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Number 347

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nitrogen + syngas

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Methanol as a shipping fuel

Caribbean nitrogen and methanol

Steam reformer improvements

Multi-stage scrubbing



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NITROGEN+SYNGAS
ISSUE 347
MAY-JUNE 2017

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Cover: ME-LGI main engine.
Image courtesy of Methanex.



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Economies at other scales



Six years ago, at the CMAI World Methanol Conference in San Diego, Deo Van Wijk, the man behind the Titan and Atlas methanol projects on Trinidad – now operated by Methanex – and the re-start of the Eastman (now OCI) methanol plant in Texas, proposed setting up twin 10,000 t/d methanol plants in the US or West Africa to produce a mix of gasoline, propylene and olefins. As always, Deo was a man ahead of his time, but methanol plant and project sizes are continuing to move upwards. In the next month or so, the Kaveh methanol plant is due to come on-stream at Bander Dayyer in Iran. This Casale-designed facility has a nameplate capacity of 7,000 tonnes per day, and will become the largest single train methanol plant in operation, breaking the previous 5,400 t/d record held by the M5000 plant on Trinidad. An even larger project is under consideration for the Pacific Northwest of the US, with Chinese developer NW Innovation Works (NWI) targeting two 10,000 t/a methanol plants – albeit not in a single stream but as two twin 5,000 t/d units; Big Methanol is definitely a phenomenon whose time has come. Indeed, methanol's step change in production and use, from 30-40 million t/a just a few years ago to over 70 million t/a today, has come about precisely because of the move from 2,500 t/d plants to units of 5,000 t/d and up, allowing greater economies of scale and cheaper production cost per tonne, bringing a raft of downstream markets like olefins production and fuel uses into economic viability.

That move to larger plant sizes is also something that can be seen – albeit more incrementally – on the nitrogen side, with ammonia plant capacities creeping to 3,300 t/d and urea to 4,000 t/d, and with plants offered by leading contractors at even larger sizes – 5,000, even 6,000 t/d. But while moving to larger plant sizes brings down unit production costs and can make production more efficient, it also brings with it restrictions – on site access, equipment size, and the requirements for there to be sufficient natural gas available for the lifetime of the plant. And it also depends upon being able to find a market for so much product, leading to a focus on deep water access for export to other regions.

These constraints have started to lead innovation at the opposite end of the scale, in the field of small-scale ammonia and methanol production units. There are many feedstocks which simply cannot be sourced at the size of a modern, world-scale chemical facility, from biomass or waste gasification to biogas, renewables, flared gas from oil production or isolated unconventional gas wells with limited pipeline connectivity – the 'stranded gas' of the present and future. Here a different approach is required; modular, pre-fabricated, mass-produced, easily transportable production facilities, perhaps using lower pressures and innovative microchannel reactors with a high surface/volume ratio and better heat and mass transfer properties than a large-scale vessel. At the moment there are a number of small firms trying to break into this market, but many of these are now establishing commercial production facilities. On the methanol side, Maverick Synfuels, Oberon Fuels, GasTechno and Primus Green Energy are among those gaining experience with commercialising these technologies. On the ammonia side, the technologies are often still with research institutes and universities, but small-scale hydrogen production is a very active field of research, and the likes of Proton Ventures are now looking towards small-scale ammonia production, via the N-Flex collaboration with Casale. As the chemical industry continues to change in the 21st century, it seems likely that, as well as the monster, headline-grabbing facilities like Kaveh and NWI, we will increasingly see a proliferation of small-scale, more easily moved units which can take advantage of advantaged feedstocks of various types, and which do not require such a huge market to take their product. ■

Richard Hands, Editor



XINJIANG XLX GO FOR A TWIN!

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Price trends



MARKET INSIGHT

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

NITROGEN

Urea prices increased uninterrupted in the opening weeks of 2017, reaching above \$250 per tonne in February amid temporarily tight supply out of key export regions and a delayed start to seasonal buying. Seen by some as a “bullish” start to the year, the relative run up in urea prices brought a welcome reprieve to producers doing business in early 2017. However, it was certainly not a signal of a complete market turnaround (which some well-meaning but less-informed optimists wrongly perceived it to be).

The urea market has since moved back in line with its wider industry cycle now that the first Indian import tender of the season has been announced. Urea prices then weakened in April as expected, with new demand failing to materialise in the face of ample supply from key exporters. The bearish price sentiment continues in the urea market, with the absence of demand remaining a key driver preventing prices from increasing in the short-term. Prices are forecast to weaken further in May and June as the gap between supply and demand becomes wider, before beginning to tighten in Q3 2017.

Despite two recent tenders from India, urea demand discussion has centred on changes in Indian demand and expectations for the year ahead. Urea imports totalled 5.5

million tonnes in the fiscal year 2016-2017 (April-March), a decrease of 3 million tonnes, or 35%, from 8.5 million tonnes in the previous year, according to the latest data from the Department of Fertilizers. These latest import figures represent the lowest levels since the fiscal year 2009-2010 when the country imported 5.2 million tonnes. In March 2017, Indian imported 178,000 tonnes of urea, up 8% compared to 165,000 tonnes in March 2016. Oman was the biggest supplier to India, primarily through the offtake agreement with OMIFCO, shipping 2.3 million tonnes of urea during April 2016 to March 2017. The other major supplier was Iran at over 1.5 million tonnes while Chinese imports declined to less than a quarter of the previous year, at 820,000 tonnes.

The Indian government continues to be optimistic in its plans to reduce urea imports by restarting closed or loss-making urea plants, expanding existing projects and building new ones. Media reports have suggested that the government would look to stop importing urea from 2022, although the availability and cost of gas supply to urea plants is a key determining factor in these aims being met.

More immediately on the supply side, and more influential in determining nitrogen prices, the Chinese nitrogen sector has come under increasing environmental pres-

sure, in addition to already struggling to operate profitably amid a squeeze on weak nitrogen prices and fluctuating coal prices. Chinese environment supervision has been strict and frequent since the end of 2016 due to serious problems with smog in the north of China, especially in Beijing.

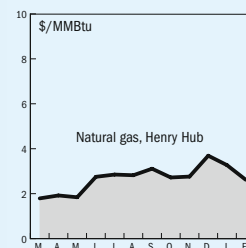
It is reported that the government will inspect 15 provinces in April 2017, including Hunan, Anhui, Xinjiang, Shanxi, Shandong and Sichuan, which are all major nitrogen fertilizer producers. In the middle of February, the Ministry of Environmental Protection of China inspected Beijing, Tianjin and another 16 cities in Hebei and Shanxi provinces, both of which are big urea producing provinces. During the periods of inspection, some urea producers reduce operating rates to avoid problems, but there were no reports that plants stopped production permanently, and so far, there is only modest direct environmental impact on urea production. Nevertheless, urea producers are still curtailing output due to challenging market conditions. Significant volumes of inefficient capacity were already closed in 2015 and 2016 due to market weakness and fierce competition.

More globally, the commodity downturn that began in late-2014 has entered into its third year, and global energy prices remain significantly below the levels seen prior to the major correction in oil prices. In North America, the ex-works urea production cost averaged \$138 per tonne in January 2017, driven by a Henry Hub gas price of \$3.10/MMBtu at the start of 2017. Ukraine posted the only decrease in ex-works costs in our sample, as the region has benefited from the diversification away from Russian gas imports towards competitively priced reverse gas imports from Europe to secure lower feedstock prices, coupled with a significant depreciation in the local currency. The Saudi Arabian and Egyptian ex-works urea cost remained unchanged in Q1 2017 on average compared to the previous year. This is due to the state-regulated gas price remaining unchanged in both of these regions.

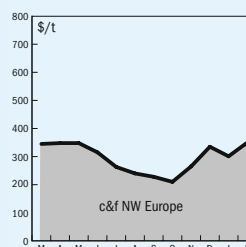
Urea margins improved by an average of 50% between October and January 2017, as all global urea price benchmarks posted increases, improving producer margins universally. Ukrainian producers continued to make losses through January 2017, although these losses have been reduced due to a revision of the state-fixed domestic gas price and off the back of the temporary increase in nitrogen prices, with the Yuzhny urea price reaching \$240 per tonne in January 2017.

END OF MONTH SPOT PRICES

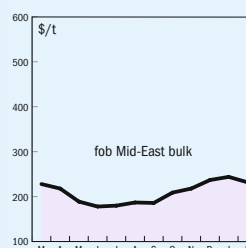
natural gas



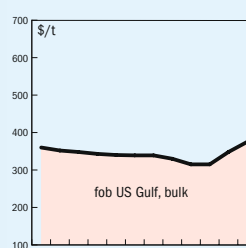
ammonia



urea



diammonium phosphate



MARKET INSIGHT

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

METHANOL

Methanol prices fell significantly during April, dragged down by negative affordability into MTO and lower demand into the MTO sector. Asian prices in April traded down \$37/t, in a weekly average range of \$287-334/t c.f.r; China weekly average prices fell \$40/t in a range of \$287-300/t c.f.r.

The official, posted reference prices from the two main US producers for April were \$1.23/gallon for Methanex and \$1.17/gallon for SCC, equivalent to \$409 and \$389/t. IHS Chemical's contract net transaction price for May was officially posted down \$0.122 at \$1.203/gallon (nominal \$400/t). In Trinidad the average overall operating rate increased to around 85% for the month of April. Methanex's Chilean unit is estimated to be running at an increased level of 75% of nameplate capacity; Methanex has secured additional natural gas supply through April of 2018 via a tolling agreement with Argentina.

North American units operated at an overall rate of 67%, with turnarounds at the Celanese/Mitsui JV unit in Clear Lake and the Lyondell unit in Channelview. Methanol demand has been slowly improving, with a modest increase in demand into construction applications; this includes formaldehyde for forest products and MMA for coatings and sheeting applications. Demand into MTBE is good. In methanol project news, Consolidated Energy Limited (CEL) and OCI entered into a binding agreement to jointly invest in the 1.7 million t/a Natgasoline project in Beaumont, TX. Yuhuang Chemical has begun construction on their first methanol unit, per a company announcement, with a Q4 2019 start-up expected.

European spot prices (T2 f.o.b. Rotterdam) for April averaged €308/t over the month, down €70 over March. The 2Q 2017 West European Contract Price was settled at €405/t, f.o.b. Rotterdam T2, up €50/t from 1Q 2017. The ongoing suspension of duty on methanol arriving into the EU implemented by the European Commission is likely to remain for the foreseeable future while a protest following the changes in GSP status is reviewed by the EC. In Saudi Arabia, Ar Razi III re-started in early April after a turnaround; Ar Razi V came offline in late April for a planned

maintenance outage. AzMeCo has been idle since November 2016 following a disagreement over prices with its Russian natural gas supplier. Viromet in Romania is idled due to high gas prices.

Liquidity was thin in the European methanol market in April; spot price volatility deterred buying. In addition, low Rhine water levels led to logistical issues and higher unit freight costs, further discouraging spot trade. Demand was steady, with formaldehyde units operating well at around 90% of capacity; acetic acid demand was stable. Inventory levels in Rotterdam and the Mediterranean were higher than the severely restricted levels seen at the start of the year, but still only at moderate levels.

In China, overall capacity utilization was at a similar level to the previous month, at around 53% of nameplate capacity, or around 68% of effective capacity. Demand into the MTO sector improved in late April after Jiangsu Sailboat's MTO facility restarted, having been offline since January. The company's methanol inventory is thought to be sufficient to support MTO production for about two months. Overall, MTO units ran at an average of around 74% in April. Demand into acetic acid in China was stable; demand into MTBE was stable-to-strong, with positive buying sentiment from the gasoline sector.

In Southeast Asia, the market was stable and long, with adequate supply from within the region and from Middle Eastern imports. Demand into biodiesel was flat, with an average operating rate of 65%; the formaldehyde industry was healthy with an average utilization rate of 70%. Acetic acid demand was lower than expected as a unit in Singapore ran at a reduced rate because of a downstream issue.

In Iran, National Petrochemical Company Executive Director Marzieh Shahdaei, was quoted in Iranian media as saying that completion of various petrochemical projects, including methanol, by the end of next year (fiscal) will raise annual production capacity to 72 million t/a, with the 2.3 million t/a Kaveh Methanol Company plant due to be “fully operational” by March 2018, around the same time as the 1.7 million t/a Marjan plant.

