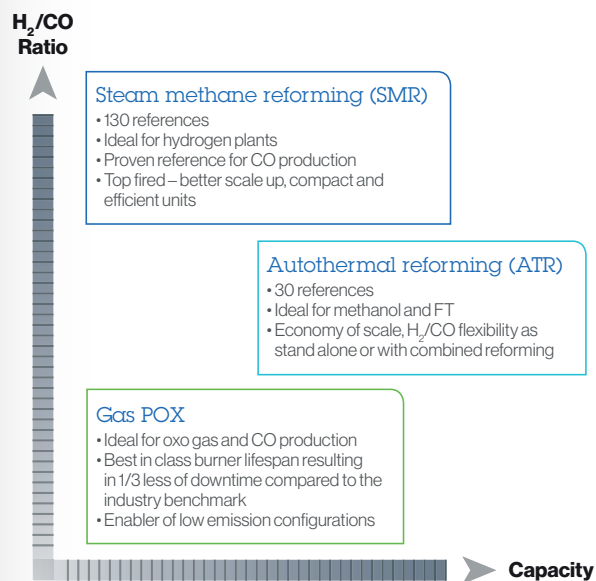
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Innovative urea technologies

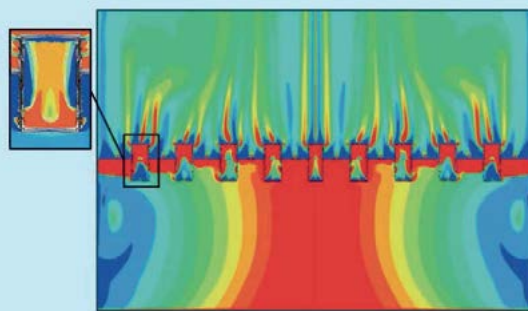
In this article we report on new proprietary designs for urea plants from Saipem and Stamicarbon and how they are being implemented to benefit urea plant performance. Case studies are provided for Saipem's SuperCups solution and Stamicarbon's Launch Melt™ flash design.

Fig 1: CFD of urea reactor with SuperCups



Source: Saipem

Fig 2: Fluid-dynamic effects of SuperCups trays



- Product distributor**
 - Uniform distribution of products
 - Optimised residence time distribution
- Mixer reactor**
 - Intensive mixing in multiple volumes
 - Continuous stirred tank reactor
- Gas equalizer**
 - Cushion of light phase below the tray
 - Uniform feeding of reactants

Source: Saipem

Saipem's SuperCups solution

Saipem has recently enlarged its portfolio of high-end solutions for urea technology with the introduction of the Snamprogetti™ SuperCups. This new tool for improving the performance of urea synthesis reactors has been developed in direct response to demand for better performing processes with the aim to optimise the capital investment of high pressure equipment, decrease energy consumptions and reduce environmental footprint of industrial operation.

The proprietary SuperCups trays drastically increase the mixing of the reactant phases, (ammonia/ammonium carbamate and carbon dioxide), thus optimising the product conversion rate in the reactor. The immediate benefit is the lower specific steam consumption requirement to decompose carbamate to CO₂ and NH₃ in downstream sections. Taking into consideration the necessity to minimise the pressure drop across the reactor, the improved mixing is obtained without any increase of compression energy for carbon dioxide.

This represents a further advance towards getting closer to the theoretical equilibrium conversion in the reactor.

Design features

The innovative concept of SuperCups (Fig. 1) lies in the realisation of a confined reaction space within the reactor tray geometry, namely the cups. They perform as a number of mixing units where ammonia is contacted with the gaseous CO₂ in small bubbles.

This peculiar behaviour is characterised by a triple fluid dynamic effect – gas equaliser, mixer reactor and gas distributor.

The first effect of SuperCups is to uniformly distribute the concentration of the light phase reagent on the entire section of the tray. In this way, the gas-like bubbles moving upwards “lose the memory” of the non-uniformity of the previous reaction stage and the non-reacted CO₂ can be evenly fed to each cup of the tray.

Fig 3: 3D model of urea unit with new design

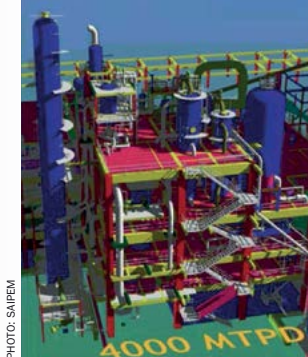


PHOTO: SAIPEM

Secondly, the cups behave as a number of confined reaction volumes in which the multi-phase reagents heavily swirl inside, thus reaching a high mixing degree. Each cup performs as a static mixer where the phases are strongly contacted (see Fig. 2).

In this way the SuperCups trays perform as active reaction stages which can be modelled as a continuous stirred tank reactor (CSTR) in series with the reactor stage.

Finally, the CO₂ can be partially streamed inside the cups to create a mixer-reactor and partially distributed on the upper stage by means of dedicated holes. This split range is one of the most critical design parameters since it allows the residence time distribution (RTD) curve of each reactor stage to be customised and the CSTR (perfect mixing) or PFR (plug flow) behaviour to increase (or decrease) according to the composition of each stage.

Applications

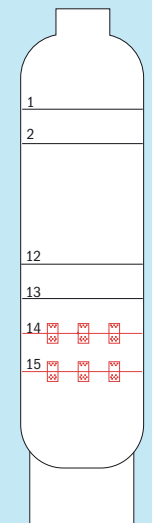
The SuperCups technology has been effectively applied to design a new generation of urea reactors, as well as to enhance the performance of existing units in retrofit design.

In the first case, the application of the SuperCups allows the process design to be optimised, thus leading to an innovative reactor with enhanced performance and reduced volume, which therefore requires a lower capital investment.

The HP section design is consequently improved, resulting in a compact layout of the entire urea unit, as shown in the 3-D model of a large scale unit in Fig. 3.

On the other hand, in the case of retrofit design, the new internals can be used

Fig 4: Sketch of modifications implemented in FFC reactor, 2 replaced trays



Source: Saipem

with the limited modifications necessary to upgrade an existing reactor result in a very short pay-back period.

Case study

The first two industrial applications of the SuperCups were for retrofit designs of urea plants for Borealis Agrolinz Melamine Int. GmbH located in Linz (Austria) and Fauji Fertilizer Company Ltd. (FFC) sited in Mirpur Mathelo (Pakistan).

Two SuperCups trays were installed in the urea reactor of the Borealis plant as additional items in April 2014, while in FFC two trays were installed in the reactor as a replacement for existing sieve trays in September 2014 (see Fig. 4).

No other modification were carried out to the urea plants during the plant shutdown.

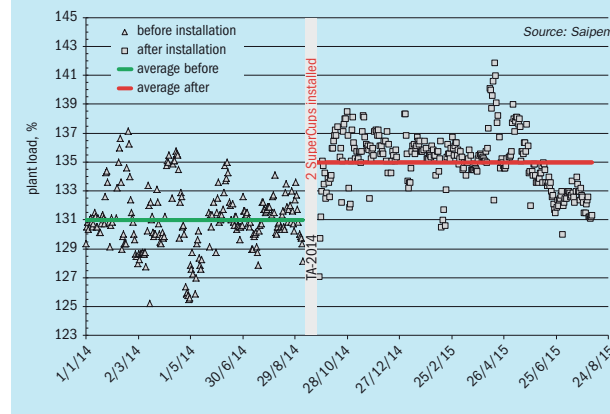
In both cases, the performance assessment of the new technology has been carried out by monitoring the high pressure loop and medium pressure steam network of the urea plant in a wide time frame before and after the installation of the trays.

Capacity increase

The first remarkable point in the evaluation of the plant performance after the installation of the new trays comes from the evidence of increased maximum achieved plant capacity.

The plant average load after the SuperCups installation has increased with respect to the period before shutdown 2014 by 2.2 % for Borealis and about 4 % for FFC (see Fig. 5).

Fig 5: FFC: plant load before and after SuperCups installation



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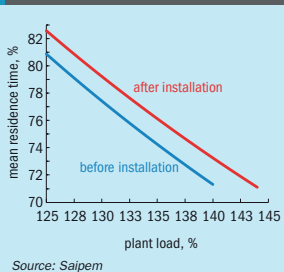
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Fig 6: Borealis: MRT curves before and after SuperCups installation vs. plant load



Steam balance

The evaluation of the overall steam duties has been based on the plant data collected on a number of dates before and after the plant turnaround of 2014.

Results show that the specific heat duty of each steam user is lower after the installation of the SuperCups trays and, in particular, the reduction of overall specific duty of medium pressure steam (MS) users was calculated as 2.3% for Borealis and about 1.9 % for FFC.

Urea reactor performance

Analytical data of the reactor outlet composition show that the installation of two SuperCups has moved the average operating area of the urea reactor towards higher conversion rates at increased plant loads.

In order to provide a visual indication of the reactor performance at different plant loads, the analytical data have been rearranged to obtain the mean residence time (MRT) of the reactor.

The MRT has been calculated as the ratio between the reactor outlet flow rate (depending on analyses) and the reactor volume, thus obtaining two curves relevant, respectively, to the reactor operation before and after the installation of the two SuperCups trays (Fig. 6).

The MRT decreases with plant capacity due to the increased flow of solution passing through the reactor. The curve relevant to the operation of reactor after the installation of two SuperCups is shifted upwards with respect to the plot obtained before the installation, thus showing that the two new SuperCups trays have effectively increased the MRT in the reactor.

In other words, when operating at medium-high plant capacities, the reactor volume

starts to become limiting but the improved fluid-dynamic patterns provided by SuperCups allows this limitation to be overcome and for the reactor to be operated at increased capacity with enhanced conversion.

SuperCups is a proven technology that can be advantageously applied to design a new generation of urea reactors as well as to improve the performance of existing equipment.

With SuperCups technology, it is possible to achieve significant improvements with only a partial renewal of internals, compared to other types of high efficiency trays on the market, which require the complete replacement of the original set.

In the present situation of investment stagnation, this approach of “marginal investment for tangible benefits” is Saipem’s strategy for boosting revamp and modernisation initiatives.

Stamicarbon’s Launch Melt™ flash design

Over the years, the Stamicarbon urea process has proved to be a reliable concept. The concept has seen some variations, with its main differentiator being the synthesis loop configuration (e.g. CO₂ stripping, pool condenser, pool reactor and a mega capacity design). The Launch Melt™ flash design is the latest variant of this concept, significantly reducing the steam consumption without compromising the reliability of the process and with minimal process adjustments.

One of the advantages of the Stamicarbon urea process is that no in-line medium-pressure decomposition stage is required because of the high degree of ammonia and carbon dioxide recovery from the urea solution before it leaves the high-pressure synthesis loop. The high efficiency of the synthesis loop is achieved by selection of optimal process conditions for urea formation (including the system pressure, the partial pressure of inerts, and the N/C ratio) rather than for CO₂ stripping. To compensate for the less-than-ideal stripping conditions, the stripper consumes a fairly large amount of high-pressure steam (typically extraction steam at about 2.1 MPa pressure) to decompose the carbamate present in the urea solution coming from the reactor. The ammonia and carbon dioxide from the stripper are fed, along with the fresh carbon dioxide, to the HP pool condenser, in which the released condensation heat is used to produce low-pressure

steam that is used in downstream processing. Thus, to keep the downstream section limited (a small LP section and no MP section), HP steam is indirectly converted into LP steam to achieve a high synthesis conversion. From the point of view of investment cost alone, the only way to go is to make the synthesis conversion rate as high as possible. But when energy-efficiency is given greater importance, there is room for improvement in the urea process.