Table 1: Price indications

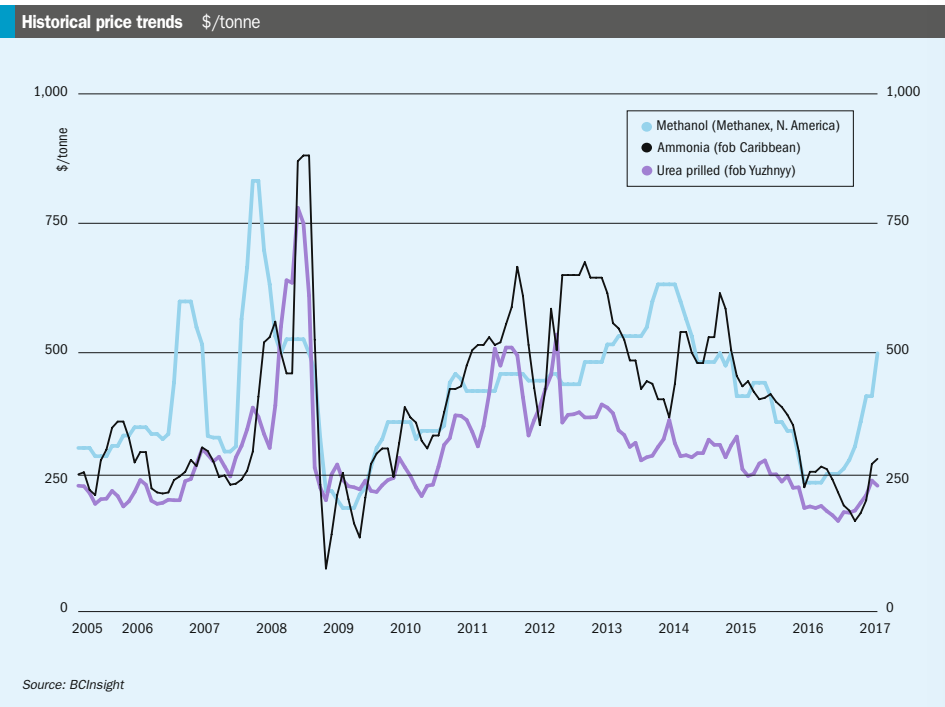
Cash equivalent	mid-Mar	mid-Jan	mid-Nov	mid-Sep
Ammonia (\$/t)				
f.o.b. Caribbean	295	215	175	195
f.o.b. Arab Gulf	350	195-221	175	165
c.f.r N.W. Europe	365	345	245	230
c.f.r India	360	230	187	225
Urea (\$/t)				
f.o.b. bulk Black Sea	237	251	219	190
f.o.b. bulk Arab Gulf*	211	260	238	181-193
f.o.b. bulk Caribbean (granular)	218	243	213	194
f.o.b. bagged China	231	265	236	196
DAP (\$/t)				
f.o.b. bulk US Gulf	375	329	323	339
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	169	169	145	137

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

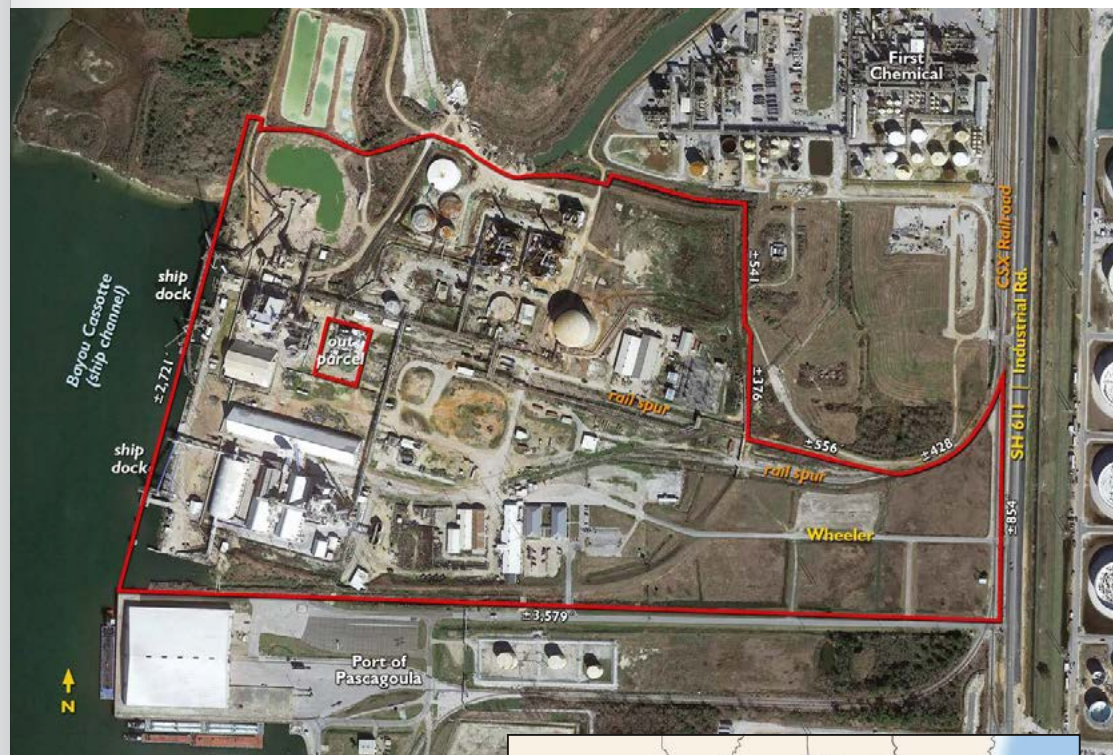
Source: Fertilizer Week

Market outlook

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- AMMONIA**
 - The short-term supply shortages seen in Q1 2017 at the port of Yuzhny have now eased, and expectations are that the price rally seen at the start of 2017 has run out of steam.
 - Despite this, strong demand in the US corn belt has allowed for strong increases in pricing across all other major price benchmarks in recent months. While this will likely allow prices to stay at a higher level, the onslaught of new capacity expansions in the US and South America that are due online in 2017 will undoubtedly add pressure and put a cap on the upward trajectory.
 - These new plants will contribute to the persistent ammonia market oversupply and a weaker price sentiment beginning in mid-to-late Q2 2017. The Yuzhny ammonia benchmark is expected to be in the range of \$290-330/t f.o.b. in April, supported by the continued steady demand.
- UREA**
 - Market players had felt that there was little downside to the urea market in early 2017, but demand has begun to soften at the end of March and this continued into April, with negative sentiment in the market beginning to take hold.
 - Demand in Europe, Brazil and the United States has continued to be weak, despite the lower prices seen since February. The prospect of new production in the US points towards lower pricing, and this has fuelled negative market sentiment.
 - Despite urea prices rising to their highest levels since November 2015 in February 2017, the Yuzhny prilled urea benchmark had fallen uninterrupted since then until press time, and is expected to continue to remain soft through May.
 - Chinese urea capacity continues to close: around 4.4 million t/a shut in 2016 and 3.3 million t/a in 2017.
- METHANOL**
 - China continues to hold the whip hand as regards global pricing, with imports to feed MTO production the key driver of methanol prices at the start of 2017. However, MTO plant operators have shown once again this year that they are not prepared to countenance prices rising too high.
 - In the longer term, the continuing addition of new methanol capacity in the US will ease any tightness in the market, with the US set to become a net exporter of methanol over the next two years, displacing tonnages normally sourced from Trinidad and Venezuela. US exports to China look increasingly likely.
 - A series of plant turnarounds around the world have kept methanol markets tighter, especially in Europe and North America, but availability should ease going forward, including in Trinidad, where gas availability is expected to ease.



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ISRAEL

Court orders ammonia tank drained

The long-running saga of Haifa Chemicals ammonia tank at the port of Haifa continues. Now an Israeli court has ordered that the tank be emptied by April 1st over concerns that a breach to the storage tank could pose a threat to life in the city. Haifa Chemicals uses the tank to store imported ammonia, which it uses to make potassium nitrate, most of which is exported, and has warned that it will have to cease operations. Haifa Chemicals employs 800 people and has an annual turnover of \$600-700 million.

The court order is a response to a petition by the city of Haifa's municipal government following the publication of a report the city commissioned which found that the ammonia operations pose a serious risk to the population. As well as accidental release, the report also considered terrorist attack – last year, Hezbollah leader Hassan Nasrallah threatened to target Haifa's ammonia facilities with rockets.

The Israeli government has been trying to develop an alternative source of ammonia, by building an ammonia production site in the southern Negev desert near the closely guarded Dimona nuclear facilities, but a tender to build and operate the plant attracted no interest last year. The main concerns were the high price of natural gas feedstock and uncertainty over future local demand for ammonia. Haifa Chemicals did not take part in last year's tender, but has since proposed to invest \$175 million to take a share in the project, and is asking the government to match the sum. The company says that so far it has received no official response to its proposal. Either way, however, construction would take at least two to three years, and Haifa would still require a source of ammonia in the interim. Israel consumes around 120,000 t/a of ammonia, two thirds of which is represented by Haifa Chemicals. ■

BRAZIL

Petrobras to sell Três Lagoas

Petrobras says that it is in negotiations with a Chinese consortium led by Sinopec for the sale of its Três Lagoas UFN3 urea and ammonia facility in Mato Grosso do Sul state. The consortium would reportedly assume debts totalling \$12.0 million as part of the purchase agreement. Construction of the \$1.2 billion facility was interrupted in December 2014 by a corruption investigation into all of Petrobras' activities, but is "81% complete", according to Petrobras. The facility was designed to produce 760,000 t/a of ammonia and 1.2 million t/a of urea.

of product delivered in 2016, Yara says that the Pardies operation "suffers from limited scale, raw material integration and export competitiveness". The closure in 2010 of a nearby industrial operation deprived the Yara Pardies plant of many synergies that existed between the two plants, forcing Yara to close the ammonia production unit at the site. Yara has subsequently impaired the Pardies assets in both 2015 and 2016. The Yara Pardies plant has 85 employees and a production capacity of approximately 100,000 t/a of technical grade ammonium nitrate.

FRANCE

Yara to close Pardies plant

Yara has announced the closure of its Pardies site in France. In a message from Svein Tore Holsether, Yara's president and chief executive officer, the company said that it is considering closing the Yara Pardies plant and seeking buyers interested in taking over the facility. This process is part of Yara's on-going efforts to strengthen long-term competitiveness, the company added. While France remains a valuable market for the company, with more than 2.5 million t/a

the new ammonia plant, its utilities and off-site infrastructure. The ammonia plant's project financing is expected to reach completion by the end of June, according to SNC-Lavalin. The new plant will have a capacity of 1,000 t/d (330,000 t/a).

UNITED STATES

Urea plant due for 2018 completion

Dakota Gasification Co's new urea plant is now scheduled for completion in early 2018, according to parent company Basin Electric Power Cooperative, after a decision by the company's board to proceed with the 300,000 t/a project. Projected costs have risen from the initial estimate of \$500 million to \$740 million, and the lead engineering, design and construction contractor AECOM/RUST has had its contract terminated and the project brought back in-house. Construction of the plant is said to be 65% complete, including the breaking down and rebuilding of a 50,000 tonne storage facility following storm damage. The project also includes a truck and rail loading facility. The urea will be produced from spare ammonia capacity at the site, which gasifies local coal to produce power, ammonia, methanol and other products.

"We believe that the urea plant will contribute a positive benefit to the long-term future viability of Dakota Gas, but more importantly, rural America," said Paul Sukut, Basin Electric CEO and general manager. "This project represents our vision for the future of Dakota Gasification Company and continues our innovative history of transforming a domestic, abundant coal – lignite – to develop several beneficial products for our agricultural and manufacturing industries. Urea will mark our third fertilizer produced at the plant and will directly serve our farming community within the tri-state area."

Cronus completion looking unlikely

Cronus Chemicals has indicated that it does not foresee completion of its new ammonia plant at Tuscola, Illinois, before 2020, several years behind schedule. Costs for the 800,000 t/a greenfield ammonia plant now stand at \$1.9 billion, \$500 million more than the initial estimate, and little or no site work has begun according to local press reports, and contracts with constructors and licensors are still not finalised. Up to \$50 million of tax incentives from the Illinois departments of Transport and Commerce stand to be forfeited if the plant is not operational by July 2020 at the latest.

Agrium commissions new urea plant

Agrium says that it has successfully commissioned a new urea plant at its Borger Nitrogen Operations facility in Texas. Production is ramping up and expected to reach its full capacity of 610,000 t/a of urea by the second quarter of 2017. Of that production, 100,000 t/a will be used for production of urea solution for Diesel Exhaust Fluid ("DEF").

"The successful completion of our first run of urea production from our Borger nitrogen expansion project continues to emphasize our commitment to operational excellence and creating shareholder value at Agrium. We look forward to bringing our reliable and high quality urea and DEF products to existing and new customers in this key agricultural region of the US," commented Agrium's president and CEO, Chuck Magro.

OCI starts up Wever plant

OCI and its wholly-owned subsidiary Iowa Fertilizer Company (IFCO) have announced the official start of production at its plant in Wever in southeast Iowa. The Governor of Iowa Terry Branstad, Lt. Governor Kim Reynolds, the Lee County Board of Supervisors and others joined OCI in an event to inaugurate one of the largest private sector construction projects in Iowa's history and the first world-scale, greenfield nitrogen fertilizer facility built in the United States in more than 25 years. The plant will produce approximately 1.5-2 million t/a of nitrogen fertilizer products, and can alternate between products at short notice, depending on market demand.

"The start of production at Iowa Fertilizer Company is a transformative moment for the agricultural industry in the United States,"

said Nassef Sawiris, Chief Executive Officer of OCI N.V. "As one of the most innovative and efficient manufacturing plants in the nation, Iowa Fertilizer is leading the way in providing American farmers a stable, high-quality and domestic source of nitrogen fertilizer products. Given its location among the highest nitrogen-consuming acres globally, on the border between Iowa and Illinois, the number one and two corn-producing states in the nation, the site houses not only a premier production facility, but also an industry-leading distribution centre."

"In Iowa, we have created a roadmap that attracts new businesses and supports key industries that drive long-term economic growth," said Governor Terry Branstad. "At the outset of the Iowa Fertilizer project, the unemployment rate in Lee County was the highest in the state at 8%. That is why my administration fought so hard to encourage the company to locate its new fertilizer plant in this great community. Today, the county's unemployment rate is down nearly three points to 5.3%, providing a positive and meaningful impact on working families in the area."