The concept

The Launch Melt™ flash design

Stamicarbon has developed a concept for urea plants with improved energy-efficiency. Typically, the steam consumption is reduced by about 100 kg/tonne of final product. In this concept a small in-line flashing step is installed between the synthesis loop and the traditional low-pressure stage. The process scheme is shown in Fig. 7.

The urea solution from the HP stripper is flashed adiabatically at a pressure of about 2 MPa in the flash separator. The urea solution leaving the adiabatic flash separator is fed to the rectifying column in the traditional 400 kPa low-pressure section. The vapours from the adiabatic flash separator are fed to the shell side of the pre-evaporator. The heat of condensation released in the shell side of the pre-evaporator is used to concentrate the urea solution in the tube side of this pre-evaporator. The resulting medium-pressure carbamate is transferred into the synthesis loop by means of an HP carbamate pump. The remaining vapours from the medium-pressure stage are washed in a 400 kPa absorber before being released into atmosphere.

The Launch Melt™ flash design without HP scrubber

The concept can be realised without an HP synthesis loop scrubber; this significantly reduces the number of high-pressure equipment items required. The process flow diagram is shown in Fig. 8.

In this configuration the function of the HP scrubber, which is to condense ammonia and carbon dioxide (in the form of ammonium carbamate) out of the vapours from the HP urea reactor, is taken over by the pre-evaporator/MP carbamate condenser. This concept has an even better heat integration and reduces the investment cost of the HP equipment, as the HP scrubber, the CW circulation pump and the HP ejector can all be dispensed with.



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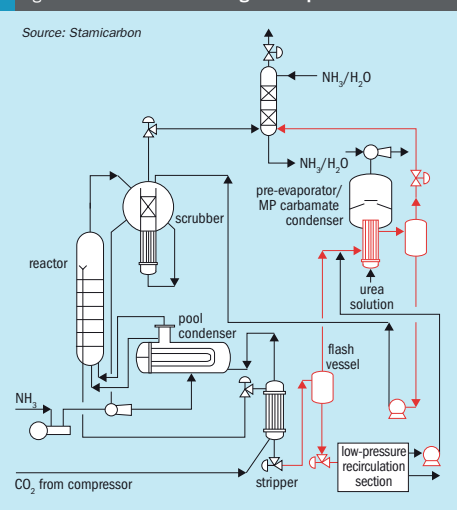
New nitric acid process

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Fig 7: Launch Melt™ flash design concept with HP scrubber



Investment and operating costs

Operating cost is one of the main factors determining the cost price of the urea end product, and its biggest component is the cost of the energy consumed in the process. The energy consumption for traditional stripping processes is significantly decreased when an adiabatic flash step is introduced between the synthesis section and the recirculation section.

Considering a grass-roots urea plant with a nameplate capacity of 3,900 t/d, a steam saving of 70 kg/t final product would result in a cost reduction of €1 million per year, while a steam saving of 100 kg/t would result in a saving of €1.5 million per year. This calculation is based on natural gas priced at \$4/MMBtu and steam consumed at a pressure of 2.4 MPa and a temperature of 300°C.

The impact on investment costs for the above example, although these are project- and region-specific, are significant. The equipment cost for the adiabatic flash concept would add up to some €2 million, but the equipment cost reduction arising from not installing the HP scrubber, circulation pump and HP ejector is about €3 million.

The Launch Melt™ flash design in operation

The Linggu project

The first grass-roots plant in operation incorporating the adiabatic flash technology was designed in 2013 and

commissioned in 2015. Some details of the Linggu project:

- Nameplate capacity: 2,700 t/d
- Synthesis loop: Launch Melt™ concept (with pool condenser and HP scrubber)
- Contractor: Chengda Engineering Corporation of China
- Location: Yixing, P.R. of China

The Linggu process concept is in accordance with the process flow diagram in Fig. 7. It embodies two energy-optimising technologies:

- heat exchange of the HP scrubber cooling water with the 1st stage evaporator;
- implementation of the Launch Melt™ flash design technology.

The reduction in steam consumption realised in the Linggu plant in comparison to the same flow scheme without adiabatic flash is well above 100 kg/t final product.

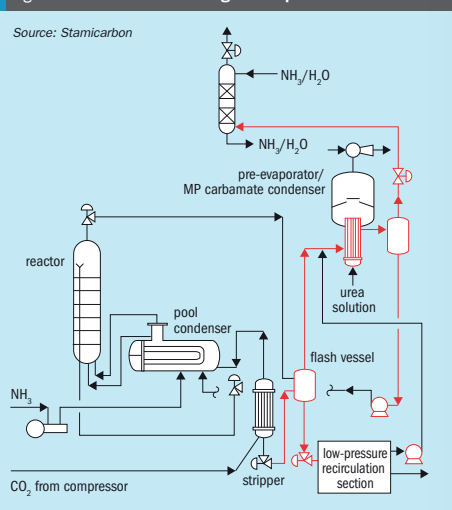
Linggu in operation

The urea plant was first started in November 2015 and reached a capacity of about 95% within a couple of days.

During more than one year of operational experience the concept has proven to be easy to operate and realises a steam consumption of well below 800 kg/t final product running at 100+ % capacities.

Plant operation was easy, as expected, thanks to the damping effect of the MP

Fig 8: Launch Melt™ flash design concept without HP scrubber



stage. The heat duty of the MP carbamate condenser (shell side of the pre-evaporator) is such that a 78% urea solution is produced as feed for the evaporation section.

Based on the experiences in the Linggu project the Launch Melt™ flash design is proven technology and has shown to perform well. With this design the stream consumption of the urea plant drops significantly; reduction of more than 100 kg/ton final product can be realised in both grass roots and existing plants.

With the flash technology, the urea plant becomes more robust in operation; variations in load from the synthesis to the downstream sections are handled by the very efficient medium-pressure condensation and do not lead to upsets in the low-pressure section.

The flash concept makes it possible to design the urea plant so that the HP scrubber can be omitted without increasing ammonia losses. This simplifies synthesis loop operation, lowers investment costs and reduces steam consumption.

The flash concept is also a very powerful revamp tool making it possible to:

- increase capacity of the downstream section;
- increase the energy-efficiency of the plant, lowering production cost;
- be used as an alternative for an end-of-life HP scrubber replacement.

Urea and melamine plant modernisation

The modernisation of urea plants and their integration with melamine facilities have been a key activity for a good share of Casale's history. The experience gained with numerous plant revamping enables Casale to specifically customise all process schemes according to any licensor's technology and the specific needs of each plant. Process solutions have been implemented and successfully proved in several urea facilities and are now available for melamine plant modernisation. **P. Bertini** and **S. Gamba** of Casale discuss the options available.

With a large number of revamping projects successfully carried out in the last decades, Casale is now the world leader in urea plant revamping, with a reference list comprising more than 150 plants revamping ranging from replacement of single equipment to massive increase in capacity. The same approach is being adopted for the recently acquired melamine technology where this concept was never investigated.

Tailored revamping technologies

There are several goals that a plant owner can pursue when revamping a urea or a melamine plant; each project begins with identification of the client's goals along with the actual bottlenecks in the plant. A thorough assessment of the current plant performance is carried out following a survey at the plant site. Later on, base-case material and energy balances are developed, reflecting actual operating conditions. Clients may benefit from the wide experience that Casale has achieved through the revamping of urea plants of any technology, ranging from stripping plants (i.e. CO₂ stripping and ammonia stripping) to total recycle ones.

Each technology has different peculiarities which need to be approached in a specific manner. In view of that, for each process scheme Casale has developed a set of tailored technologies in order to fulfil the required aims of the revamping for the best return.

Additionally, clients who own a melamine unit with a high pressure process have the possibility to upgrade their unit through a revamping scheme developed based on the knowhow acquired from Borealis and the revamping capabilities of Casale.

The more representative revamping schemes specifically for major urea and melamine technologies are detailed in the following sections.

CO₂ stripping process

In CO₂ stripping plants urea is synthesised at a pressure of 140 bar (gauge pressure is assumed within the entire paper), a temperature of 180-185°C and a molar NH₃/CO₂ ratio of 2.95-3.0 in the reactor. Carbon dioxide conversion under such conditions is 58-60%. The reactor effluent, containing unconverted ammonia and carbon dioxide in the form of ammonium carbamate, is subjected to a stripping operation at essentially the reactor pressure, using carbon dioxide as the stripping agent. The stripped-off ammonia and carbon dioxide are then partially condensed and recycled to the reactor.

The heat produced by this condensation is used to generate 3.5 bar steam. The unreacted carbamate from the stripping section is thoroughly decomposed in a decomposition stage operating at 3 bar and is subsequently condensed to form a carbamate solution, which is recycled to the 140 bar synthesis section. Further concentration of the urea solution leaving the 3 bar decomposition stage takes place in the evaporation section.

**Revamping CO₂ stripping plants
Boosting capacity/efficiency**

The Split Flow Loop™ process is an improved CO₂ stripping process. A minor portion of the gas flow leaving the HP stripper (sufficiently large to maintain the correct heat balance and provide the amount of passivation air needed in the reactor) is routed directly to the reactor, while the remainder is sent first to the carbamate condenser and then, after separation of the carbamate solution, directly to the inert scrubber. In this way the volume of inert gases passing through the reactor is reduced, which improves CO₂ conversion efficiency (because inert gases are detrimental to CO₂ conversion).

The Split Flow Loop™ scheme is provided in combination with Full Condenser™, Casale's proprietary design of HP carbamate condensers for CO₂ stripping plants. In contrast with traditional designs, it operates as a submerged condenser, which is more effective at carbamate condensation. Due to its high efficiency, it would be a total condenser, were it not for the inert gases, which prevent complete conversion of the reactant.

Thanks to its performance, the combination of Full Condenser™ with Split Flow Loop™ is a very powerful tool for debottlenecking CO₂ stripping plants with minor modifications. A traditional CO₂ stripping plant is actually transformed into a Split Flow Loop™/Full Condenser™ process rather easily by:

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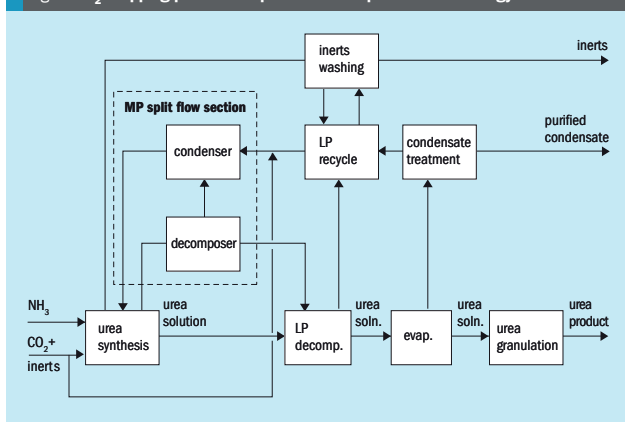
New nitric acid process

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Fig 1: CO₂ stripping plant revamped with MP Split Flow technology



- addition of specifically designed internals to the existing HP carbamate condenser;
- modification of a few lines to implement the new process flow scheme.

In combination with other Casale technologies such as high-efficiency trays in the reactor, the Split Flow Loop™/Full Condenser™ configuration can be used to debottleneck CO₂ stripping plants for a very low investment.

In combination, those technologies can increase the HP loop capacity by as much as 30-50%.

Several plants have been revamped based on Split Flow Loop™ technology which is nowadays a consolidated process scheme for CO₂ stripping urea plants. It is a mature technology with easy operation during normal conditions as well as during start-up/shut-down phases.

Massive capacity increase

Split Flow Loop™ and Full Condenser™ are reliable technologies for revamping CO₂ stripping plants, simultaneously debottlenecking the reactor and increasing the thermal capacity of the HP carbamate condenser. The HP stripper benefits as well, as the conversion within the urea reactor is boosted up to close on the thermodynamic limit, so there is less unreacted carbamate to deal with.

Still, where a large capacity increase is wanted, the stripper capacity is likely to become a constraint because of the very high risk of flooding at the desired plant

load. To overcome the hydraulic limit of the stripper, Casale has developed the medium-pressure splitting concept. A new plant section is installed in parallel with the existing HP stripper. Flow from the urea reactor which exceeds the allowable load of the stripper is diverted to a parallel plant unit working at about 18 bar. The MP section is equipped with a decomposer and a condenser. The unreacted carbamate is partially decomposed and the developed vapours are condensed with the aid of carbonate solution from the downstream LP section. The resulting carbamate solution is recycled to the HP scrubber, while the urea solution is sent to the LP decomposer along with the solution from the HP stripper.

MP Split and Split Flow Loop™ technology are nowadays consolidated process schemes for CO₂ stripping urea plants. Several plants have been revamped based on these process schemes. Fig 1 shows a block flow diagram of a CO₂ stripping plant revamped with MP Split Flow technology.

The MP Split Flow Section increases plant flexibility; the plant can be operated in steady conditions at very low capacity with MP Decomposer not lined up, as well as at higher capacity with MP Decomposer in line. The range of plant operability can vary between 50% and 100% of the design capacity. MP Decomposer is lined up or is excluded from the plant operation when it is necessary to raise or to decrease the capacity of the plant.

All the operations are very simple and within a couple of hours the plant capacity is adjusted to the desired value.

With the implementation of Split Flow and Full Condenser equipped with MP Split technology it is possible to achieve a throughput of about 6,000 t/d in a single train plant.

Improving reliability

The high-pressure synthesis section of CO₂ stripping plants is practically an isobaric loop since all of the HP equipment operates at substantially the same pressure with only minor deviations and/or relatively small pressure drops through pipes and fittings. Fluid circulation is therefore governed by gravity and/or density gradients; the latter are mainly a result of different compositions and gas/liquid ratios. In order to ensure good circulation within the HP section, the urea synthesis reactor is typically installed above the stripper, which ensures that the level of liquid in the reactor provides the required driving force for the solution to flow towards the stripper. Being a natural-circulation loop, any upset in the operating conditions, such as a change of liquid/gas ratio or density, may reduce the available flow driving force. In the worst case reverse-flow circulation may occur, which could over-pressurise the HP loop and make the relief valve open.

To improve the stability of the synthesis section of CO₂ stripping plants, and therefore avoid the onset of flow reversal conditions, Casale has patented a device to detect the direction of the flow in the reactor outlet line, measuring the driving force by the difference of pressure and thus the flow rate from the reactor to the stripper.

In particular, the device can measure the pressure drop across the level control valve in the reactor effluent line to the stripper. A positive pressure drop across the valve denotes that the loop is in normal operation, quantifying the available driving force. A negative pressure difference, on the other hand, indicates the unwanted, dangerous condition of reverse flow from stripper to reactor. The device is of great help to the operator since it predicts the risk of reverse flow, and thus helping to prevent it, during plant start-up, when loop circulation has not yet been established and the likelihood of a reverse flow is even higher.

Ammonia stripping process

In the ammonia stripping process the synthesis section is operated at slightly higher pressure than in CO₂ stripping plants. In fact, ammonia and carbon dioxide are converted to urea via ammonium carbamate at

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Fig 2: Medium-high pressure section in NH₃ stripping plant

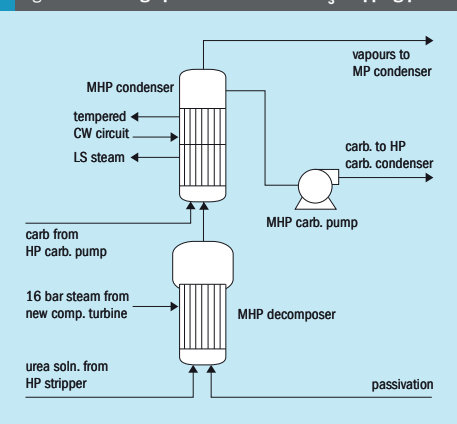


Fig 3: Improved loop scheme

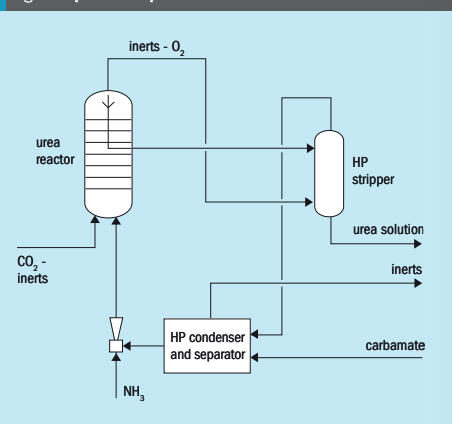


Fig 4: Revamped MP absorber

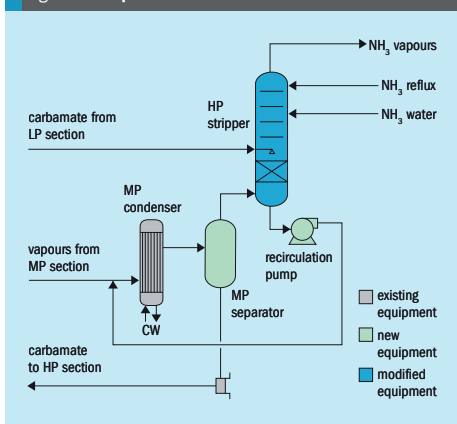
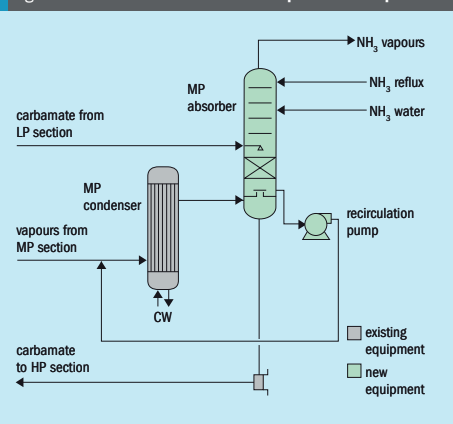


Fig 5: New MP absorber for Casale improved concept



a pressure of 160 bar and a temperature of 185-190°C. A molar ratio of 3.2-3.4 is typically maintained in the reactor, achieving a CO₂ conversion of up to 62%. The urea-carbamate solution enters the stripper, where a large part of the unconverted carbamate is decomposed by the stripping action of the excess ammonia. Residual carbamate and carbon dioxide are recovered downstream of the stripper in two decomposition stages operating at 17 bar (medium pressure) and 3.5 bar (low pressure) respectively. Ammonia and carbon dioxide vapours from the stripper top are mixed with the recovered carbamate solution from the medium-pressure (MP) and low-pressure (LP) sections, condensed in the HP carbamate condenser and recycled to the reactor. The heat of condensation is used to produce LP steam. The urea solution leaving the LP decomposition stage is later on concentrated in the evaporation section.

Revamping NH₃ stripping plants

Massive capacity increase

Casale has designed a process scheme that is particularly suitable for revamping ammonia stripping plants where a massive capacity increase is desired. Rather than replacing several items which are among the most complex and costly in the plant (stripper, HP carbamate condenser, MP decomposer, etc.), Casale introduced the medium-high pressure section (MHP) concept.

MHP consists of a new plant section (Fig. 2) which operates at an intermedi-

ate pressure between that of the synthesis and MP sections. The urea solution stream from the stripper outlet is further purified in the MHP decomposer before reaching the MP decomposer. Thanks to this intermediate decomposition, the quantity of vapours from the MP decomposer is significantly lowered, so no modifications are necessary to the MP section (including the ammonia recovery section) or to the HP carbamate pumps and HP ammonia pumps. Additionally, because of the lower quantity of unreacted carbon dioxide and ammonia from the new MHP section, the urea solution at the outlet of the MP section is purer, thus reducing the load on the LP section. The intermediate operating pressure is sufficient for the resulting vapours to condense at 155°C, which is high enough to generate LP steam.

This scheme is quite rewarding, not only because it saves some steam, but also because the carbamate solution from the new condenser has a significantly lower water content than it would if it were recovered in the MP section. For that reason, the H/C ratio in the reactor is reduced, with beneficial effects on the CO₂ conversion in the reactor and on steam consumption in the HP stripper.

Where the HP stripper and HP carbamate condenser cannot handle the desired increase in plant capacity in the revamp scheme, MHP equipment is designed to handle the required additional urea solution from the HP section to allow the HP stripper (as well as the HP carbamate condenser) to run at lower load.

The MHP section includes the following items:

- MHP decomposer;
- MHP condenser;
- MHP carbamate pumps.

The MHP condenser is divided into two sections: in the first section, the condensation heat is removed by generation of LP steam in the shell side while, in the second section, carbamate condensation is completed using a tempered water circuit. Part of the carbamate from the HP carbamate pumps is fed to the MHP condenser to aid the condensation of carbamate and to reduce its crystallisation temperature. Carbamate from the MHP carbamate condenser is recycled to the HP carbamate condenser via the new MHP carbamate pumps.

Improving reliability of the HP loop

In Casale's patented Improved Loop technology (Fig. 3), the vapour phase leaving the reactor, containing inert gases and unreacted ammonia and carbon dioxide, is used to passivate the HP stripper. With a minor modification of the HP loop piping, instead of passivation air (from a dedicated compressor), unreacted gases from the reactor are conveyed to the stripper bottom (provided it is not a titanium stripper, for which this technology is not appropriate). Improved Loop technology eliminates the maintenance requirement of the passivation air compressor, and the amount of inert gases supplied to the synthesis section is minimised, since the air supplied to the reactor is also used for the passivation

of the stripper. In consequence, a smaller overall amount of inert gases ends up in the ammonia recovery system, so proportionately less ammonia is vented from the MP washing column. The amount of water recycled to the synthesis section is also reduced, since less condensate is required to scrub the gas stream vented from the MP washing column.

Improving reliability of MP section

The MP absorber column separates carbamate condensed in the MP carbamate condenser from ammonia and inert vapours. It is crucial that uncondensed CO₂ is thoroughly scrubbed below the upper section of the column to avoid crystallisation of carbamate in the overhead lines, which might upset the ammonia pumps or even force the plant to shut down. To ensure good separation, the velocity of vapours rising up the column must be kept well below a critical threshold to avoid liquid entrainment. If significant entrained liquid reaches the bubble cap trays in the upper section of the column, both gas/liquid separation and carbon dioxide recovery from the gas phase are affected. Carbon dioxide can easily be carried over if the column is overloaded even for a short time, or if insufficient reflux is provided.