INDIA

Revamp for MCF

KBR Inc. has been awarded a contract by Mangalore Chemicals and Fertilizers Ltd (MCF) for the revamping of its ammonia plant at Panambur, Mangalore, for an undisclosed sum. Under the terms of the contract, KBR will provide its ammonia technology to enhance the energy efficiency of the plant.

"This contract shows the faith of our customers in KBR's ammonia technology," said John Derbyshire, President, KBR Tech-

nology & Consulting. "We are firmly committed to delivering world class projects using KBR technologies to help our clients meet their performance objectives."

CHINA

New melamine expansion

Xinjiang Xinlianxin Energy Chemical Co. Ltd has decided to go ahead with a second 60,000 t/a melamine plant at its site in Xinjiang province. The company's previous 60,000 t/a unit, which like the new plant features the world's largest single high pressure melamine reactor, was commissioned in September 2016. Eurotecnica has been selected to license an identical plant, using the company's newest 4th generation Euromel™ melamine process, which combines low energy consumption, lower capital cost and zero pollution. This will be the 21st melamine plant licensed by Milan-based Eurotecnica, a subsidiary of the Proman Group.

NORWAY

Fire at Yara Porsgrunn

On April 24th Yara reported that there had been a fire at the ammonia plant at its Porsgrunn facility. The fire was extinguished and no personnel were injured, according to the company. Investigations into the cause and material damage of the fire are on-going, but Yara says that the damage is limited to the ammonia plant. Porsgrunn has the capability to produce for full finished fertilizer production based on imported ammonia. It has an annual production capacity of approximately 0.5 million t/a ammonia, 2.2 million t/a NPK and 0.8 million t/a of calcium nitrate. ■

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- Gas market liberalisation – the future of low-cost nitrogen production?
- The impact of falling oil revenues on nitrogen producers in MENA
- How do these changes shape Integer's forecasts?

integer >> Watch the webinar recording here: www.integer-research.com/nitrogen-webinar

*Webinar was recorded 27 April 2017

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GERMANY

New reforming catalyst

Clariant has launched a new generation of catalysts for steam reforming. The new *ReforMax 330 LDP Plus* and *ReforMax 210 LDP Plus* catalysts have been designed with a unique 8-hole flower-like configuration which ensures an extremely low pressure drop in the tubular reforming reactor while maintaining catalyst activity and selectivity. The shape of the catalyst used for primary reforming plays a key role in the catalyst's activity, heat transfer, pressure drop and physical strength.

The new *ReforMax LDP Plus* catalysts build on the success of Clariant's previous *ReforMax LDP* series, commercially proven to be effective for any condition

of process feed and design. However, compared to its 10-hole predecessor, the new 8-hole "floral" design reduces pressure drop by up to 20%. This allows plant operators to significantly reduce energy costs and/or increase the reformer gas throughput in existing plants. The new catalysts retain the high geometric surface area of the previous shape, thus maintaining high activity for the steam reforming reaction, but heat transfer is improved due to increased hole diameters. Particularly when used together, *ReforMax 330 LDP Plus* and *ReforMax 210 LDP Plus* also effectively suppress carbon formation in the process. ■

UNITED KINGDOM

Johnson Matthey celebrates 200 years of innovation

Johnson Matthey, one of the longest-trading businesses in the FTSE 100 Index, celebrates its 200th birthday this year. Now a global leader in science and technology, the company was founded in London by Percival Norton Johnson in 1817 as a gold assaying business. Two hundred years later, the company has become a global business with operations on all continents and annual sales of more than £3 billion (\$3.75 billion). The company also employs 13,000 people in 30 countries worldwide.

Percival Norton Johnson began his business at the age of 25 with just £150 of capital, and established himself in the city of London as an 'assayer and practical mineralogist'. His pioneering work in assaying (determining precious metal content) and refining precious metals quickly established Johnson's reputation for the quality and accuracy of his work. As his reputation grew, his business flourished. George Matthey joined the business as an apprentice in 1838, becoming a partner in 1851. In the early years, Johnson Matthey alloys of platinum and iridium were used to create the benchmark metre and kilogram, as well as standards for imperial measurements.

Today, innovative technologies developed by the company's scientists are transforming the quality of air around the world, reshaping battery technology for the automotive industry and optimising

the efficiency of world scale processes used to produce many important chemical intermediates. One third of all new cars on the planet are fitted with catalysts manufactured by Johnson Matthey, dramatically reducing vehicle emissions. At the same time, the company is applying its expertise to create vital products for the pharmaceutical and medical industries, making a difference to the health and wellbeing of many people around the world.

Robert MacLeod, chief executive of Johnson Matthey said: "This is a very special year for all of us at Johnson Matthey as we celebrate our 200th anniversary. This extraordinary achievement belongs to my colleagues worldwide and to our predecessors. For two centuries Johnson Matthey has been at the forefront of inspiring science. Much of the important work that we do is not visible to the naked eye but the impact of our science is global and profound. This year we renew our mission to make the world a cleaner and healthier place for everyone".

Hydrogen from biomass

A team of scientists at the Christian Doppler Laboratory for Sustainable SynGas Chemistry at the University of Cambridge has developed a way of using solar power to generate hydrogen from biomass via a high-temperature gasification process. The technology relies on a photocatalytic conversion process; catalytic nanoparticles are added to alkaline water in which the biomass is suspended. This is then placed in front of a light which mimics solar out-

put. The solution is ideal for absorbing this light and converting the biomass into gaseous hydrogen, which can then be collected from the headspace. The nanoparticle is able to absorb energy from solar light and catalyse the decomposition of water and biomass to form hydrogen and other organic chemicals, such as formic acid and carbonate. The team used different types of biomass in their experiments, including wood, paper and leaves, none of which required prior processing.

The head of the laboratory, Dr. Erwin Reisner, said: "Our sunlight-powered technology is exciting as it enables the production of clean hydrogen from unprocessed biomass under ambient conditions. We see it as a new and viable alternative to high temperature gasification and other renewable means of hydrogen production. Future development can be envisioned at any scale, from small scale devices for off-grid applications to industrial-scale plants, and we are currently exploring a range of potential commercial options."

UNITED STATES

Methanol plants planned for West Virginia

California-based US Methanol says that it is looking to develop new methanol capacity in West Virginia. The company is initially targeting two sites at Institute, WV and Belle WV, both near Charleston, code-named 'Liberty One' and 'Liberty Two'. The plan is to relocate two small used methanol plants from overseas to the area to serve the northeastern US market, using locally-sourced shale gas as feedstock. The Liberty One facility will have a capacity of 480 t/d (nominal 160,000 t/a) and the Liberty Two site 410 t/d (135,000 t/a), following minor upgrades, repairs and modifications to the two units. US Methanol has reportedly signed an agreement with Cabot Oil and Gas to supply natural gas to at least one of these plants.

NWI secures permit for Kalama plant

Washington State's Cowlitz County has approved a key environmental permit for the new mega-methanol plant being planned at Kalama by Chinese-based Northwest Innovation Works (NWI). The \$1.8 billion project will produce up to 10,000 t/d of methanol for export to China to feed rapidly expanding methanol to olefins (MTO) production there. As well as designing the plant to minimise CO₂ emis-

sions, NW Innovation Works has expanded its environmental mitigation plans to offset any potential damage to local wetlands, protected species and habitat. The plans now include a promise by the Port of Kalama to permanently protect more than 90 acres north of the proposed project site, and the Washington Department of Fish and Wildlife, which initially opposed the environmental permit, has approved of the revised plan.

Partnership for small-scale methanol plants

Maverick Synfuels, a developer of alternative fuels and chemicals production technology, and global engineering and fabrication company Plant Process Equipment Inc., have formed a partnership to manufacture and sell small-scale gas-to-methanol plants. These skid-mounted modular plants can be rapidly deployed and are capable of producing between 3-10,000 gallons/day (9-30 t/d) of methanol from natural gas or methane-rich waste gas. Maverick will have the exclusive rights to sell and deploy these plants under the agreement. The aim, say the developers, is to provide a financially viable alternative to flaring or generating electricity. Waste gas sites are abundant worldwide as a source of low-cost methane, albeit in locations remote from markets or pipelines.

However, despite government subsidies, the economics of electricity production at these locations remain challenging. Methane-rich waste gas originates from numerous sources including oil and gas fields (associated or flared gas), landfills, wastewater treatment plants and anaerobic digesters associated with agricultural waste disposal.

Maverick says that converting methane to methanol is one component of the company's 'spoke and hub' distributed production strategy whereby methanol produced at the small-scale sites is more readily transportable to larger hub facilities, where it can be converted to higher value products such as clean fuels and specialty chemicals like propylene.

Sam Yenne, CEO of Maverick said: "the combination of skid-mounted and small footprint simplifies deployment into remote regions where many of these waste gas sources reside. Small-scale fuel and chemical production and lower capital requirements have aligned to produce a cost competitive and cleaner alternative to crude oil derived products."

The first methanol plant from the PPE/Maverick partnership is destined for deployment at a large-scale dairy in the upper Mid-West where Maverick use methane from anaerobic digesters.

GasTechno appoints strategic advisors

GasTechno Energy & Fuels (USA) LLC, a developer of a patented single step 'mini-GTL' gas to methanol technology, has appointed market analytics and energy solutions firm Stratas Advisors to help identify growth within its target markets and further deploy and commercialise its technologies. Following the recent start-up of GasTechno's first commercial-scale gas-to-liquids Mini-GTL[®] plant, Walter Breidenstein, CEO of GasTechno, says that he is looking to Stratas Advisors as a resource for market intelligence and analytics within the GTL industry.

"We have been evaluating multiple strategies for commercialisation of GasTechno, and it has been hard to focus outside of gas flaring reduction in North Dakota," said Breidenstein.

The GasTechno[®] process is designed to monetise small-scale sources of natural gas and associated gas from 50,000 scf/d to 30 million scf/d. This niche market represents 80% of the global stranded and flared gas market.

Gasifier issues keep Kemper off-line

Mississippi Power's Kemper County coal gasification plant missed its mid-March target date for commercial start-up, according to a filing with the US Securities and Exchange Commission (SEC). The delay, caused by tube leaks in a syngas cooler to one of the two gasifiers, will delay the facility's start-up to mid-April according to Mississippi Power, adding a further \$25-35 million in project costs to a project which has already overrun its original \$3 billion budget by \$4 billion dollars.

Contract awarded for project information system

Orascom Construction has selected US-based Aconex, a provider of global platforms connecting teams on construction and engineering projects, to manage project information and processes during the development of Orascom's new greenfield methanol complex in Texas. The Natgasoline facility will produce up to 1.75 million t/a of methanol, making it one of the world's largest merchant methanol production facilities based on nameplate

capacity. Large-scale oil and gas projects such as Natgasoline require a large team of designers, suppliers and subcontractors across various disciplines, and, to deliver the project on schedule, all participants must communicate and exchange project-related information efficiently. Orascom said that in the early design phase, they realised they needed an information management and collaboration system, and concluded that Aconex was the best fit for their needs.

CHINA

MTO start-up for Jiangsu Sailboat

Honeywell says that Jiangsu Sailboat Petrochemical Company, Ltd. has successfully started its UOP-designed methanol-to-olefins (MTO) unit at Lianyungang City in China's Jiangsu Province for a 10-day test to confirm successful operation. When the full unit goes on line, it will have an annual production capacity of 833,000 t/a, making it the largest single-train MTO unit in the world. The facility will produce propylene for the production of acrylonitrile, used to make clothing and fabrics, and high performance polymers used in automotive parts, hard hats and other hard plastic products. The plant also will produce ethylene for the production of ethylene vinyl acetate copolymers, which are used to make adhesives, foams, medical devices, photovoltaic cells, and other products, as well as C4 olefins for the production of butadiene, an ingredient in synthetic rubber.

"We expect China to invest more than \$100 billion in coal-to-chemicals technology in the next five years," said Mike Millard, vice president and general manager of UOP's Process Technology and Equipment business. "With China's demand growth for propylene of 7% per year, ethylene demand growing nearly 6%, and butadiene at almost 4%, our Advanced MTO process provides an excellent solution to meet that demand."

Honeywell UOP's Advanced MTO process combines the UOP/Hydro MTO process and the Total/UOP Olefin Cracking Process to significantly increase yields and feedstock efficiency. The process converts methanol from coal and natural gas into ethylene and propylene. At the heart of the technology are UOP's proprietary catalysts, which make it possible to efficiently adjust the ratio of propylene and ethylene produced so operators can most effectively meet demand for those products.

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New PDH unit for China

Clariant has been awarded a contract by Dongguan Grand Resource Science & Technology Co. Ltd. to develop a new propane dehydrogenation unit in cooperation with CB&I. The project includes the license and engineering design of the unit, which is to be built in Dongguan City, Guangdong Province, China. The Dongguan plant will be one of the largest single-train dehydrogenation units in the world. Clariant's technology partner CB&I will base the plant's design on its *Catofin*® catalytic dehydrogenation technology, which uses Clariant's tailor-made Catofin catalyst and heat generating material (HGM) – an innovative metal-oxide material designed to significantly increase the selectivity and yield of Catofin units.

IRAN

Petrochemicals production to increase 50%

Iranian petrochemical production could increase by more than 50% by 2020, according to industry consultants AmanpourConsult. Iran currently produces 60 million t/a of petrochemical products, but this could increase by at least 28 million t/a between 2016 and 2020, with about half of the expansion coming through production of methanol. Amanpour calculate that investments in Iran could see ethylene production expand by 5 million t/a, propylene by 5 million t/a, methanol by 10-15 million t/a, mono ethylene glycol (MEG) by 2 million t/a, and aromatics and derivatives by at least 2 million t/a. With global methanol production at around 80 million t/a, the methanol capacity expansions would mean global supply increasing by almost 20%. At least 4 million t/a of new Iranian methanol capacity is due to come on-stream in the next 12 months; Kaveh Petrochemical Company's 2.3-2.5 million t/a plant in Bandar Dayyer is expected to start commercial production by the end of this year, while Marjan Petrochemical Company's 1.7 million t/a plant at Assaluyeh is expected to start up by early 2018. Much of the additional supply is expected to be exported to China. – Iran is already the biggest supplier of methanol to China, shipping on average 200,000 tonnes per month. So far much of that supply has gone to fuel China's 14 methanol-to-olefin plants, but the sheer scale of expansion of methanol supply in Iran has sparked

rumours the country might construct its own MTO plants and export olefins, polyolefins or monoethylene glycol, according to Amanpour.

CANADA

Methanex replies to shareholder criticisms

Methanex Corporation has replied to the filing of a revised schedule 13D by its largest shareholder, UK-based M&G Investment Management Ltd. M&G, which owns 19.5% of Methanex, filed the revised schedule with the US Securities & Exchange Commission on March 24th, required when a significant shareholder shifts from being a passive investor to one who more actively asserts an agenda with management. M&G said in its filing that it believes that Methanex's market valuation does not reflect its intrinsic value, and encourages management to use all excess cash, with the exception of potential modest capital expenditures to refurbish Methanex's Chilean assets, towards share buybacks.

John Floren, president and CEO of Methanex commented, "We understand M&G's frustration with Methanex's share valuation and we believe that M&G's views are quite aligned with our strategy with respect to capital allocation. We have a long track record of a disciplined approach to capital allocation and of returning cash to shareholders, while maintaining a prudent balance sheet and liquidity given the cyclical nature of our business. Over the last 20 years we have repurchased over half of the company's shares outstanding, and we have grown our dividend every year except during the 2009-2010 financial crisis and during 2016, when we maintained our dividend despite very low methanol prices. We also remain committed to a meaningful and growing dividend that is sustainable at the bottom of cycle methanol prices."

INDIA

Coal India looking for interest in CTL project

According to local press reports, Coal India Ltd (CIL) has agreed to float an expression of interest for a coal to liquids (CTL) project at Chatar in Jarkhand province. The company had earlier sought expressions of interest from technology licensors for what it describes as a 'CTL' project at Dankuni

in neighbouring West Bengal – actually a coal-based methanol development using coal from the Eastern Coalfields. The Chatar project however is reportedly based around Fischer-Tropsch production of automotive fuels. CIL has previously been in discussions with South Africa's Sasol as a potential technology licensor. CIL is also looking to produce coalbed methane from the Raniganj and Jaria coalfields in West Bengal, which could be an alternative feedstock for the project, and is also looking towards the potential of underground coal gasification (UCG).

RUSSIA

New hydrogen unit for Gazprom Neft

Gazprom Neft is constructing a new hydrogen plant at its 21 million t/a Omsk refinery in Siberia as part of the company's ongoing modernisation and upgrading program across its Russian refineries, aimed at reducing environmental impacts and improving processing capacities, conversion rates, energy efficiency by 2020. Work began on the 12,300 t/a hydrogen plant in March and is due to be complete by the end of 2017. It will feed hydrotreating capacity at the site for the production of Euro-V quality gasoline and other light petroleum products.

SOUTH AFRICA

UCG project still proceeding

African Carbon Energy says that it is still working on an underground coal gasification (UCG) power plant project at its 1 billion tonne coal deposit in Theunissen, in the Orange Free State. Design engineering on the 50 MWe Theunissen power generation project was completed in 2015, but the project has been delayed by uncertainty caused by the refusal of state power utility Eskom to sign power purchase agreements with independent power producers. However, president Jacob Zuma announced during his February State of the Nation address that Eskom would sign the outstanding purchase agreements. The Theunissen project construction and grid connection will take about 24 months to complete once offtake agreements are signed. The cost of the project is put at 2.7 billion rand (\$200 million). African Carbon Energy says that in the longer term it is also looking towards a 250 t/d syngas to liquids plant based on syngas from underground coal gasification. ■

People

Incitec Pivot says that its managing director and CEO **James Fazzino** will be stepping down from his role, after eight years in that position. Fazzino will remain at Incitec Pivot for a period of 12 months to allow the company time to identify and appoint a successor. Company chairman Paul Brasher said in a statement: "during his time as Managing Director & CEO, James has transformed Incitec Pivot from a fertilizer business on the east coast of Australia to a global diversified industrial chemicals company."

Rashtriya Chemicals and Fertilizers Ltd (RCF) has announced that **C.M.T. Britto** has been appointed as the company's Chairman and Managing Director, following the relinquishing of the role by his predecessor Manoj Mishra. Britto currently serves as the company's technical director. In a filing on the Bombay Stock Exchange, RCF said: "we would like to inform you that the Ministry of Chemicals and Fertilizers has entrusted the additional charge of the post of chairman and managing director to CMT Britto, Director (Technical), Rashtriya Chemicals and Fertilizers for a period of three months with effect

from March 14th or until further orders, whichever is earlier."

Omnia's board has advised that **Neville Crosse** will retire as non-executive director and Chairman of the Board on 31st May 2017. Crosse has served 40 years with the Group, after joining Omnia in 1977 as a project engineer, and has since served the Group in many capacities including managing director Omnia Fertilizer from 1985), group managing director from 1991, and since 2000 as non-executive chairman of the board. He steered Omnia through many milestones, including the acquisition of its mining division, the construction of the state-of-the-art nitrogen complex at Sasolburg and the establishment of Omnia Fertilizer's first operations in Zimbabwe and Zambia. His replacement will be **Rod Humphris**, who will retire as group managing director of the company from 31st May 2017 and become non-executive director and chairman of the board with effect from 1st June 2017. Humphris joined the Group in 1982 as a project engineer and has served in various positions within Omnia, becoming managing director of Omnia Fertilizer in 1995 and group managing direc-

tor of the company in 1999, expanding the company's geographical footprint in Africa and into regions such as Australasia, South America and South East Asia, and supervising the acquisition of its Chemicals division in the form of Protea Chemicals, as well as the construction of its second nitric acid plant, thereby becoming one of the largest producers of compound chemical fertilizers in Africa. He has also served as President of the Fertilizer Society of South Africa and was recently appointed as Chairman of CAIA. Omnia has also approved the appointment of **Adriaan de Lange** as group managing director and as executive director of the board with effect from 1st June 2017. De Lange joined the Group in 2003 as financial controller for BME and was promoted to financial manager, where he played an important part in developing and implementing the mining division's business strategy. In 2007 he was transferred to Omnia Fertilizer as financial manager and was soon thereafter promoted to financial director of Omnia Fertilizer. He is currently the Chairman of the Fertilizer Association of Southern Africa (FERTASA). ■

Calendar 2017-18

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

26-30

Nitrogen Fertilizer: Advances in Technology, Products, Safety and Global Impact, LONDON, UK
Contact: International Fertilizer Development Center, P.O. Box 2040 Muscle Shoals, Alabama 35662, USA.
Tel: +1 256 381-6600
Email: training@ifdc.org
Web: www.ifdc.org

29-30

International Fertiliser Society Technical Conference, LONDON, UK
Contact: International Fertiliser Society, PO Box 12220, Colchester, CO1 9PR, UK.
Tel: +44 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

15-18

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

24-26

IFA Crossroads Asia-Pacific Conference, SHANGHAI, China
Contact: IFA Conference Service, 28 rue Marbeuf, 75008 Paris, France.
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

FEBRUARY 2018

26-March 1

Nitrogen+Syngas 2018, GOTHENBURG, Sweden. 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

Plant Manager+

Problem No. 42 Coated urea fertilizers

Coating urea prills (granules) with a water-insoluble, semi-permeable, or impermeable (with pores) material delays the release of nitrogen from the urea. Urea is highly soluble in water, but the solubility of coated urea is dependent on the coating material, its thickness, and the coverage and uniformity of the coating on the granule. As the urea is gradually released from the coated granule, it is exposed to

the same chemical and biological processes as non-coated urea. Coated urea provides a safer and more efficient form of urea by:

- safeguarding against nitrogen losses through volatilization and degradation;
- slowing down leaching due to its slow-release characteristics;
- improving stability in fertilizer blends.

Amirhossein Hadian from Khorasan Petrochemical company, Iran starts the roundtable discussion: I am researching coated urea fertilizers – controlled release fertilizers consisting of urea prills, coated with less-soluble chemicals such as sulphur, polymers, etc. Does anyone have any suggestions for coating urea prills to slow down dissolution rates when used on farms?

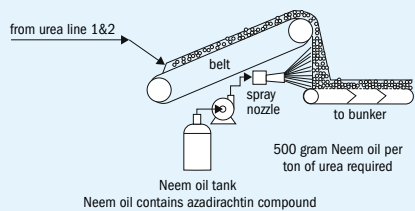
Luis Nogue from Bunge, Argentina shares his information: There is a company called NAQ Global who specialise in anti-caking and anti-dusting agents. They are present in Asia, Middle East, North America you can see more info on their website.

Prem Baboo from National Fertilizers Ltd, India provides more information: We are also producing neem (azadirachtin) coated urea. It is well known that neem has great potential for increasing the efficiency of urea. Indian agricultural scientists were the first in the world to establish neem as a nitrogen regulator. National Fertilizers Ltd., Vijaiapur started using it in October 2004.

Neem-coated urea has the following advantages:

- Neem cake when applied along with urea retards the nitrification rate for about two weeks and thus more nitrogen remains available as ammonium for a long period.
- 350 ppm of neem oil content is being maintain at NFL Vijaiapur as per the guidelines under section 20(a) FCO.
- Useful as a germicide to help crop decaying.
- Neem product namely neem oil, cake, neem bitters concentrate and neem oil were identified as good nitrification inhibitors.

Fig 1: Spraying arrangement in NFL Vijaiapur



Advantages:

1. Urea efficiency increased
2. Caking problem reduced
3. As a germicide
4. Crushing strength improved



Neem coated urea fertilizer has become very popular with Indian farmers.

Development of process for coating urea prills

NFL has carried out development work for the coating of urea in fertilizer plants, where plant conditions require a new approach to use neem cake or neem bitters for urea coating. The work was divided in two parts: (1) developing a suitable neem product which could easily be sprayed on urea prills in the final product stage and (2) development of a suitable arrangement for spraying neem product after leaving the prilling tower.

Amirhossein Hadian from Khorasan Petrochemical company, Iran asks for more information: We are interested in neem products. How much dust reduction can we expect by spraying neem oil? We currently spray Uresoft-150 after the urea fluidised bed, can we substitute it with neem oil?

Prem Baboo from National Fertilizers Ltd, India provides more information: Neem coating is being carried out in the final stage, i.e before bunkering because neem oil has a bitter smell and it is

PHOTO: PIXELVISIONSD / ISTOCKPHOTO.COM

immediately loaded in bags. When farmers apply urea on the farm, the rats and rabbits vacate the field. It is also a germicide. Neem coating definitely reduces dust generation. You can switch from Uresoft-150 to neem. Crushing strength is also improved by neem e.g. before coating 650 gm/prill and after neem coated 670 gm/prill. You can apply neem after the urea fluidised bed.

We started using neem coating in 2004 as a trial run, nowadays there is increasing demand from farmers. At present, it represents about 40% of total production by National Fertilizers Ltd. Fertilizer companies, including Tata Chemicals & Fertilizers, Babrala and Indo Gulf Fertilisers, Jagdishpur also produce neem-coated urea.

Vinay Gandhi from GSFC, India provides more information: GSFC, Vadodara, Gujarat, India has also started production of neem coated urea prills. The response from farmers is overwhelming.

George Van Bommel from Energy Consultancy UREA, The Netherlands shares new information: There are at least 10 suppliers of various urea agents, which all claim various improvements of properties. The question is: Which property do you want to improve, and how much do you want to pay for it per ton of prill or granule...

Read chapter 16 of the Fertilizer Manual, then make your choice of the following products (suppliers) in no specific order (others may also be available):

- NovoFlow (Novochem)
- UreaSoft (Kao)
- UreFlo (Filtraz)
- Galoryl (Armaz)
- AC Fert 100 (Kephaz)
- Flotigam (Clariant)
- UltraCoat (SSCI)
- UreCoat (Neelam)
- Fertibon products
- FA1665 (Forbon)

Amirhossein Hadian from Khorasan Petrochemical company, Iran raises new questions: When neem oil is sprayed onto urea prills, do the coated prills have a special odour and does it cause problems for storage and workers in bagging?

Prem Baboo replies: Neem coated urea does have a bitter smell but it is not pungent, and poses no problem for any workers, nor harm to health. In India about 11 plants are producing neem coated urea and there have been no problems with loading and handling.

Mark Brouwer from UreaKnowHow.com, The Netherlands provides supplementary information: Neem also acts as an anti-caking agent.

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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Waterfront Shipping's Taranaki Sun, with Mount Taranaki, New Zealand, in the background.