For those reasons, for a traditional MP absorber the correct operating range is quite narrow, and small deviations are sufficient to cause a significant upset. Casale has developed and patented a process scheme which improves the flexibility of this section, resulting in smoother opera-

tion of the plant. In Casale's scheme, the gas/liquid phases are separated in dedicated equipment and carbon dioxide recovery is optimised by making a few modifications in the column internals.

The carbamate mix from the MP condenser is fed to a separator, where liquid carbamate solution separates from the uncondensed gases. The carbamate is then pumped to the HP synthesis section (Fig. 4). The vapour stream is washed in the MP absorber column by carbonate solution from the LP section trickling through a packed bed. New dedicated pumps circulate the solution from the column bottom to the MP condenser.

This arrangement makes operation of the system much more reliable and flexible. Also, provided the new separator is appropriately sized, a higher plant load can be handled, so in effect the section has been debottlenecked by means of only a few modifications.

If, for some reason (e.g., poor condition), the existing column needs to be completely replaced, there is an opportunity to optimise the layout of the above concept with fewer new items and thus to save on the investment cost. For such a case, Casale has developed a new design in which the column and gas/liquid separator are combined in a single piece of equipment. Phase separation takes place in the lower section, while the carbon dioxide is absorbed in the upper section. The two sections are separated by a chimney tray, where lean carbamate is collected and then recirculated to the MP

Revamping total recycle plants

Increase efficiency and capacity

The High Efficiency Combined (HEC) process (Fig. 6) was specifically developed for revamping total recycle plants where the required capacity increase demand is within 50-60% of the original nameplate value. In addition, the process scheme is particularly suitable for integration with melamine production facilities.

The base concept of the HEC process is to recast the existing synthesis reactor as a once-through synthesis step which is fed only with ammonia and carbon dioxide. Because no water is recycled to it, it is possible to achieve a CO₂ conversion of up to 75-77%. To maximise conversion, this "primary" reactor is operated with rather high N/C ratios (3.5-3.8) and at 240 bar. A kettle-type HP condenser is lined up upstream of the once-through reactor to remove part of the heat of carbamate formation and avoid excessive amounts of vapours in the reactor. LP steam up to 8 bar is generated during carbamate formation.

The small amount of residual carbamate is decomposed, condensed and recycled as aqueous solution to a synthesis section which is added in parallel to the once-through reactor. This section is equipped with a "secondary" urea reactor and HP decomposer. The "primary" reactor effluent is decomposed in the HP decomposer with 20 bar steam and the developed vapours are routed to the "secondary" reactor, whereas the urea solution from the bottom is sent to the existing downstream MP and LP decomposition stages. The "secondary" reactor is fed only with vapours from the HP decomposer and recycled carbamate. The outlet urea and carbamate solution joins the urea solution from the stripper bottom. The "secondary" reactor is operated at 150 bar. At the typical N/C ratio of 4.5; CO₂ conversion is 55%.

The combination of the once-through synthesis with the "secondary" process yields a combined CO₂ conversion of up to 72%.

The advantage of the HEC process is that, due to its high efficiency of conversion, the load on the back-end equipment is not significantly increased. Therefore, even for a capacity increase of 60% of the original capacity, major interventions are limited to the high-pressure section; the back-end equipment is less affected. The resulting revamping program thus requires

only short downtime, since the new section can be installed with the existing reactor operating conventionally.

The efficiency of the process, in terms of steam consumption, is also significantly improved in comparison with conventional total recycle processes.

The typical specific consumption for a HEC process is in the range of 900 kg/t urea.

Massive capacity increase

When the demand is for a really massive capacity increase (up to 100% of the nameplate capacity), Casale's approach is to apply ammonia stripping technology to the synthesis section of a conventional total recycle plant. The HP section is provided with all the equipment of the ammonia stripping process: HP stripper, kettle-type HP condenser, HP carbamate separator and carbamate ejector. Depending on the required capacity increase, the existing reactor may be maintained as it is or additional reaction volume may be added downstream.

The resulting CO₂ conversion of the revamped HP section is in line with the typical value for ammonia stripping processes (80%), which compares very favourably with the conversion achieved by total recycle reactors (typically 60%). So the urea solution going to the back end has a lower carbamate content and, even in case of a massive capacity increase, only minor changes need be made in the back end and normally all existing equipment items will be fully part of the revamped scheme. The steam consumption of the revamped

plant broadly similar to that of a modern ammonia stripping plant: expected values are in the neighbourhood of 700 kg/t urea, which is drastically lower than the usual consumption of total recycle plants.

Conversion of the HP section of existing total recycle plants to ammonia stripping technology is a proven strategy for achieving drastic capacity increase combined with a drastic improvement in plant performance.

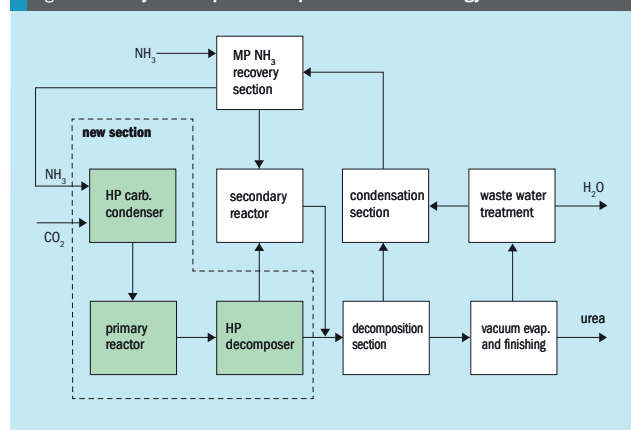
Melamine integration

Industrial production of melamine is nearly all based on urea as feedstock. Since gaseous ammonia and carbon dioxide are formed as by-products of melamine synthesis, it is convenient to combine melamine and urea plants so that these by-products can be recycled directly to the urea synthesis process. Therefore, new melamine plants are always erected next to an existing urea plant to supply the raw material and receive back the off-gases to reprocess.

The main technical problem with integrating a melamine plant with an existing urea plant is that, after the integration, the urea plant synthesis loop will have to run at a higher capacity to accommodate the additional ammonia and carbon dioxide coming from the off-gas.

The off-gases are normally produced at a lower pressure than the urea synthesis loop pressure, so they have to be condensed and pumped back up to the synthesis loop pressure. Off-gas condensation

Fig 6: Total recycle urea plant revamped with HEC technology



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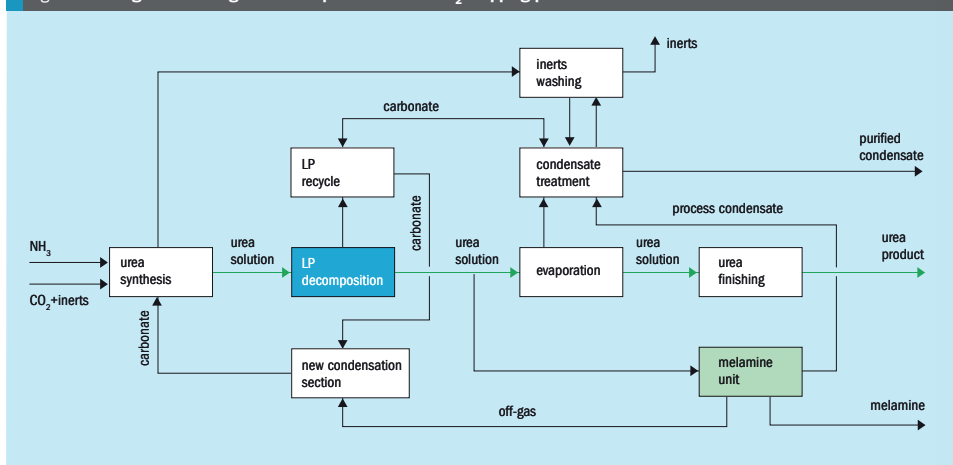
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Fig 7: The integration of Lurgi melamine process with a CO₂ stripping process



requires a certain amount of water to keep the ammonia and carbon dioxide in a liquid solution.

The amount of water depends on the pressure and composition of the relevant off-gas, which varies according to the melamine unit technology. The additional water necessary for off-gas condensation is then recycled to the synthesis loop, reducing the efficiency of the synthesis itself.

Casale designs for off-gas condensation and recycle plants are specifically tailored for the combination of urea and melamine plant technologies.

The purpose of each integration plant is to make the most efficient use of the water that is already present in the urea process so as to minimise the need for additional water for off-gas condensation.

Integration of LP off-gases (e.g. Lurgi process)

Melamine plants based on a low pressure process (e.g. Lurgi AG process) generate off-gases at 3.5 bar. Given the low operating pressure, condensation has to be aided by the addition of process condensate. The off-gases from the melamine plant, including ammonia, carbon dioxide and water vapour, are partially condensed in a low-pressure condenser with chilled cooling water (Fig. 7). The resulting mix is separated in a dedicated column, where the uncondensed vapours are scrubbed with process condensate. A recirculation pump continuously feeds the obtained lean car-

bonate solution to the LP condenser to help ammonia and carbon dioxide condensation into carbonate. Owing to the low pressure level of the incoming off-gases, the resulting solution is recovered in the LP section of the urea plant. Since the solution is rather lean and rich in water, it is recovered in the LP condenser so that no additional water is introduced into the urea plant.

Integration of MP off-gases (e.g. Eurotecnica process)

Off-gases from melamine plants based on Eurotecnica technology are typically produced at 20 bar. The integration process scheme requires a medium-pressure condensation step and some additional modifications to the overall urea plant in view of the additional water recycle necessary for the condensation and liquid handling of the off gases (Fig. 8). Given the pressure level, the required additional water content is definitely lower than for Lurgi off-gases. The stream from the melamine plant is integrated in a chilled water condenser. Carbamate solution from the LP section of the urea plant is mixed with the condensing vapours to aid condensation. Thanks to the operating pressure, the process is quite efficient and only a minor fraction (inert gases) remains in the vapour phase. Uncondensed vapours are vented to the LP section of the urea plant, whereas the carbamate solution is recycled to the HP synthesis section where some modification may be necessary.

Integration of HP off-gases (Casale process)

Casale melamine plants produce dry ammonia and carbon dioxide off-gases at high pressure (120 bar) without water. The off-gas condensation generates carbamate that is recycled directly to the urea synthesis reactor by means of a dedicated HP carbamate pump. A minor stream of lean carbamate solution is diverted from the urea plant to the melamine plant to facilitate off-gas condensation. Thanks to the high pressure and absence of water, the condensation of the off gases generates steam integrated in the existing network. The integration of such kind of plant does not foresee additional modifications to the urea plant.

Product finishing debottleneck

In cases where the finishing section becomes a bottleneck for any further capacity increase, Casale's portfolio of technologies offers the possibility of augmenting solid production capacity. If the limitation is the size of the prilling tower, rather than replacing the tower or adding a new one, Casale has developed its own fattening and granulation technologies based on so-called Vortex technology.

By adding one unit based on those technologies in parallel or in series with the prilling tower, it is possible to increase the capacity while retaining the existing prilling tower.

Melamine plant revamping

The main drawbacks of single-reactor HP melamine plants with ammonia-based purification are their high energy consumption and the water content of the off-gas.