Methanol as a shipping fuel

The approach of new IMO regulations on marine fuels in 2020 presents an opportunity for methanol to make inroads into a new and potentially lucrative global fuels market, if concerns over pricing and distribution can be overcome.

Global methanol demand has more than doubled over the past 20 years, as economies of scale have allowed the production of methanol at ever-larger facilities, bringing down the unit cost and allowing it to break through from its traditional chemical markets into new fuel uses. Particularly in China, which now consumes half of the world's methanol, it has become an important blendstock in gasoline, and a source for dimethyl ether (DME), which is blended in LPG. There are methanol and DME fuel trials and mandates in a number of countries, an

However, a new and potentially even larger source of demand is presented by

the world's shipping fleet, which is facing new and much tighter regulations on the sulphur content of the fuel it burns. These new regulations are encouraging experimentation by what has traditionally been quite a conservative industry, as they face the prospect of new clean fuels becoming much more expensive after the January 1st 2020 deadline for compliance with the new rules.

MARPOL

According to ship designers ScandinaOS, global shipping provides 90% of the world's transportation needs by tonnage

while emitting only 15% of the world's carbon dioxide emissions, but it emits 42% of the world's nitrogen oxides and 73% of sulphur oxides. The reason for this is that ships mainly run on heavy fuel oil (HFO), which consists of heavy refinery 'bottoms' which are left over after lighter fractions like condensates, gasoline, diesel, kerosene etc have been removed. The sulphur present in oil has often ended up in HFO, such that HFO sulphur content can be up to 3-5% by weight. As a result, reducing this has become an international priority, with the International Maritime Organisation (IMO) taking the lead.

The main international shipping convention regulating emissions from ships is the IMO International Convention on the Prevention of Pollution from Ships (referred to as MARPOL). MARPOL Annex VI establishes limits for SOx and NOx globally and in emission control areas (ECAs) – mainly the Baltic and North Sea in Europe, and the east and west coasts of North America and the Caribbean. It is likely that these will be extended to the Mediterranean Sea soon. The global limit of sulphur content in fuel will be reduced from 3.5% to 0.5% in 2020, while in ECAs it has already dropped to 0.1% sulphur from January 2015. Equivalent purification of exhaust gas by exhaust gas scrubbers is accepted under the legislation, but these are expensive (\$4-10 million per vessel) and so far

only 300 ships of a global cargo fleet of over 60,000 vessels have been converted. Otherwise ship owners will be looking for a lot of low sulphur fuel from 2020, and there are doubts as to whether the existing supply of marine gasoil (MGO) – a 'middle distillate' blend based on diesel – will be sufficient to meet demand, and costs may increase drastically.

Consequently, ship owners and operators have been looking towards other potential low-sulphur fuels. Liquefied natural gas (LNG) has been suggested, and a number of conversions have already been made to run ships of LNG, but methanol has also come under serious consideration as a potential fuel to run ships. The Methanol Institute, the trade association for the global methanol industry, says that methanol "is compliant with the strictest emissions standards, plentiful and available globally, could be manufactured from a wide variety of fossil and renewable feed-stocks, and its properties are well-known because it has been shipped globally, handled and used for a wide variety of ends for more than 100 years. Moreover, it is similar to current marine fuels in that it is a liquid. This means that current marine fuel storage and fueling infrastructure would require only minor modification to handle methanol, necessitating relatively modest infrastructure investment costs compared with the sizeable investments required for the construction of

liquefied natural gas (LNG) terminals.

The world's ships consume around 370 million t/a of fuel per year. It seems clear therefore that, even if only a relatively small number of ships were to take up the use of methanol as a fuel, it could have a major impact on demand for methanol. Methanol producer Saudi Basic Industries Corp (Sabic) estimates that using methanol as a replacement for marine fuel may grow to a 5 million-15 million t/a market over the next decade.

Methanol Institute

In December 2015, FCBI Energy published a report on methanol as a marine fuel by professor Karin Andersson of Chalmers University in Sweden, commissioned by the Methanol Institute (MI). As well as highlighting methanol's relative ease of use, availability and cost advantage, it also noted that methanol readily dissolves in water and is biodegraded rapidly, as most micro-organisms have the ability to oxidise methanol, greatly reducing the impact of any spill.

IMO study

A study conducted by DNV for the International Maritime Organisation, and backed by Transport Canada, looked at the potential environmental benefits of using methanol as a fuel on ships with regard to the emission of greenhouse gases, NOx and SOx. It sought to calculate the total life cycle emissions of methanol propulsion compared to conventional fuels – specifically marine gasoil (MGO) and high sulphur fuel oil (HFO), on a 'well-to-propeller' basis, meaning that the emissions of extracting and refining raw fossil fuels were taken into account. While admitting that there was "uncertainty in the emission of gas extraction and transportation", well-to-tank GHG emissions from methanol produced with natural gas are dominated by the emissions from natural gas combustion occurring at the methanol plant. This led the report to conclude that "emissions from the well-to-tank phase of methanol produced with natural gas are slightly higher than corresponding emissions from MGO and HFO". However, it did admit that life-cycle GHG emissions from methanol produced from biomass, such as forestry residues like black liquor in pulp and paper mills, "are considered climate neutral, and they are therefore not included in the life-cycle emissions".

Methanol of course also contains zero sulphur and therefore easily meets SOx requirements. On NOx emissions, Wärtsilä has tested NOx emissions from methanol against those from HFO in two engine models which show that NOx emissions were approximately 40% of emissions from HFO from the same engines at similar load. MAN Diesel has performed tests with methanol in marine diesels resulting in a 30% reduction in NOx emissions compared to diesel. Overall, the life-cycle NOx emissions from methanol were put at approximately 45% of those of conventional fuels per unit energy and the life-cycle SOx emissions of methanol 8% of those of conventional fuels per unit energy.

The report also concluded that in spite of methanol's relatively low flashpoint and toxicity, its storage and handling do not present and health and safety aspects which cannot be solved with some modifications to existing storage and handling systems, such as double-walled piping with sufficient ventilation, in addition to segregation by remotely operated valves throughout the whole supply system. Methanol vapour is heavier than air and it

will therefore move downwards, hence the placement of gas detectors and ventilation at lower elevations is also necessary.

The additional costs of methanol propulsion for a new build vessel were calculated to be approximately half the size of those for a retrofit case, mainly due to the fact the tank in the case of a new build is incorporated into the design of the vessel from the start, and its placement in the vessel will not constitute an additional cost to the ship owner. These additional capital costs were used to calculate the payback time of a methanol fuel system compared to switching to MGO or installing a scrubbing system to allow the continued use of HFO to cope with the regulations and environmental requirements in ECAs. This of course depends on the anticipated cost of MGO, which may find itself in considerable shortage in 2020 when the new phase of IMO regulations become law. The report used a high price scenario of \$865/tonne for MGO and a low price scenario of \$450/tonne. Even so, at the low MGO price methanol was found to have a payback time of 6.8 years compared to MGO, although for a new build not as economical as installing a scrubber. In a high MGO price environment, methanol had a much lower payback period and was more economical than a scrubber for a methanol price of \$205/tonne.

OBATE

In Northern Europe, the potential for methanol and other similar fuels was examined by a programme called SPIRETH ("Alcohol (spirits) and ethers as marine fuel"). Beginning in 2012, the project focused on two concepts for using methanol fuel on ships: either conversion of a full scale marine diesel engine to run efficiently on methanol; or use of dimethyl ether, which can substitute for diesel. Rather than store DME directly, which has attendant problems in terms of dissolution of rubber seals etc, the DME would be produced on-board from methanol using a process from Haldor Topsøe called OBATE™ (On board alcohol to ether) process. For OBATE unit was tested on-board the Stena Scanrail, a ro-pax ferry that sailed between Gothenburg and Fredrikshavn, between 2012 and 2014.

The SPIRETH project work showed that methanol and DME-based fuels are viable alternatives for reducing emissions from ships. Risk and safety analysis work carried out in the project contributed to the development of ship classification society



Methanol powered vessel at anchor.

rules for methanol as a ship fuel and to the International Maritime Organization's draft IGF code (International Code of Safety for Ships using Gases or Other Low-Flashpoint Fuels). The work also led to a full scale methanol ship conversion project by project partner Stena – the Stena Germanica, which became the world's first commercial methanol powered ship.

Current methanol vessels

As well as the Stena Germanica, methanol supplier Methanex has been demonstrating methanol-powered ships via its subsidiary Waterfront Shipping, which operates a fleet of 22 tankers used for carrying methanol. It has ordered seven 50,000 dwt tankers from three shipbuilders, Mitsui OSK, Marininvest/Skagerack and Westfal. The first of these, the Lindanger, was delivered in April 2016, with two more following soon after, and the remaining four in October 2016. The ships are powered by a MAN-designed dual-fuel, two-stroke engine, which can run on methanol, fuel oil or marine diesel. The 10 MW ME-LGI engines offer have cylinder covers equipped with additional methanol booster injectors, achieving a typical injection pressure of 10 bars.

Other research projects under way or

recently started include a German Project, Methaship, to develop designs of methanol passenger vessels, and the EU Horizon 2020 project LeanShips, which includes a work package to test a marine methanol engine in a laboratory. Ship designers ScandiNAOS are also working together with the Swedish Maritime Administration (SMA) and the Swedish Maritime Technology Forum (SMTF) on a conversion project of a pilot boat torun on methanol, aiming to demonstrate that it can improve competitiveness and reduce environmental impact.

Nevertheless, at present, according to Maersk, while 346 ships out of a global fleet of 60,000 cargo vessels have converted to use of scrubbers, and another 102 use LNG as a fuel. The number of methanol-powered vessels is currently just eight, and seven of these are methanol tankers which can use their own cargo as fuel.

Barriers to uptake

There are a number of barriers to the greater uptake of methanol as a marine fuel. While technical feasibility and regulatory issues have largely been addressed, there remain costs of conversion, cost of the fuel vs MGO, and the availability of refuelling infrastructure. The conversion of the Stena

Germanica cost €13 million, and while larger scale uptake would bring this down by an estimated 30-40%, it still compares to the cost of installing scrubbers, although still considerably cheaper than the cost of LNG conversion. An added difficulty at the moment is the global oversupply in the world's shipping industry which has led to ship owners and operators being extremely cost-conscious – one thing which has also reduced the uptake of LNG and scrubbers. Equally, with oil prices low, HFO and MGO are also low, and at the moment there is little incentive on cost grounds to switch to methanol use. In some senses methanol has been here before, with much excitement over its uptake in flexible fuel vehicles in California in the 1990s, and it is often foundered on a distribution infrastructure and who will pay for the development of it.

However, methanol is much cheaper today compared to the costs of alternative hydrocarbon fuels, and the situation may be very different in 2020 – if a large number of vessels have not switched to scrubbers, the MGO price is likely to spike very sharply, and the impetus for methanol may well suddenly be much greater. Likewise, it has been suggested that it may be in niche markets where methanol fuel may find the greatest traction. The IMO report suggests that ships operating primarily in ECAs such as the Baltic, North Sea and perhaps soon the Mediterranean may be the area where methanol finds greatest attraction, as it is far more costly for refiners to supply a shipping fuel with less than 0.1% sulphur than it is to provide one with less than 0.5% sulphur. Inland waterways, in places such as the Rhine or Mississippi, with proximity to urban centres where emissions controls are desirable or mandated by regional or national governments may also be a potential growth area. For example, last year the Indian government issued the National Waterways Act, which requires developing inland waterways transportation that is fuel efficient, cost effective and environment friendly, a potential catalyst for the promotion of methanol as fuel. ■

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Nitrogen+Syngas 2017

A report on the 2017 Nitrogen+Syngas conference, held at the Hilton Paddington Hotel in London at the end of February this year.



The Shard at night, Southwark Bridge in the foreground.

For the first time in many years, CRU's Nitrogen+Syngas conference returned to the company's home base of London. Opening the conference, Mike Gallagher, CRU's general manager of the Fertilizers division noted that a lot of water has passed under the bridge since the first British Sulphur Nitrogen conference – Nitrogen '86 in Amsterdam. Never-

theless, the record attendance of over 700 delegates testified to the conference's continuing popularity and relevance. The meeting happened at a time when coal prices had risen in China and the idling of Chinese urea capacity had led to a rebound in urea prices, lifting the market for a while, but fundamentals still looked poor for the year ahead.

Market papers

As always the conference began with a round-up of the major markets of interest to the nitrogen and syngas industries, first and foremost of which is natural gas. Jane Rangel of Energy Aspects presented the gas market outlook, telling delegates that there has been a convergence in global gas markets as prices have fallen, and although there are still some peaks and price spikes in Asia, the wave of new LNG capacity is finally hitting the market; around 50% of Australia's new capacity is now on-line, with a total of 60 million t/a being added from 2014-22, while much new US capacity is still to come, another 50 million t/a to 2022. The LNG market is seeing an additional 50% of new capacity from 2014-2020, and while there is much regasification capacity ramping up, with new demand potential in China, the Middle East and north Africa, Europe and Pakistan, it will not match the new supply availability. Australian LNG is mainly contracted to Asia, squeezing out Qatari spot cargoes to European markets instead, and possibly squeezing US cargoes out of Asia and even Europe. This will lead to the continuing convergence between Henry Hub and UK national balance point (NBP) prices – outside the US, NBP is increasingly becoming the price setter, and may end up being no more than Henry Hub +\$1.00/MMBtu. Northeast Asian prices likewise may not rise higher than Henry Hub +\$2.50/MMBtu. The overall market will only balance if Europe takes a lot more gas – possibly another 25 million t/a – but there is a lot of unused LNG import capacity, and as Europe continues to switch to gas-based power, away from coal, another 30-50 bcm per year of demand is likely and up to 70 bcm possible, especially with the carbon pricing increment on coal. However, LNG will probably not squeeze out Russian pipeline imports, she said, especially now the devalued rouble has made Russian gas more competitive. If spare gas goes unexported in the US, there could also be room for additional power switching from coal to gas there.

Anders Isberg of CRU considered nitrogen costs in a supply-driven market.

Overcapacity is now the nitrogen market's defining feature, he said; weak energy prices and currencies have created a deflationary price environment, and demand has struggled to keep up after a year of poor conditions in key markets – India has seen record grains production and weak demand, pushing stocks to record levels, while China is reforming its agricultural sector and has recently slashed its corn support price from \$300/t to \$160/t, and also aims to cap nitrogen fertilizer consumption from 2020. Meanwhile there is still more new urea capacity coming on-stream from 2017-19, in China, Africa, Iran, the USA and CIS. The cost curve has flattened due to falling gas prices as well as weak non-dollar currencies. Russian producers have particularly benefited from the depreciated rouble, although it may rebound a little this year. Chinese anthracite coal prices also halved from 2011-16, although there is some movement back up now, which has also kept a lot of Chinese capacity more competitive, at least until 2016, when falling nitrogen prices made most Chinese capacity loss-making once again. Going forward, Chinese coal policy is likely to set an upper price bound based on the profitability of power producers, and a lower one based on the profitability of coal producers, leading to falling prices for thermal coal, but relatively higher prices for anthracite. On the supply side, China is expected to close about 12 million t/a of the most polluting urea capacity over the next few years and may institute seasonal production cuts in energy intensive industries around major cities to reduce smog, affecting another 36 million t/a of capacity around 45% of China's urea. This is likely to mean less urea available for export, dropping from 13 million t/a in 2015 to 7.4 million t/a this year and as low as 3-4 million t/a in 2021. This should help push global urea prices back up to \$300/t by the end of the decade.

Europe's fertilizer industry has faced particular challenges from high feedstock prices and burdensome regulations, said Jacob Hansen of Fertilizers Europe, but it nevertheless remains a €13.2 billion industry employing 95,000 people directly and indirectly. Imports of urea into Europe are still growing, rising from 3 million t/a to 5.5 million t/a over the past decade, and while most nitrogen in Europe is consumed as ammonium nitrate this still has a knock-on effect on pricing. However, in the past couple of years European gas prices have

fallen dramatically compared to its competitors, and made the European fertilizer industry much more competitive – previous runs of high gas prices had already made the European industry the most energy efficient, and plants are also older and generally depreciated in capital terms as well. The main challenges remain regulatory, with EU attempts to reduce CO₂ emissions by 40% having a disproportionate effect on the nitrogen industry. However, new markets in technical urea, premium prices for nitrates which better suit European growing conditions, and value added advantages in product specialisation can still help European producers compete, said Jacob. He remarked on the 18th century scientists who could not work out how the bumblebee was able to fly, and said that Europe's fertilizer industry, like the bumblebee, nevertheless continues to fly. Ruud Schiers of Rabobank enlarged on the topic of speciality fertilizers and nitrogen use efficiency. The characteristics of the dominant farming model is an important predictor of fertilizer demand, he said – Asia and Europe have a scarce land model, whereas the US, Brazil and Russia have an abundant demand model.

Turning to the Chinese situation, Gavin Ju of CRU's Beijing office noted China's continuing market transition for many sectors – from 2015 rail freight has been the same for all commodities, and rail freight rates have quintupled in a decade; from 2016 power tariffs have been the same to all industries, with charges rising an average of 43% last year; and natural gas has become an open market. There are no VAT exemptions any more, and fertilizer export taxes were removed at the end of 2016. China's nitrogen industry has now become much more market-oriented, with gas prices now decided by negotiation and not the government, and coal prices also rising. The industry response to these increasing costs has been to move to new gasification technologies with larger capacities and more productivity, and which are more energy and labour efficient (up to 50-70% lower specific energy consumption). A switch to bituminous coal, direct agreements with power suppliers and rail freight companies, and a switch to bulk packaging (1 tonne 'big bags' rather than 50 kg sacks) have all helped to shave costs, but only large scale producers can achieve some of these measures. Inefficient capacity is now closing, around 12.6 million t/a from 2013-16 and probably

another 14 million t/a from 2017-21. He still foresaw no serious import of urea into China, however, as tariff quotas and import taxes still mitigate against this.

Euronext are now offering a UAN futures contract, as described by Ulrich von Furstenburg. Europe is the second largest market for UAN after the US, consuming 4 million t/a, of which 2.2 million t/a is represented by France. Euronext's UAN-30 is a physically deliverable futures contract for 30-tonne lots, responding to the specific request of French farming cooperatives, allowing them to manage price risk by hedge tools, but he hoped it would find wider application in Europe.

Reforming

The heart of any syngas process is the reformer, and a sizeable section of the conference covered reforming technologies and issues. Mark Loring of KBR compared increasing the size of reformer tubes against increasing the number of reformer tubes as a way of increasing reformer throughput. Both can work, depending on the specific project situation – adding a tube row allows most of the structural work to be done pre-turnaround, allowing for a lower downtime penalty when done at the same time as the convection section modifications and is worth considering in any revamp study.

Peter Sandberg of Haldor Topsoe suggested the Haldor Topsoe heat exchange reformer (HTER) as a way of increasing capacity to an existing syngas front-end without major modifications to existing equipment. Capacity increases of up to 25% are possible and can be accommodated in most plot plans, and in a grass-roots plant it can allow the use of petcoke or coal as a feedstock. The main challenge is integration into the steam balance to ensure steam requirements are met when ammonia steam generation is reduced.

KBR have their own heat exchange steam reformer, the KBR Reforming Exchange System (KRES), and Mahesh Gandhi of KBR described scenarios where the KRES reformer can help achieve capacity increase, reduced energy consumption, and reduce steam export.

Was gas-heated reforming (GHR) ahead of its time? Anthony Fenwick of Johnson Matthey showed that the GHR plus auto-thermal reformer (ATR) flowsheet involved the greatest potential for saving process energy by importing electricity, and when

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combined with renewable electrical generation could generate the lowest carbon impact of any methanol flowsheet.

BD Energy Systems have developed a new design method for reformer flue gas tunnels called Tunnel Optimal Performance (TOP), which avoids non-uniform gas flow, including vortex formation, and hence non-uniform catalyst heating, and showed computational fluid dynamics (CFD) modelling results which showed the performance improvements which can be achieved.

Haldor Topsoe also presented some of their recent developments for use of oxygen in secondary and autothermal reformers, which can extend plant reliability and availability even in today's more severe operating conditions, including a new generation of burners, shaped dense ceramic tiles, optimised catalyst loading techniques, improved refractory lining, and a new design of catalyst bed support.

Daniel Drabble of Quest Integrity explained how an inspection regime can provide a better understanding of and prediction of reformer tube lifetime and time to failure, allowing operators to avoid costly unplanned outages.

John Brightling of Johnson Matthey and Muhammad Majid Latif of Engro Pakistan presented a discussion of two serious incidents in a secondary reformer at Engro's old ammonia plant at Daharki; the first of which was an air compressor surge that caused a flameout and damage to the catalyst support from explosions. A second incident was a low air flow and consequent temperature increase caused by a booster compressor tripping due to a spurious alarm. In both instances the catalyst was examined and found to be in good condition.

Revamps

There is always pressure to achieve more from existing infrastructure, and so there was also a sizeable section covering revamping. VK Arora of Kinetics Process Improvements presented three case studies of revamping Benfield CO₂ removal systems in ammonia plants which mitigate CO₂ slip and allow for increased ammonia production.

Fatima Fertilizer Co Ltd detailed an ammonia plant revamp at their 1967-vintage plant in Pakistan which increased production from 1,500 to 1,700 t/d and decreased energy consumption from 8.3 to 8.04Gcal/t ammonia, as well as improving reliability and plant availability.

Casale were involved in revamping two 40-year old Kellogg ammonia plants for Azomures at Tigru Mures in Romania, as described by Marco Lonetti. Capacity was increased from 900 t/d to 1,050 t/d while reducing specific energy consumption by 10%, and bringing emissions and environmental parameters within current EU limits. There was also a significant increase in reliability and operability gained by adding a new state of the art distribute control system and emergency shutdown system, replacing the previous pneumatic control system.

Other strategies for increasing capacity were examined by Joerg Weidenfeller of ARVOS GmbH, by a new design of steam superheater which allows operation at higher temperatures and pressures – up to 540°C and 130 bar, reducing the duty on the process gas cooler and so providing the potential for improving overall process efficiency by either reducing gas consumption in fired heaters or increasing electricity production.

The KazAzot ammonia plant in Aktau, Kazakhstan, had an issue with high ammonia content in the flash and purge gases, up to 20-40% by volume, which went to flare. In order to recover this useful product, JSC GIAP instituted an ammonia recovery section, using nitric acid to neutralise the ammonia and generate ammonium nitrate solution, which was fed to the AN granulator on-site.

Operating experience

KBR shared their experiences of starting-up several world-scale Purifier-based ammonia plants over the past two years, including the 2,300 t/d Dyno Nobel plant at Waggaman, Louisiana, the Kaltim V 2,700 t/d ammonia plant in Bontang, Indonesia, the 1,000 t/d BCIC plant in Bangladesh and the 2,300 t/d Indorama Eleme plant in Nigeria, including pre-commissioning steps, problems encountered during start-up and ways around them.

Haldor Topsoe and Mitsubishi Heavy Industries likewise reported on the start-up and handover of a new integrated methanol and ammonia plant for JSC Ammoni at Mendeleevsk in Tatarstan, Russia, as well as the downstream urea formaldehyde unit. The plant can produce 2,050 t/d of ammonia in single mode, or 1,380 t/d ammonia, 67 t/d of methanol and 17 t/d of UFC-85 solution in co-production mode. Then in the next paper, and an interest-

ing companion piece to the preceding one, Russian nitrogen technology firm JSC NIIK looked at the same project from an outside battery limits (OSBL) point of view, including provision of demineralised water, ammonia storage etc.

Engro Pakistan started up their new 2,200 t/d ammonia plant in 2010, and presented lessons learned during the first five years of the plant's operation, including recovery from a water ingress incident in the high temperature shift catalyst, steam drum issues due to an exchanger leak, low flow in the synloop exchanger, and primary reformer burner choke issues. The company also gave a separate paper describing improvements to the associated urea plant which have overcome start-up issues at the plant.

Waqas Shehryar of Fatima Fertilizers in Pakistan listed all catastrophic incidents at urea plants over the last 50 years, and the lessons that his own company had taken from these and implemented at their own site.

Efficiency improvements

Abu Qir Fertilizers in Egypt shared the results of modelling work they have been conducting to represent the behaviour of their radial flow ammonia synthesis reactor, which has been verified against plant data. The model can predict the first bed outlet temperature, something not normally capable of being measured, and allows calculation of catalyst activity coefficient. It can also assist adjustment of synloop operating conditions to identify bottlenecks and improve performance.

Casale and Clariant presented a joint paper highlighting several case studies of ammonia converter upgrades which illustrate how teamwork between catalyst supplier and technology licensor can have a synergistic effect in performance improvements across the board within an ammonia plant.

Mitsubishi Heavy Industries compressor division looked at the requirement for modernising and upgrading of syngas turbines to cope with the higher duties required of them as a result of revamping operations, and the advantages that can be obtained by getting the original equipment manufacturer (OEM) to participate in the project, highlighting improvements to turbines which can now be offered by Mitsubishi.

Jovica Zorjanovic of Clariant showed how the combination of Clariant's Shiftguard 200 and ShiftMax 217 can effec-

tively absorb and retain chlorides and sulphides, allowing the superior performance of the ShiftMax 217 to provide ammonia and hydrogen plants with energy savings and higher production rates.

Klaus Noelker of thyssenkrupp Industrial Solutions presented an analysis of energy consumption for ammonia and urea production, and areas where there is still room for optimisation of energy use. While in general there is only minor scope for such optimisation, where steam export is possible there are fewer restrictions for the designer and improvement can come from the steam system efficiency.

Taking lessons from the airline industry, Arunkumar Murgan of consultancy Fitri looked at whether the human factor in plant operations management can be similarly 'optimised' to the plant's engineering, via what he called a 'context aware plant operations management system' (CAPOMS), equipping plant operators with the context-sensitive information needed to make good, timely decisions.

Anshuman Pandey of OPR Turbines took a different approach, using hydrogen-rich by-product tail/purge gases to cogenerate electricity and heat. Such a system can have a payback time of only 2 years, he said, and high ongoing operational savings.

Urea technologies

Leon Postma of Stamicarbon presented an improvement to Stamicarbon's existing LAUNCH MELT urea process, which can achieve up to 5,000 t/d capacity in a single train. The LAUNCH MELT Flash is based on reducing the steam consumption of the high pressure stripper by reducing the stripping efficiency of the HP stripper. An in-line flash step between the stripper and the LP recirculation system with heat integration can even substitute for the HP scrubber, lowering investment and operating costs.

Saipem's offering also involved optimisation of the steam system but also the power generation system of a fertilizer complex, tailored to specific sites, and via close cooperation with technology and major equipment suppliers.