In these plants, no heat can be recovered for direct use in the melamine process from the off-gas, which is separated from the melamine solution in the quencher of the low-pressure (purification) section, to which the whole reaction effluent (melamine melt and reaction off-gas) is fed. Off-gas is then returned to the urea plant water-saturated at a lower pressure than the synthesis one. The off-gas sent to the quencher also saturates the melamine solution, so to recover all the off-gas for recycling to the urea plant and to minimise carbon dioxide in the downstream operations, a stripping stage is needed. This stripping stage contributes to the high energy consumption of the process.

Casale has exploited some features of its LEM™ process to patent a method for revamping single-reactor HP melamine plants with ammonia-based purification.

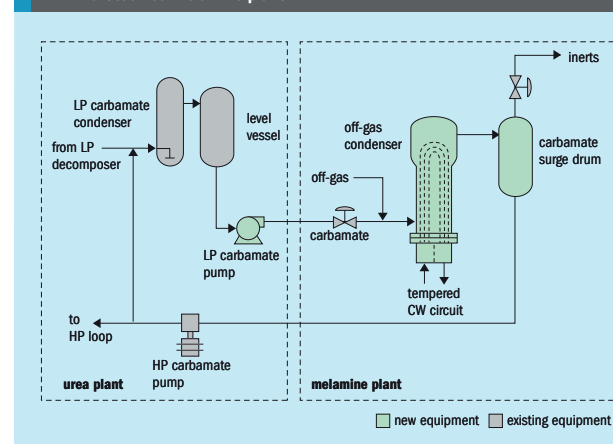
The previous state of the art consists of one synthesis reactor alone. Molten urea is directly fed to this reactor along with gaseous ammonia. The produced melamine melt and reaction off-gas are not separated in the reactor and they are sent together to the quencher.

The modification proposed in Casale's revamping method comprises installing a second reactor and a scrubber equipped with a steam generator. The new equipment operates at the same pressure as the existing reactor. The revamped scheme is shown in Fig. 9.

The resultant scheme is substantially the same as that of the synthesis section of the Casale LEM™ technology and thus has the same advantages, which are as follows:

- Higher urea conversion to melamine is obtained by an enhanced OATs conversion to melamine and reduced melam formation.
- A fraction of the heat from the off-gas is recovered directly in the melamine plant. Molten urea feed is preheated in the scrubber before reaching the first reactor and further heat is recovered by the production of steam from the cooling of circulating urea melt. This steam can be used in the melamine steam system.
- The washed off-gas is a high-pressure, water-free ammonia and carbon dioxide stream. This has a beneficial effect on

Fig 8: New MP section dedicated to condensation of off-gases from Eurotecnica melamine plant



the integrated urea plant, to which water will no longer be recycled, thus creating room for additional urea production.

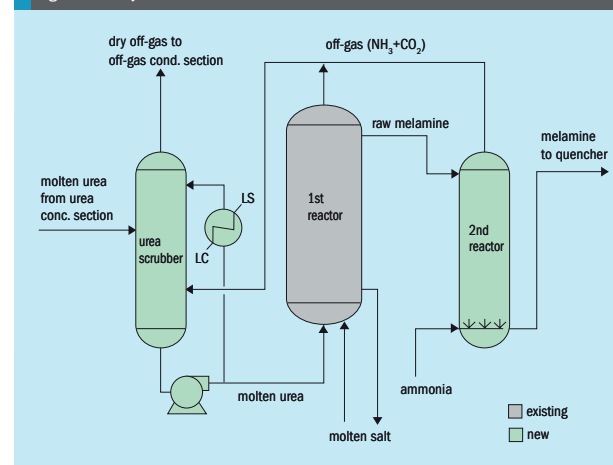
The off-gas can be condensed at high pressure in a new dedicated off-gas condensation section with the production of low-pressure steam.

Revamping the synthesis section of the plant will lead to advantages in the low-pressure (purification) section of the plant as well. Reaction off-gas will no longer be

treated in this section of the plant, which will be fed by a CO₂-free melamine melt.

The energy consumption of the low-pressure section is reduced in proportion to the lower gas load (in particular the lower carbon dioxide load) in that part of the plant, enhancing the energy-efficiency of the whole process. The results of this modification are a significant increase of energy efficiency of melamine and urea units and in addition a potential for increasing urea plant capacity.

Fig 9: Revamped HP section



New dual pressure process for nitric acid

The process chemistry for the production of nitric acid may have been developed over 100 years ago, but developments to the production process continue to take place. Weatherly's new dual pressure nitric acid production process is designed to deliver larger nitric acid plants (>1,000 t/d) as part of larger fertilizer complexes with lower operating costs and less capital cost than competing designs.

Nitric acid is an essential raw material for the production of fertilizers. Approximately 80% of total world consumption of nitric acid is used for the production of ammonium nitrate (AN) and calcium ammonium nitrate (CAN) fertilizers. Fertilizer producers have been under increasing pressure to remain competitive by securing favourably priced feedstocks and reducing cost of production. As a result, fully integrated, large fertilizer complexes are becoming more popular.

Weatherly Inc., a subsidiary of KBR, is a market leader in smaller-scale nitric acid production with its advanced high mono-pressure nitric acid technology. Since 1959 Weatherly has built 80 nitric acid plants worldwide (approximately 30% market share of installed plants) with a majority presence in North America, followed by India and the Asia/Pacific region.

Despite their lower total installed cost (TIC), mono-pressure nitric acid plants may not be economical for producing over 750-1,500 t/d of nitric acid due to high metal catalyst losses and lower ammonia selectivity.

To meet the growing need for larger nitric acid plants as part of larger fertilizer complexes, Weatherly now offers its own dual pressure nitric acid production process, which is designed to enable production of nitric acid on a large scale (over 1,000 t/d) at very low costs.

The technology has a highly efficient heat recovery design. Tail gas exits the system at 620°C, compared to a typical temperature of 490°C, enabling more

efficient recovery of energy that is subsequently used to generate energy to power up the plant. This allows the production of nitric acid at a much lower operating cost (about \$4 to \$5 per tonne lower) compared with competing dual pressure plants of the same capacity.

In addition, the Weatherly dual pressure design utilises its proven vertical reactor and heat recovery design, resulting in a much more compact foot print, enabling installation in tight plot spaces and reducing capital expenditure for piping, pipe racks and structural steel by 5-10% compared to traditional plants.

Another technology feature is the use of tube-side cooler condensers. Unlike shell-side condensers that have shorter total useful life due to shell-side corrosion, Weatherly technology utilises zirconium tubes with zirconium-lined tubesheets on the process side, increasing heat exchanger life to as high as 20+ years. This technology has been proven and used to retrofit shell-side coolers in existing nitric acid plants.

Weatherly dual pressure process description

Fig. 1 shows a block flow diagram of the Weatherly dual process nitric acid process.

The raw materials required for production of nitric acid are atmospheric air and ammonia. These raw materials are combined at elevated temperature and pressure and passed over a platinum catalyst where the ammonia reacts with

the oxygen. The ammonia oxidation reaction takes place at low pressure. The resultant low pressure process gas is passed through the heat exchanger train where the major portion of this reaction energy is recovered as heat to generate steam and reheat tail gas. The process gas is cooled and oxidised further in the low pressure cooler condenser where nitric oxide, nitrogen dioxide, oxygen and water combine to form weak nitric acid. The low pressure process gas is then compressed further in the NOx gas compressor and then fed to the high pressure cooler condenser and absorber where the product acid is produced. The tail gas leaving the absorber is reheated to provide power for the air compressor by driving a hot gas expander.

Air compression

Atmospheric air is filtered in a two-stage inlet air filter. The filtered air is then compressed by the air compressor which is part of the air compressor set along with the NOx gas compressor. The air compressor set is powered by a steam turbine and a hot gas expander.

A portion of the air from the air compressor is sent to the air/tail gas interchanger where it is cooled by heating the tail gas from the absorber tower. It is then used as bleach air and is routed under manual flow control to the bleach air cooler and bleacher. The main portion of process air enters the ammonia/air mixer before going to the platinum gauze to oxidise ammonia.

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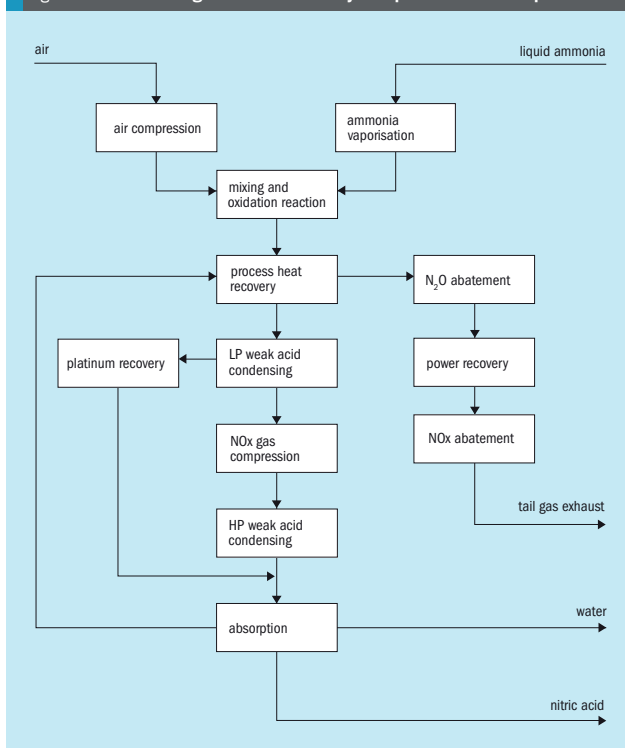
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Fig 1: Process flow diagram of the Weatherly dual process nitric acid process



Ammonia vaporisation

Liquid ammonia is fed to the plant and filtered in a cartridge type filter for removal of suspended solids before entering the ammonia vaporiser. The ammonia vaporiser uses circulated condensate to vaporise the ammonia. This condensate is continuously circulated through the top of the absorber where waste heat is recovered to vaporise ammonia. This chilled condensate loop provides lower temperature cooling water to the top of the absorber further enhancing the efficiency of the absorber.

To prevent any liquid carryover, which could damage the platinum catalyst, ammonia vapour is superheated in the ammonia superheater using low pressure steam. The resulting superheated ammonia vapour stream is filtered in a high efficiency sintered metal filter to remove possible contaminants and protect the platinum catalyst.

Mixing and oxidation reaction

The clean streams of air and ammonia are intimately mixed in the ammonia/air mixer and the mixture is evenly distributed over the catalyst where reaction occurs producing nitric oxide and water vapour. The dual pressure design utilises two identical side by side ammonia/air mixers and converters. Catalyst temperature is controlled by direct adjustment of the ammonia flow to the ammonia/air mixer. This control scheme has proven extremely effective in maintaining stable catalyst temperatures and has been used widely in Weatherly nitric acid plants. The resulting high temperature process gas then flows through the heat recovery system.

Process heat recovery – process gas

The heat recovery system consists of the expander gas heater, the waste heat boiler, the steam superheater, the oxidation spool, the tail gas heater, and low

pressure cooler condenser. For this dual pressure design, two identical side by side expander gas heaters and waste heat boilers are utilised. The two process gas streams are combined to flow through a steam superheater, tail gas heater, and low pressure cooler condenser.

The heat recovered by the waste heat boilers and steam superheater is used to generate 41 barg, 400°C steam. The steam so generated is sufficient to supply a steam export after fulfilling the steam turbine requirement. Additional energy is recovered by the tail gas heater and expander gas heater to reheat tail gas which increases power recovery in the hot gas expander.