Martina Schmitz of thyssenkrupp IS described a new granulation exhaust scrubbing system – this paper is given in more detail on pages 45-49.

Nitric acid

A short session on nitric acid plants and technology began with a report by thyssenkrupp IS on the new 1,500 t/d nitric acid plant they designed and built for Nitrogenmuvek in Hungary, using the company's tried and tested dual pressure process, and highlighting the environmental compliance features.

Willi Boll of Heraeus showed that the campaign length of a primary catalyst in a nitric acid plant can be significantly extended by optimisation of Heraeus' precious metal secondary catalyst for N₂O abatement, preventing the plant breaching emission limits for longer – from around a currently typical 40 days between primary catalyst changeouts to more than 80 days, and increasing secondary catalyst lifetime from 3 to 4 primary catalyst campaigns.

Walter Bachleitner of Messer Group showcased his company's Oxyboost technology, which improves the absorption efficiency of nitric acid plants by using pure oxygen to oxidise nitrous acid (HNO₂) and nitrous gases in the liquid phase. As well as reducing NOx emissions, it can produce up to a 10% capacity increase at low investment cost. A case study of the system in action at Azomures in Romania was also presented.

Product finishing

The final session looked at product granulation and finishing. Keiji Sano of Toyo Engineering Co presented TEC's recent experiences of start-ups of large-scale granulation plants; a 3,500 t/d plant at PT Pupuk Kalimantan Timur (Kaltim) in Indonesia, and a 4,000 t/d plant for Indorama Eleme Fertilizer & Chemicals Ltd in Nigeria. Toyo has now completed a technical evaluation of a 6,000 t/d single train urea plant, and believes that the same approach as these two plants can be successfully scaled up to this throughput.

Uhde Fertilizer Technology has been looking at ways of removing the need for formaldehyde addition in urea granulation, which as well as having possible health effects, can also prevent the urea's use in various technical applications, including diesel exhaust fluid (DEF). UFT has now developed a new proprietary additive which

works in the same way as urea formaldehyde, but without any of the drawbacks.

Ken Monstrey of Green Granulation Technology highlighted the use of a 'deep vacuum' in a variant on cold recycle urea granulation. The vacuum leads to more efficient water evaporation, removing or reducing the need for cooling and fluidisation air, and allowing a single exhaust fan for a lower overall pressure drop, as well as leading to more efficient dust removal. The system has been trialled at two fertilizer plants in China, including one producing 2,700 t/d.

Stamicarbon showed the results of an investigation into service life of a liquid divider in the high pressure stripper of the Pardis Petrochemical Company urea plant in Iran. Made from Safurex stainless steel, the observed rate of corrosion after 5.5 years – even in this most demanding of applications – means that the liquid divider should have a 10 year service life before requiring replacement.

And Sandvik – the manufacturers of Safurex – followed this presentation with a report on their newest grade of duplex stainless steel, Safurex Star, which combines all of the expected properties of Safurex with even better corrosion resistance (an improvement of around 10-20%), allowing it to be used in the most demanding applications such as HP stripper heat exchanger tubes, allowing increased lifetimes overall for HP strippers.

Careful handling of fertilizer granules is required to avoid breakage during production and conveying. Nikolai Velten of AUMUND Fordertechnik detailed some work conducted in conjunction with the Otto von Guericke University of Magdeburg and Institute für Baumaschinen on the stresses experienced by fertilizer prills during transport in a bucket elevator. While it is not possible to completely avoid prill breakage during transfer operations, the results show that it can be greatly reduced by the choice of type of conveyor.

With sulphur as a fertilizer nutrient becoming increasingly important, Nenad Zecevic of Petrokemija in Croatia reported on experiments conducted by his firm on synthesising ammonium nitrate sulphate as a double salt using sulphuric acid and ammonia to add to the ammonium nitrate reaction mix and successfully granulate it into a 26%N 15%S compound fertilizer. A similar thought was behind the development by thyssenkrupp IS of a new fluidised granulation process for ammonium sulphate, which is detailed in the Industry News section of this issue, page 10. ■

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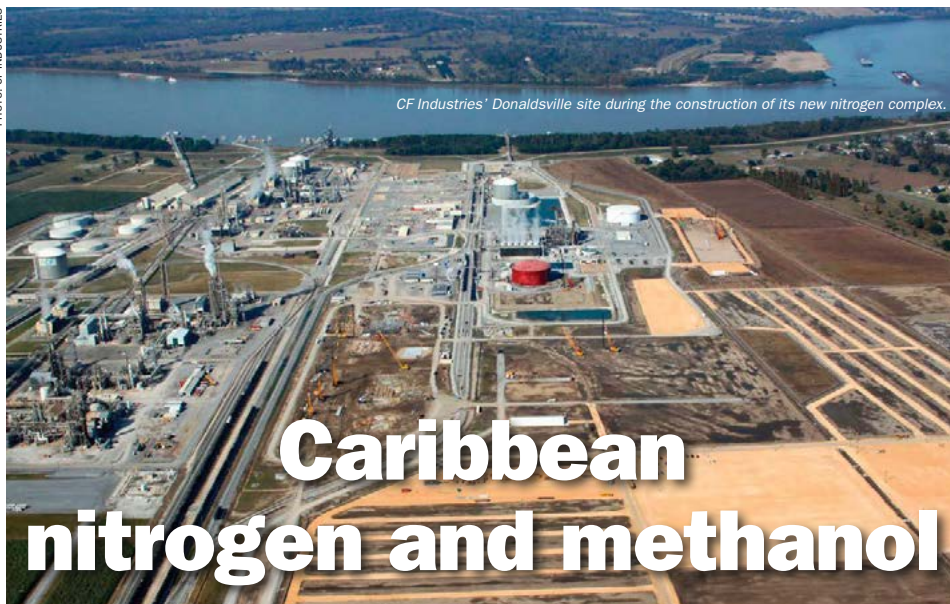
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CF Industries' Donaldsonville site during the construction of its new nitrogen complex.

Caribbean nitrogen and methanol

The rebirth of the US nitrogen and methanol industries due to cheap shale gas has coincided with gas supply issues on Trinidad and Venezuela's continuing political paralysis, and is likely to force more ammonia and methanol out onto the global market.

If any region illustrates how closely tied to the natural gas industry the methanol and ammonia and downstream industries are, it is surely the Caribbean. During the late 1990s and early 2000s, as high gas prices began to force US domestic producers to close down or relocate, Trinidad, and to a lesser extent Venezuela became the main beneficiaries, having as they did at the time ample supplies of cheap natural gas with which to feed new ammonia and methanol plants, and able to easily supply the large US market on their doorstep. But the past decade has seen a complete reverse of the situation. Trinidad now finds itself overcommitted in terms of natural gas resources, while the slump in domestic US gas prices caused by shale gas drilling has led to re-starts of mothballed facilities and a number of new projects.

United States

The remarkable turnaround in US natural gas production over the past few years has been the largest factor in the move of nitrogen and methanol production back to the US and the re-opening of some shuttered plants. US gas production has risen by 50% in a decade, from 511 bcm per year in 2005 to 726 bcm in 2015, according to BP. Indeed, so great has the turn in US fortunes been that, whereas a decade ago the country was forecast to become a major importer of LNG, in fact the US is now an exporter of LNG. Worries among North American syngas producers that exports of LNG from the US would drag domestic gas prices upwards, as has happened in Australia, do not seem to have materialised so far. Indeed, it is currently projected that if US gas prices were to rise

towards \$5.00/MMBtu as a result, this would draw more new shale gas production into the market, offsetting the gas that is exported.

On the demand side, the US remains the third largest consumer of nitrogen fertilizer in the world. Supplying this demand at the same time that domestic nitrogen production had closed has led to the US historically becoming the world's largest importer in the world of nitrogen fertilizer; in 2015 the US imported 11.9 million tonnes N of nitrogen fertilizer, with Canada, Trinidad and Russia the largest suppliers.

Now however lower US gas prices are leading to the re-starting of closed capacity and the start-up of new nitrogen plants. This began with the re-start of the idled PCS ammonia plant at Geismar in 2013, Louisiana, now revamped to 495,000 t/a of capacity, and a new ammonia side-stream from the Eastman methanol plant at Beaumont, Texas totalling another 240,000 t/a. This year, there are several of the new plant developments beginning to come on-stream, including the OCI nitrogen complex at Wever, Iowa, and new production trains at CF Industries' sites at Donaldsonville, Louisiana and Port Neal, Iowa. Between them these plants will add 2.5 million t/a

of ammonia, 2.7 million t/a of urea and 2.8 million t/a of UAN capacity. Another 800,000 t/a of ammonia came on-stream last year at Dyno Nobel's Waggaman facility, and recently there has also been the start-up of 600,000 t/a of urea plus an ammonia revamp at Agrium's Borger, Texas plant. Koch Nitrogen has added a 900,000 t/a urea plant at Enid, Oklahoma.

As well as gas-based plants, there is some new US nitrogen capacity based on petroleum coke and coal. Dakota Gasification is building a 330,000 t/a downstream urea unit at its coal-based plant in North Dakota, due for completion in 2018, and there is now a 20,000 t/a ammonia stream from the new Kemper County integrated gasification combined cycle (IGCC) power facility in Mississippi. And while some plants have seen delays and cancellations – Fatima, Eurochem and most recently the Cronus Chemicals development at Tuscola, Illinois – there are still a number of new projects on the slate, including a 750,000 t/a ammonia plant being built by Yara and BASF in Freeport, Texas due for completion this year, based on off-gas from other chemical processes.

Methanol

As with ammonia production, so things have changed in similar fashion for methanol. The US methanol industry had suffered a double blow from rising gas prices on the one hand and the spreading ban on the fuel additive MTBE – which had been the major source of demand for methanol in the US in the early 1990s, and as with ammonia production, Trinidad was the major beneficiary of the demise of the US methanol industry, which contracted from 18 plants producing 6.6 million t/a in 1998 to four plants producing 1.0 million t/a in 2005. Now, however, rising production in the US is threatening production in the Caribbean. In 2011, Methanex restarted its mothballed 470,000 t/a plant at Medicine Hat, Alberta, which had been idled since 2002, followed by a re-start for Eastman's Beaumont, Texas methanol plant in 2013. Methanex relocated two plants from Chile, where the company has faced gas curtailments, to Geismar, Louisiana, south of Baton Rouge, adding another 2 million t/a of capacity, and LyondellBasell restarted its 800,000 t/a Channelview methanol plant near Houston, Texas in late 2013, which had been idle since March 2003. Again, as well as restarts and relocations in North America, several large new methanol plants are under development,

Table 1: New methanol capacity, North America

Company	Location	Capacity, million t/a	On-stream	Status
Celanese	Clear Lake, TX	1.3	2015	C
Methanex	Geismar, LA	1.0	2015	C
	Geismar, LA	1.0	2015	C
G2X Energy	Pampa, TX	0.07	2015	C
Natgasoline	Beaumont, TX	1.3	2017	UC
Primus Energy	Two sites	0.1	2018	UC
US Methanol	W Virginia	0.3	2018	CA
NW Innovation	Kalama, WA	3.6	2020	P
Yuhuang Chem	Lake Charles, LA	1.8	2020	P

Key: C = complete/commissioning. UC = under construction. CA = contracts awarded. P = planned.

most of them in the Gulf Coast region, as shown in Table 1. Celanese Corporation completed a 1.3 million t/a methanol plant at its existing Clear Lake site outside in 2015, and Natgasoline is building a similar sized plant at Beaumont, Texas. There are also some smaller, modular units being developed by Primus Green Energy and two 15,0,000 t/a methanol plants in West Virginia planned by US Methanol. Finally, Chinese involvement in the US methanol market has led to Yuhuang seeking permits for a 1.8 million t/a methanol plant at Lake Charles, and two major methanol projects in the US Pacific Northwest proposed by Chinese firm Northwest Innovation Works LLC. These huge units will generate 1.8 million t/a each for onward transport to China to be used in methanol to olefins (MTO) production. China has a number of methanol to olefins plans under development which will use methanol from the merchant market as feed, and while there is plenty of coal-based methanol capacity, the theory is that cheap gas-based capacity could undercut this.

Trinidad

Trinidad rapidly expanded its gas output during the 1990s and early 2000s. New gas development was able to counter the island's falling oil production, and the development of gas-based chemical industries was extremely important to Trinidad's rising GDP. In 1998 the country also began exporting gas as LNG, via the Atlantic LNG project. However, Trinidad's problem stemmed from government control of gas prices. Although there was an escalator built into the price, depending on the price of finished products (eg ammonia and methanol), there was also

a cap on the price which the government paid the extracting companies for the gas, and as global gas prices rose during the late 2000s, this made it relatively less attractive to develop gas resources in Trinidad as compared to elsewhere in the world. Trinidad's gas production began to plateau, and peaked in 2010 at 44 billion cubic metres. Since then, as gas fields have matured and declined, there has not been sufficient new gas development to make up for falling output, and this has had a knock-on effect on downstream gas-based industries. Trinidad's gas output fell to 39.6 bcm in 2015, and, perhaps more worryingly, the country's proved natural gas reserves have fallen by nearly half over the past decade, to around 300 bcm in 2015, according to Trinidad's National Gas Company (NGC).