Low pressure weak acid condensing

Process gas from the tail gas heater is fed to the low pressure cooler condenser where it is cooled by cooling water. Water vapour is condensed and reacts with the nitrogen dioxide in the gas stream to form weak nitric acid. The weak acid and process gas are initially separated in the outlet channel of the cooler condenser. Weak acid is further removed from the process gas in the low pressure acid separator. This weak acid separated from the process gas is pumped through a platinum filter to recover condensed platinum and then is fed to the absorber via weak acid pumps.

NOx gas compression

The process gas from the low pressure acid separator is combined with the bleach air from the bleacher and flows to the NOx gas compressor where it is compressed to 12 bara.

High pressure acid condensing

The high pressure process gas is fed to a low pressure steam waste heat boiler which recovers heat to generate low pressure steam. After passing through the boiler, the process gas is fed to the high pressure cooler condenser where additional acid is condensed. This acid is combined with acid from the absorption process in the product acid sump of the absorber tower.

Absorption

The absorber is a sieve tray absorber with cooling coils on each tray to remove the heat of reaction. The process gas flows upward through absorption trays where it is contacted counter-currently with absorber

feedwater and weak acid to produce nitric acid of the desired strength. Product acid flows from the bottom absorption tray to the product acid sump and then into the external bleacher.

In the bleacher, the product acid contacts a counter-current flow of bleach air which strips the remaining dissolved nitrogen oxides from the acid. The stream of clear, bleached acid is then allowed to flow under pressure to storage. The tail gas from the NOx abatement unit can operate during start-up and shutdown to help achieve a near colourless tail gas stack. The tail gas from the NOx abatement unit flows into the economiser to preheat boiler feedwater. The tail gas then exhausts to the atmosphere through the stack.

Process heat recovery – tail gas

The tail gas from the absorber, which has been reduced in NOx content to approximately 500-550 ppm by volume, leaves the absorber and flows to the tail gas reheating system.

Tail gas first enters the air/tail gas interchanger where it is heated by cooling bleach air. The steam tail gas preheater then uses low pressure steam to preheat the tail gas sufficiently to avoid process gas condensation in the tail gas heater, where it is heated further. It then flows to the expander gas heater where it is heated to 620°C before being fed to the N₂O abatement unit.

N₂O abatement

The N₂O abatement unit catalytically decomposes nitrous oxide (N₂O) by approximately 95% before entering the expander.

Power recovery

Tail gas leaves the N₂O abator and is fed at pressure 11 bara and temperature 620°C to the hot gas expander. The expander is coupled to the air compressor/NOx gas compressor set and generates over 90% of the compression requirement in an expansion turbine.

NOx abatement

Tail gas exit from the hot gas expander is mixed with a small stream of ammonia vapour and recycled tail gas in the ammonia/tail gas mixer before entering the NOx abatement unit. In the NOx abatement unit, the tail gas NOx concentration is reduced to 35 ppm by volume or less.

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Toxic safe havens

Various gas detection mechanisms are used in ammonia plants to protect personnel and equipment from accidental release of toxic gas. One common method of mitigating risk posed by toxic hazards is to designate occupied buildings as a toxic shelter-in-place (SIP). The purpose of this article is to discuss toxic gas detection and its application within SIPs. **M. I. Gandhi** and **A. G. Sarrack** of Baker Engineering & Risk Consultants discuss the application of various gas detection technologies to strengthen the SIP by providing much-needed data in the form of gas concentrations at various locations within the plant and also within the SIP to prevent personnel from evacuating when it is safer inside the SIP, or to ensure that occupants evacuate when necessary.

Many facilities in the chemical and petrochemical industry handle acutely toxic materials. Multiple gas detection mechanisms are available in the process industry, with applications ranging from modelling gas releases, to detecting an accidental release in a process facility, which may trigger a shutdown or mitigation function. Many of those technologies are used for gas detection in ammonia plants, in order to protect personnel and equipment. Toxic shelter-in-place (SIP) or toxic safe havens are vital for deployment of gas detection as part of a strategy to manage risks from toxic releases, as they can help shelter or safely evacuate personnel based on the ammonia gas concentration during a release scenario. Toxic SIPs depend on reliable, timely toxic gas detection in order to allow the ventilation system configuration to be aligned to the specific sheltering mode and to alert personnel that toxic emergency procedures must be implemented.

Key aspects of a highly effective toxic risk mitigation strategy for SIP are as follows:

1. Timely, reliable detection of toxic gases in order to take actions, such as:

- Outdoors – isolate heating, ventilation, and air condition (HVAC) prior to impact by the toxic plume and issue guidelines for evacuation once the plume clears.
- At the SIP HVAC inlet - ensure reliable, timely isolation when the toxic plume impacts the building.
- Within the SIP – provide informed decisions for evacuation from the SIP by providing information about the toxic concentrations outside.

2. Timely, reliable isolation of ventilation systems to avoid ingress of toxic gases.

3. Establish a leak-tight SIP volume to minimise infiltration:

- Establish a secondary barrier, to minimise impact of toxic air infiltration. Use a room or set of rooms within the SIP building as the protected space(s) to address impacts due to doors being opened after the toxic plume impacts the building.
- Address occupancy/volume/tightness to ensure that any CO₂ build-up and/or O₂ depletion issue is understood.

4. Train personnel and provide instructions to ensure that sheltering activities are performed properly.

5. Provide an effective backup/evacuation plan:

- Provide indoor toxic gas monitoring for the SIP.
- Develop procedures that identify when to evacuate the SIP.
- Train personnel so they take appropriate actions.
- Provide clear communication channels between the SIP location and emergency response personnel.
- Maintain reliable, appropriate escape packs to allow safe evacuation. Additional enhancements can be implemented to further reduce toxic risk or to improve comfort levels within the shelter location. These include the following:
 - Implement a filtration / scrubbing system to reduce toxic concentration.
 - Provide reliable, efficient purging of SIP and reduce effective infiltration rate.

- Provide an air-supplied header with full face respirators to allow long-term occupancy by essential personnel (typically limited to control room locations, this is intended only for trained personnel).
- Enable heating and cooling systems to remain functional without causing any ingress or potential path of infiltration.
- Provide potable water and lavatory.
- Include sealed windows and/or cameras to better reveal outdoor conditions to the SIP occupants.
- Establish outdoor / additional indoor toxic gas monitoring.

Aspects of an effective risk mitigation strategy for SIPs are addressed in more detail later.

Fig 1: Toxic gas monitor

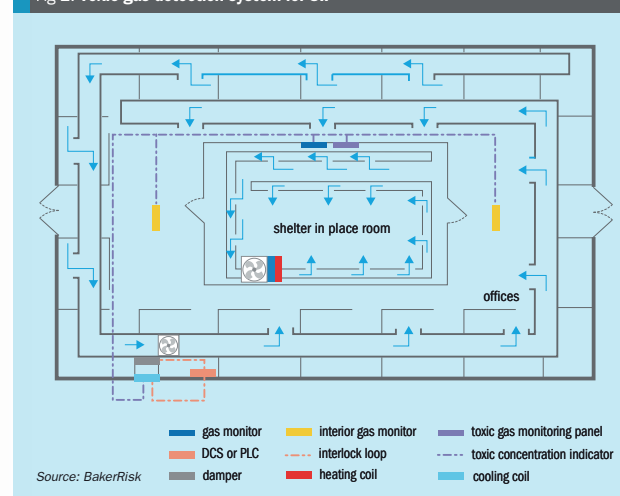


PHOTO: SENSIDYNE

Toxic gas detection

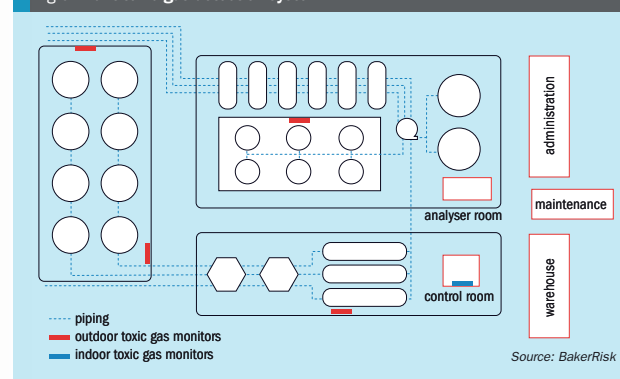
Facilities with severe toxic hazards should be equipped with toxic gas monitoring to ensure that personnel are made aware of possible toxic gas infiltration in their work area. Effective monitoring will allow personnel to take appropriate actions in response to the hazard (Fig. 1).

Fig 2: Toxic gas detection system for SIP



Source: BakerRisk

Fig 3: Plant toxic gas detection system



Source: BakerRisk

To be effective, toxic gas monitoring should be provided in these areas:

- ventilation intake of the SIP;
- inside the SIP;
- outside of the SIP.

The most important location for toxic gas monitoring is at the ventilation system intake of each occupied building intended to be used as an SIP. Without toxic gas monitors at the ventilation intake, a highly reliable ventilation system isolation strategy cannot be implemented.

Functional requirements can be summarised as follows:

- short response time;
- highly reliable;
- practical concentration threshold;
- appropriate design for the toxins of interest.

Because it is possible for the SIP environment to become dangerous, it is important for the SIP to also provide toxic gas monitoring for the indoor environment. It is not critical for indoor toxic gas monitors to have as short a response time as the ventilation intake monitors because indoor concentration will not rise as quickly as the concentration at the ventilation intake (outdoors).

Functional requirements can be summarised as follows:

It is important that the indoor toxic gas monitors are maintained to be reliable and are appropriate for the toxins of interest (toxins with potential to cause dangerous concentrations within the SIP). It is not as important to establish interlocks or alarms on indoor toxic gas monitors, as occupants who are sheltering in place would almost certainly pay close attention to the monitors, and are likely to have necessary training and knowledge to act appropriately. In addition, actions would likely be taken as conditions degrade, so timeliness and responsiveness are not nearly as critical as with ventilation isolation.

To take full advantage of the safety afforded by an SIP, it is important for occupants to remain within the SIP while it continues to provide a safe environment. Providing proper PPE will allow occupants to evacuate the SIP before it becomes dangerous to remain within the SIP.

Although indoor toxic gas monitors within the SIP do not need to have alarms, it is important for outdoor concentration thresholds to be established and understood by occupants of the SIP. Without this understanding, occupants may evacuate the SIP even though the environment within the SIP is safe, and the outdoor toxic gas concentration is highly lethal. The lack of pre-established concentration thresholds and response actions may also result in occupants remaining within the SIP as the conditions become too dangerous to stay there.

In addition to toxic gas monitors at ventilation intake and within the SIP (shown in Fig. 2), it is essential to also provide reasonably thorough toxic gas monitoring within outdoor areas of the plant as shown in Fig. 3.

Providing toxic gas monitoring in areas where releases are most likely to occur (pumps, compressors, load/unloading areas, etc.) improves the likelihood that the hazard will be detected before the SIP is impacted. This allows ventilation to be isolated (reduce ingress), and, equally as important, assists in determining when it is safe to evacuate the SIP after the release has been isolated.

Outdoor monitoring should provide real time concentration readings to emergency response personnel so they can provide helpful advice regarding evacuation routes and mustering points. The information may also be used to identify the release location so it can be rapidly isolated.

It is critical to select appropriate instrumentation for toxic gas detection and

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concentration monitoring. For example, the detectors and associated instrumentation must be designed for the material as well as the concentration ranges that may occur. Detectors also need to be located appropriately to ensure that vapours are reliably detected in a timely manner. Point gas detectors vs. open path should be considered.

Point gas detectors are contact type detectors and need the gas to come in contact with the sensor.

If the sensor is not laid out correctly, the most expensive and responsive sensor may fail to detect a release. Open path detectors (typically infra-red or laser based) provide the product of toxic gas concentration and distance alone lines of interest between sensors, which helps determine if the area under the detector coverage is impacted by a gas release.

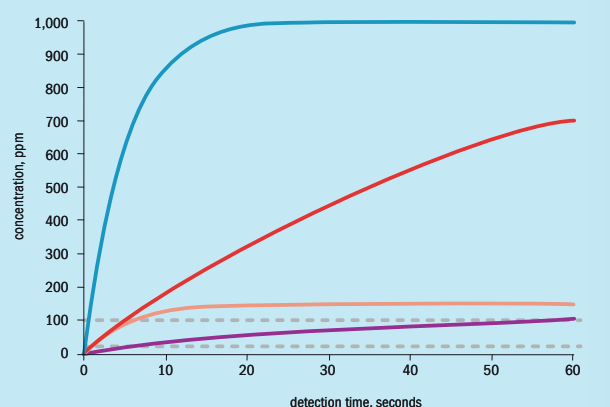
Open path detectors are generally more expensive than point gas detectors, but since they do not need to contact the gas, fewer detectors may be needed to adequately cover a given area and may be more practical in some cases, if an existing toxic gas system is being upgraded, and the new detection system can interface with the existing PLC/DCS in the area. Costs may be very similar for point detectors vs. open path system in terms of supporting hardware and software, as well as training of personnel.

Other aspects for selection of gas detectors are the signal generation/response time and the alarm set point. Response time is the time taken by a sensor to generate a signal after coming in contact with a gas. It can be thought of as the amount of time the system lags the actual gas concentration. It is an important parameter in all cases where rapid response is desired. For example, it is important for detectors on the HVAC inlet to respond quickly to ensure that the amount of toxic gases drawn in by the ventilation system is minimised.

However, response timing is not important for detectors within the SIP because conditions change relatively slowly, and actions that occur in response to the alarm are not immediate.

Fig. 4 shows a range of different gas concentration vs. time profiles for a hypothetical HVAC inlet toxic gas detection system. The importance of response time and alarm set point is discussed for each example concentration profile to clarify this point.

Fig 4: Example concentration profiles and alarm set points



Source: BakerRisk

For the purple line, maximum concentration is only marginally higher than the high set point (100 ppm), and is about five times as high as the lower set point (25 ppm).

If the detector has a 30-second response time, and the alarm set point is 25 ppm, it would alarm approximately 40 seconds after the toxic gas initially reaches the detector (10 seconds to reach 25 ppm plus 30 seconds response time).

However, if the alarm set point were 100 ppm, it would take 85 seconds (55 seconds to reach 100 ppm plus 30 second response time).

Note the extra 45 seconds to reach the alarm set point in this example may be critical in a real world situation.

The peach line shows a more rapid concentration rise, so alarm set point is less important, since the amount of time it takes for gas concentration to rise from the 25 ppm alarm set point to 100 ppm is only about 5 seconds. In that example, the alarms would be tripped at approximately 31 seconds or 36 seconds after toxic gases initially reached the target for the low and high set points, respectively.

The red line indicates that the rate at which concentration rises to the maximum concentration is lower, but since the maximum concentration is dramatically higher than the alarm set points, the time it takes to rise from the lower to higher set points is short (very similar to the peach case, about 5 seconds).

The blue line is an example showing that the effect of an alarm set point is negligible for the timing of an alarm because the maximum concentration is dramatically higher than the alarm set points being considered, and the concentration rises quickly to that level.

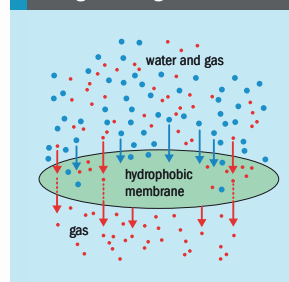
Although a lower alarm set point means a shorter alarm delay, it is also more likely to result in nuisance alarms. Alarm set points should be optimised with consideration of the types of toxic gas concentration profiles that might occur, the importance of alarm timing, and the likelihood of nuisance alarms.

General characteristics of toxic gas detectors

Toxic gas detectors are generally electrochemical, point-type sensors. Some vendors have toxic line-of-sight gas detectors, which are not covered in this paper, typically infra-red or laser based sensors. Other technologies for toxic detection are rarely found.

Electrochemical sensors operate by reacting with the gas of interest and producing an electrical signal proportional to the gas concentration. Gas that comes in contact with the sensor first passes through a small capillary-type opening and then diffuses through a hydrophobic barrier as shown in Fig. 5, and eventually reaches the electrode surface. This approach is adopted to allow the proper amount of gas to react at the sensing electrode. The gas

Fig 5: Hydrophobic membrane for gas sensing¹



that passes through the barrier then reacts with the sensor and produces an equivalent electrical signal.

Some of the key characteristics to look for when selecting toxic gas detectors are described as follows:

Detection Range

The range in PPM, depends on the specific gas. The sensor should be chosen based on the gas of interest. For NH₃, the range is normally 0-100 ppm or 0-500 ppm. Consideration should be made also for the location: e.g., the sensors inside the building can have a lower range, while those outside could be a higher range.

Response Time

T90 approximately 1 minute where T90 is the time for the concentration of the gas in contact with the sensor to reach 90% of its full scale value. Faster response time is generally advantageous, especially for external sensors. For sensors inside the room, a higher response time may be acceptable as the building prevents rapid build-up of gas; hence the approximately one minute response time has no impact on the overall SIP response.

Accuracy

10% of reading or 5% of full scale value are acceptable. Toxic detectors average about 10% accuracy throughout the different manufacturers.

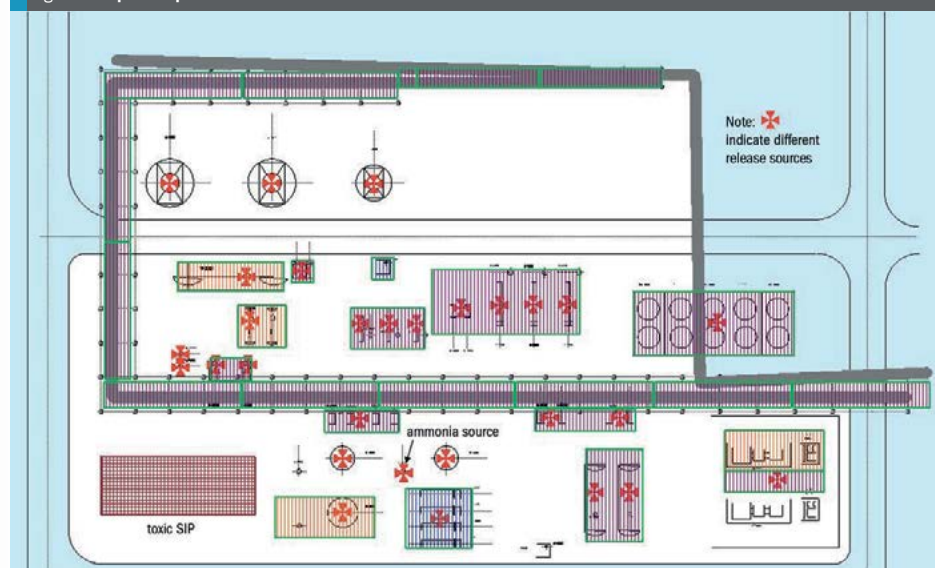
Nuisance Readings

Nuisance readings or false alarms can reduce the overall reliability of the system. Alarm set points should be low enough to alert personnel of build-up of toxic gas concentration, but high enough to reduce nuisance alarms/trips – this is more important for outside sensors, as inside sensors should usually indicate a zero value.

Humidity

Sensors are designed to operate at certain relative humidity (typically 15-90% RH). Provision should be made to operate the sensor in the permitted environment. In high humidity conditions, prolonged exposure

Fig 6: Example of a plant with toxic source and SIP



Source parameters:

• Ammonia at pressure of 150 psig, 70°F, pressurised liquid. • Unlimited inventory, 0.5-inch release at 3.3 ft (1 m) elevation

Building parameters:

• Wood trailer, with HVAC air changes of 0.6 ACH (air changes per hour) • Isolated building (Toxic SIP) 0.5 ACH at 5 mph wind speed • SIP room inside building 0.15 ACH; egress delay after source isolation: 5 minutes

Case 1 (without detection): • Time to HVAC isolation: 3 minutes. Case 2 Building Parameters (with detection): • Time to HVAC isolation: 1 minute

Evacuation from SIP (Building) at NH₃ concentration: 500 ppm. PPE availability: 95%

Source: BakerRisk

can cause excessive water build-up and create leakage. In low humidity conditions, the sensor can dry out.

Installation location

Location of sensors should be determined using consequence based tools (e.g., the best location is where the sensor comes in contact with toxic gas for maximum possible credible release scenarios.)

For SIPs, it is critical that detection be provided at the HVAC inlet to ensure timely HVAC isolation when needed. Within the SIP, the location of detectors is not important, since concentration would typically rise slowly and readily disperse throughout the protected volume. Location should also consider ease of maintenance and calibration.

Calibration

Some manufacturers require separate calibration gas and more frequent calibration. Sensors like these should be provided with calibration kits to reduce maintenance times. Other manufacturers have auto calibration where a sample gas is always present in the sensor body thereby not requiring an external calibration gas assembly.

Calibration and testing of detectors should be performed at least at the manufacturer's recommended frequency. If the governing standard in the area or calculations require more frequent testing, that should be followed.

Test gases and sample gases

To achieve proper calibration of the sensor, it is important to have the correct concentration of test and sample gases. If the gas concentrations of the sample gas and the actual process gas do not match within the tolerance range, response during a release may be delayed.

Diagnostics

Sensors provide diagnostics such as end of life, out of calibration, signal issues, etc. Diagnostics should be closely monitored to improve accuracy and reduce nuisance readings.

Hazardous area classification

Sensor assembly should be classified according to the area of installation

Regional and national certifications

Local certification requirements should be met.

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Table 1: Building occupant vulnerability – Cases 1 and 2

Case No.	Building section	Wind section	OV 15 min: no HVAC isolation	OV 30 min: no HVAC isolation	OV 15 min: with HVAC isolation	OV 30 min: with HVAC isolation
1	Admin – no detection	90	41.1%	76.8%	1.9%	4.7%
1	Admin – no detection	112.5	41.0%	76.8%	1.9%	4.7%
1	Admin – no detection	67.5	39.7%	75.8%	1.7%	4.4%
2	Admin – with detection	90	0.6%	0.6%	0.6%	0.6%
2	Admin – with detection	112.5	0.6%	0.6%	0.6%	0.6%
2	Admin – with detection	67.5	0.5%	0.5%	0.6%	0.6%

Source: BakerRisk

IEC61508 Certification

Safety Integrity Level (SIL) certification is available for certain devices. If the toxic gas detection is part of an automatic action associated with a specific reliability requirement (e.g., HVAC shutdown), that certification should be considered.

Case Study

An example of a processing plant with ammonia is shown in Fig. 6. There is only one building in the plant (marked with brown dashes), it is set up as a toxic SIP. There is an ammonia release source approximately 130 ft (40 m) from the building. A 1/2-inch release from the source is expected to reach over 1,500 feet (457 m) at 90% lethality levels for an assumed exposure duration of 10 minutes.

As shown in Table 1 for Case 1, occupant vulnerability (OV) resulting in a fatality for 15 minute duration shelter inside the building is approximately 40% for all the dominant wind directions. For 30 minute duration, OV is approximately 75%. In both these scenarios, all personnel are sheltering in place and not evacuating. Also, the HVAC isolation has failed to occur, since this is a manual shutdown and not based on gas concentrations in the HVAC duct.

For Case 1 with successful HVAC isolation, the OV values reduce to <2% and <5%, respectively, for 15 and 30 minute duration sheltering. Since the HVAC was successfully isolated within 3 minutes, the concentration inside the SIP room within the building was estimated to be approximately 1,500 ppm.

Evacuation is estimated 5 minutes after the source is isolated; total time for personnel exposure is 26 minutes.

As shown in Table 1, for Case 2, OV for 15 minute and 30 minute exposures with and without VAC isolation is approximately 0.6%. Due to toxic gas detection inside the SIP, personnel evacuate when the indoor concentration in the SIP room reaches 500 ppm. With 95% success probability for PPE, OV is calculated to be significantly lower than Case 1.

Conclusions

Developing toxic SIPs is one strategy that can be implemented to protect building occupants in case of an unintentional release of ammonia or other toxic gas. Toxic gas detectors play a very important role in making a toxic SIP highly effective. It is important to select appropriate detectors for the use, place them in proper locations, maintain them to ensure reliability, and implement automatic HVAC isolation to support SIP effectiveness and backup plan reliability. ■

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Acknowledgement

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The KAPP CO₂ chiller

KAPP Heat Transfer Engineers, together with UreaKnowHow.com, have developed the KAPP CO₂ chiller, a debottlenecking tool for any urea plant that is limited by the CO₂ compressor capacity during summer conditions when the CO₂ feed temperature exceeds design conditions. Three options are presented with short payback times.

In most urea plants the CO₂ compressor is the bottleneck for further capacity increase. In summer the CO₂ inlet temperature is typically higher than the design figure. In these conditions, cooling the CO₂ feed to return to design temperature will increase the CO₂ density and increase the capacity of the CO₂ compressor. Some CO₂ chillers make use of existing cold energy sources such as the ammonia refrigeration compressor. In summer, however, these cold energy sources can also be a bottleneck.

To overcome these problems, KAPP Heat Transfer Engineers, together with UreaKnowHow.com, have developed the KAPP CO₂ chiller, which cools the feed CO₂ temperature without using cold energy sources from the existing ammonia and urea plant. This article describes and evaluates three options for the KAPP CO₂ chiller:

- Option 1: Cooling feed CO₂ with 20 bar feed ammonia
- Option 2: Cooling feed CO₂ with atmospheric feed ammonia
- Option 3: Cooling feed CO₂ with an external cold energy source

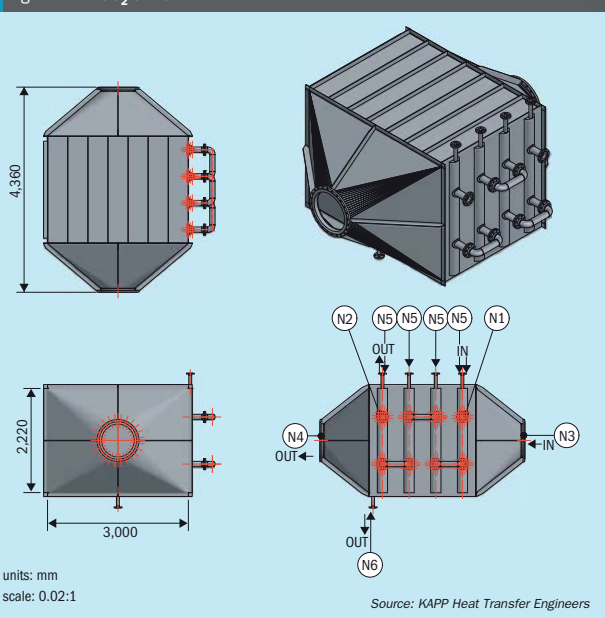
The base case for these evaluations is a 3,500 t/d Stamicarbon pool condenser urea plant with a CO₂ feed temperature of 45°C in summer.

The optimum design for the KAPP CO₂ chiller is a tube cooler as this type of heat exchanger leads to an extremely low pressure drop on the CO₂ side of only 600 Pa (0.06 bar), which is very important for a CO₂ chiller in order to maximise the density of the CO₂ at the inlet of the CO₂ compressor.

Option 1: Cooling feed CO₂ with 20 bar feed ammonia

The 80 t/h feed ammonia with a temperature of 17°C will cool the 120 t/h CO₂ feed of the urea plant from 45°C to 26°C. The CO₂ density will increase by 7% from 2.42 kg/m³ to 2.60 kg/m³.

Fig 1: KAPP CO₂ chiller



The higher CO₂ density has the following benefits:

- A higher load on the existing CO₂ compressor and approximately 5% increased urea production capacity. Assuming a 5% increase of urea production for six months of the year, for a 3,500 t/d urea plant, this equates to an additional 31,500 t/a of urea. Assuming a profit margin of \$100/tonne of urea this means an additional profit of \$3.15 million per year.
- The higher CO₂ density will also lead to a lower steam consumption on the turbine when the plant load is not fully maximised.

Using the 20 bar feed ammonia as the cooling medium also has other benefits:

- No extra energy is required to cool the CO₂. On the contrary the CO₂ chiller provides energy.
- The ammonia feed will increase from 17°C to 28.5°C, which leads to more LP steam production in the pool condenser. The extra duty is about 1,260 kW, which equals some 2.1 t/h extra LP steam production. Low value heat is thus converted into high value heat.

A drawing of the KAPP CO₂ chiller with some typical overall dimensions are provided in Fig. 1. Nozzle N1 and N2 are the

NH₃ inlet and outlet, Nozzle N3 and N4 are the CO₂ inlet and outlet. Nozzles N5 are the NH₃ vapour outlet on the NH₃ side, Nozzle N6 is the liquid drain on the CO₂ side.

Option 2: Cooling feed CO₂ with atmospheric feed ammonia

Atmospheric feed ammonia is first heated up to 0°C to avoid any ice formation on the CO₂ side of the chiller. Then 80 t/h of atmospheric ammonia with a temperature of 0°C is used to cool the 120 t/h CO₂ feed of the urea plant from 45°C to 15°C. The ammonia feed temperature will increase to 19°C. The CO₂ density will increase by 12% from 2.42 kg/m³ to 2.72 kg/m³.

The higher CO₂ density has the following benefits:

- A higher load on the existing CO₂ compressor and approximately 10% increased urea production capacity. Assuming a 10% increase of urea production for six months of the year, for a 3,500 t/d urea plant, this equates to an additional 63,000 t/a of urea. Assuming a profit margin of \$100/tonne of urea this means an additional profit of \$6.3 million per year.
- The higher CO₂ density will also lead to a lower steam consumption on the turbine when the plant load is not fully maximised.

Other benefits of using the atmospheric feed ammonia as a cooling medium include:

- No extra energy is required to cool the CO₂.
- The atmospheric ammonia will be freed from any inerts and hydrogen leading to higher temperatures in the urea synthesis section and to higher conversion figures in the urea reactor. Plus minimised risk of explosion.

Note: Ammonia delivered at about 18 bar contains inerts and hydrogen dissolved in it. Inerts decrease the conversion in the urea synthesis and hydrogen leads to explosion risks. Typical inert analysis figures are: hydrogen content 0.01 vol-%, nitrogen content 0.07 vol-%, argon content 0.03 vol-% and methane 0.09 vol-%. Ammonia from atmospheric storage will not contain any inerts or hydrogen as they will have been flashed off, thus making atmospheric a better choice when optimizing for maximum capacity and minimised risk of explosion.

Option 3: Cooling feed CO₂ with an external cold energy source

In the oil and gas industry it is quite common to rent an external cold energy source during summer conditions. With the continuously decreasing electrical power prices nowadays it can also be very attractive to rent such a packaged unit in an ammonia and urea plant.

For example, chiller rental company Aggreko from the Netherlands provides these services worldwide. Aggreko's chiller units can realise up to 1,500 kW cooling capacity, sufficient for the CO₂ chiller of a 3,500 t/d urea plant. KAPP Heat Exchange Engineers are able to adapt the design of the CO₂ chiller to such a cooling unit. The unit can be rented and connected to the CO₂ chiller during summertime only.

For example, when renting two Aggreko WCC800 units at ambient conditions of 50°C and 50 Hz power frequency the optimum chilled water temperature and delta-T is 15 and 6°C. With this cooling capacity it is possible to cool 120 t/h CO₂ from 45°C to 22.8°C with a density increase to 2.63 kg/m³. This is a density increase of more than 8%, thus even better than cooling with feed ammonia.



The WCC800 air-cooled fluid chiller (above) has been specially designed for the demanding rental market, to meet the different temperature control needs of many industry sectors, including food and beverage, refining, chemicals, utilities and manufacturing.

The units, suitable for wide voltage (380 / 480 volt) and frequency range (50 and 60 Hz), can operate in ambient temperatures ranging from -18°C to +50°C and deliver fluid from -12°C to +15°C.

High cooling capacity and increased coefficient of performance (COP) were key drivers for this innovative unit, which achieves 742 kW cooling capacity at Eurovent normalised conditions and a COP of 3.10.

All fans are inverter controlled to save energy and reduce noise, with a built-in sound enclosure for compressors. As with any other Aggreko chillers, the WCC800 is fitted with Aggreko's own remote operating system and uses environmentally friendly R134a refrigerant.

This option minimises the investment costs and requires only some power consumption, still realising a very short payback time.

An average price for 1,400 kW of chillers with associated hoses, pump, cables and manuals valves amounts to about \$25,000 per month. This is an average price based on the countries in the Middle East in which Aggreko operates.

The higher CO₂ density has the following benefits:

- A higher load on the existing CO₂ compressor and approximately 5% increased urea production capacity. Assuming a 5% increase of urea production for six months of the year, for a 3,500 t/d urea plant, this equates to an additional 31,500 t/a of urea. Assuming a profit margin of \$100/tonne of urea this means an additional profit of \$3.15 million per year.
- The higher CO₂ density will also lead to a lower steam consumption on the turbine when the plant load is not fully maximised.

Using the Aggreko chilling unit as a cooling medium has further significant benefits:

- No impact on the existing cold energy sources.
- No additional investment costs required.
- Very limited rental costs only during summer.
- High flexibility to use the cold energy from the Aggreko chilling unit wherever needed.

An alternative cold energy source is to use vapour absorption recovery (VAR) technology to produce chilled water instead of the compressor technology used by Aggreko. KAPP Heat Transfer Engineers can also provide optimum CO₂ chiller designs using VAR technology.

Finally, the KAPP CO₂ chiller has another noteworthy benefit. Often CO₂ compressor internals get fouled by carry over of washing solution from the CO₂ washing section in the ammonia plant. This fouling leads to lower capacities and vibration issues. The KAPP CO₂ chiller will condense the washing liquid thus reducing to a significant extent any future fouling problems.

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