In the meantime, Trinidad continues to export gas as liquefied natural gas. Atlantic LNG was the world's sixth largest exporter of LNG, producing over 13.7 m t/a in 2012 from four trains. Originally most of the gas was exported to the US, but as the US's own gas production has risen from shale gas, so American demand for gas has fallen and now Atlantic exports mainly to Latin America. As gas availability has fallen, so has Atlantic's output, dropping 13% year on year to this April.

The fall in gas output has led to rationing among ammonia and methanol producers, with gas supply down up to 20-30% during 2011-12, becoming slightly less severe in more recent years, and the curtailments are expected to ease this year as new production from BP, BHP Billiton and EOG Resources comes on-stream. It has also belatedly pushed Trinidad into new licensing rounds – nine deep water blocks were licensed in

2011-13, and there has been more licensing rounds this year. Authorities estimate that the recently auctioned offshore blocks TTDA 3 and 7 could hold 0.5-2.0 billion barrels of oil and 200 bcm of associated gas. How long these blocks take to develop and get gas ashore is however another matter, and oil and gas companies have complained about the gas prices paid by the Trinidadian government which do not encourage riskier and more expensive deep water drilling. In the meantime, Trinidad has looked to import gas from Venezuela as a stopgap. At the end of last year Trinidad signed an agreement with Venezuela to receive gas via an interconnection through the Dragon Field export gas pipeline. PDVSA says Dragon will produce 300 million scf/d of gas from four wells in the first phase, and twice that one an offshore platform is installed.

Downstream capacity

There are currently seven companies operating ammonia and downstream nitrogen plants on Trinidad, all of them at the Point Lisas industrial estate in the west of the country. The largest operator is PCS Nitrogen, which has four ammonia units and a urea plant at Point Lisas. Yara, formerly Hydro Agri, inherited the Trinidad plant when it bought WR Grace's ammonia interests in 1991, and it strengthened its position by buying a 49% stake in the two government-owned plants run by Tringen. Koch Nitrogen, which bought the old Farmland MissChem plant, a large nitrogen complex run by Methanol Holdings Trinidad Ltd under the banner of AUM, and two plants owned by a consortium of Koch with Ferrostaal and Proman and gas producer EOG make up the remainder – these latter plants were once developed by local entrepreneur Laurance Duprey's Colonial Life Financial empire, but were sold on after the latter's bankruptcy during the 2008 financial crash. Altogether there are 11 ammonia plants with a total of 5.5 million t/a of capacity, as well as 600,000 t/a of urea and 1.4 million t/a of UAN capacity. On the methanol side, the various plants have gradually consolidated into two main companies: Methanol Holdings (Trinidad) Ltd (MHTL) – a consortium of Ferrostaal, Proman and Helm, and two large units operated by Methanex. There is 6.4 million t/a of methanol capacity in seven plants.

The current gas shortages have served to put a hold on new downstream developments, and Sabic withdrew from a proposed methanol to olefins (MTO) development, but

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Mitsubishi Gas Chemical and Mitsubishi Corporation, together with local partner Neal & Massy Holdings Ltd, are still attempting to develop an \$850 million methanol and dimethyl ether (DME) project. Phase 1 of the project aims to produce 1.0 million t/a of methanol, of which 140,000 t/a will be used to produce a further 100,000 t/a of DME. A gas to liquids (GTL) plant was also constructed during the early 2000s, but faced massive cost overruns and issues during start-up which led to creditors calling in loans and the plant went into receivership in 2008. After several years of legal wrangling and the potential scrapping of the plant, WorldGTL has finally been bought by NIQuant Energy Ltd, who are refurbishing the plant with the expectation of start-up in 2019.



Installing a distillation tower at LyondellBasell's Channelview methanol plant.

Venezuela

Oil-rich Venezuela has developed its own nitrogen and methanol industries on the back of associated gas from oil production, run mostly by state-owned Petroquímica de Venezuela (Pequiven) and its subsidiaries. Pequiven has four complexes across Venezuela at El Tablazo, Jose, Paraguana and Moron, which have a total of 2 million t/a of urea capacity and 1.5 million t/a of methanol capacity. Some abortive attempts to develop new or replacement capacity did finally lead to the Moron nitrogen complex being replaced by a new facility in 2014 which has 1,800 t/d of ammonia and 2,200 t/d of urea capacity, developed with financial support from China. However, other plans to increase methanol capacity have struggled to gain finance. Meanwhile, the run of low oil prices has crippled the country's balance of payments, and increasing shortages of everyday items have led to strikes, protests, and even riots and looting in Caracas.

Market impacts

Increased US nitrogen production in 2017 will amount to over 4 million tonnesN/year, once the new CF plants at Donaldsonville and Port Neal and OCI Wever are fully up and running, and new capacity at Dyno Nobel, Yara/BASF, Simplot and LSB Industries is taken into account. This will still leave the US nitrogen market undersupplied to the tune of 7.6 million tonnes N, however, according to CF Industries. Most of the plants have downstream urea and UAN capacity, and the impact on ammonia imports may not be drastic in the short run – CF projects US ammonia imports of 4.1 million t/a this year, down from 4.6 million t/a in 2016, 5.2 million t/a in 2015 and 8 million t/a in 2011, and once the Yara plant is working at the end of the year this could remove another 0.7 million t/a of import requirements. Likewise urea imports are expected to fall to 5 million t/a in 2017, down from 7.2 million t/a in 2015. UAN imports will fall from 3.1 million t/a to 1.5 million t/a over the same period. US ammonia imports have mainly come from Trinidad and the FSU, and this continuing fall will displace production elsewhere, with Trinidadian suppliers – only now returning to full capacity as gas supplies recover – having to look to markets in South America, Europe and North Africa to compensate. Nevertheless, as the current wave of new US capacity peaks, there is still room for import of nitrogen products into the US market, and that situation is likely to continue for the foreseeable future.

The impact is likely to be far greater on the methanol side, however. US methanol production has risen from less than 1 million t/a in 2010 to over 5 million t/a in 2016, and could reach 11 million t/a in 2020 if all of the current projects stay in schedule. While US methanol demand will continue to rise at about 2.5% per year, from about 6.5 million t/a in 2016 to 7.2 million t/a in 2020, this will turn the US from a net importer – currently at a level of about 1.5 million t/a – to a major net exporter of nearly 4 million t/a. Trinidad and Venezuela have traditionally sold their product mainly into North America, but now will be trying to secure new markets in Europe and the Far East, and having to compete with new US methanol capacity. It looks to be a bad time to be trying to build new methanol capacity in Trinidad, although perhaps a better time to be looking downstream to methanol to olefins, gasoline, acetic acid or other derivatives.

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Overcapacity continues to stalk urea markets

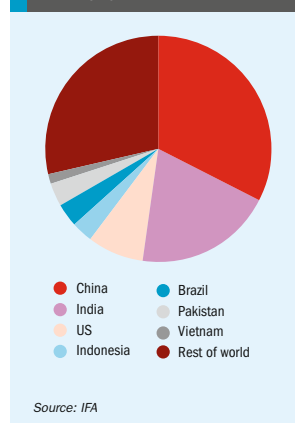
In spite of a dramatic fall in Chinese production and exports due to higher coal prices, continuing additions of new urea capacity worldwide continue to keep the market oversupplied.

Urea remains the bellwether for nitrogen prices – of the approximately 150 million tonnes of nitrogen produced as ammonia in 2015, around half was used for the manufacture of urea. Urea is preferentially shipped to ammonia as a dry bulk commodity with a high nitrogen content (46% w/w) and remains the key nitrogen fertilizer. In spite of continuing above-trend growth in chemical and 'industrial' demand sectors for urea for production of melamine, urea-formaldehyde resins and urea solutions for selective catalytic reduction of vehicle exhausts (AdBlue/DEF), agriculture continues to dominate demand for urea, representing about 80% of its consumption. Nitrogen fertilizer markets are gradually maturing and becoming more sophisticated, with multi-nutrient blends of fertilizer starting to take over from traditional single nutrient sources like urea, but its continued popularity in Asian agriculture, as demonstrated by Figure 1 – China, India, Indonesia, Vietnam and Pakistan collectively represent 60% of all urea consumption. Overall urea demand looks to increase by about 2% in 2017.

Feedstock costs

Most urea, outside of China, where coal still predominates, depends on natural gas feedstock. Merchant urea production has thus tended to gravitate towards cheaper gas locations such as the Middle East. This is why countries like Iran, Saudi Arabia, Qatar and Russia are so prominent in Figure 2. However, the gas market is changing rapidly as gas-on-gas competition begins to replace oil-indexed or controlled pricing, and gas availability is also now becoming a major factor, with the Middle East – outside of Iran – no longer having the amount of gas available as it used to. Now new factors are coming into play, such as the rise of shale gas production in the United States,

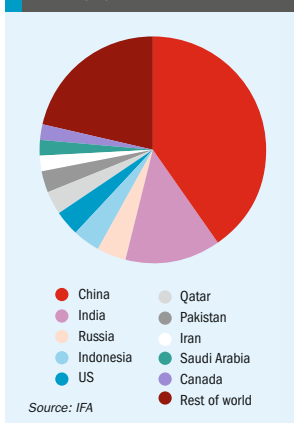
Fig 1: Urea consumption by country, 2015



allowing the re-start of domestic production there. The US market is more mixed in terms of nitrogen consumption, with UAN, DAP and direct application ammonia all playing a part, but as Figure 1 shows, the US is also the world's third largest consumer of urea, and the comparatively small slice of US production in Figure 2 is now growing as new domestic plants start up.

Global natural gas prices have fallen with the fall in oil prices and general slump in commodities, but the fall has become entrenched globally because of huge overcapacity in the liquefied natural gas (LNG) market, which has been pushed down by new export capacity in the US and Australia. LNG oversupply has helped the convergence of global gas prices, pushing down prices at the UK National Balance Point (NBP) hub to only \$1.00/MMBtu or so above Henry Hub prices, and greatly assisting the competitiveness of Euro-

Fig 2: Urea production by country, 2015



pean fertilizer producers. In this changed gas price situation, it has been Chinese feedstock costs which have become the dominant factor in the global urea market.

China

China's investment in new urea capacity over the past decade, in an attempt to keep pace with domestic demand, has set the tone for the urea market for some time. Tens of millions of tonnes of new capacity were added, about 70% of it based on domestically available coal. However, Chinese government policy is changing in several areas as the country transitions from an industrial to a consumer-driven economy, and this too is having and will continue to have a major impact on urea.

On the one hand, China has recognised the problem caused by over-application of nitrogen fertilizer – particularly urea – at the

expense of other fertilizers. China's nutrient use efficiency is considerably lower than North America or Europe, even though it uses much more fertilizer per hectare than those regions. It also faces a slower growing population, albeit one that is moving towards a diet higher in protein – more livestock rearing will make more manure available for farmers. The Chinese government decided in the most recent five year plan (2016-2020) to let nitrogen fertilizer demand rise only 1% per year to 2020, at which point it will be capped. Future productivity gains will come from more efficient application.

Meanwhile, China is also undergoing an internal transition to market pricing in a number of areas, including freight rates, power costs, natural gas pricing, VAT etc, many of which are increasing costs for urea producers at the same time that coal costs are rising. On coal, the government is trying to slim down the country's bloated mining sector, which is also suffering from huge overcapacity. In April 2016 it cut the number of days that coal mines are allowed to operate from 330 per year to 276. This was reversed in November after some coal prices had more than doubled, but the National Development and Reform Commission (NDRC) says it is still targeting 150 million t/a of mine closures this year and 800 million t/a by 2020 (at the same time that 500 million t/a of newer, more efficient capacity will be added). The coal price spike hit Chinese urea producers hard, even those that have switched to running on cheaper, bituminous coal rather than more expensive anthracite, and significantly reduced China's exports of urea, which have already fallen from a record 13.8 million t/a in 2015 to

8.9 million t/a in 2016, and an estimated 5.0-7.5 million t/a in 2017 due to low operating rates among coal-based producers.

At the same time that it slims its coal sector, China is also making similar moves to tackle overcapacity in the urea sector, forcing the closure of less competitive capacity at the same time that new, more efficient plants are coming on-stream, with larger capacities (600-800,000 t/a) and more modern gasification technologies. The Chinese Nitrogen Fertilizer Industry reported that 9 million t/a of urea capacity closed in 2014-15, and around 8 million t/a in 2016. CF Industries estimates that, while 36 million t/a of new urea capacity has come on-stream since 2012, around 23 million t/a has closed at the same time, most of it higher cost anthracite-based plants, and CRU forecasts that another 12-14 million t/a of capacity will close from 2017-2021, significantly more than forecast capacity increases of around 8-9 million t/a. For the first time in decades, Chinese urea capacity may actually fall. China is also restricting production from coal-based plants near population centres during winter to alleviate smog problems, which is also reducing output at up to 45% of plants, representing 36 million t/a of production.

India

India is another major imponderable for the global urea market. It is the largest importer of urea; 8.5 million tonnes in financial year 2015-16, although this dropped to 5.5 million t/a for FY 2016-17. The country's urea consumption is complicated by a subsidy scheme which has decontrolled the prices

of all fertilizers except urea, leading to nutrient imbalances in application. However, the government is now attempting to move to direct subsidies to farmers. At the same time, the government is trying to boost domestic production by revamping and reopening old, closed plants and allowing the construction of new plants, but allocation of scarce natural gas is a crucial factor in whether these projects will be able to proceed or not, and many Indian companies are looking overseas to see if capacity can be developed there, with Iran and various locations in Africa also under consideration.

New investment

With prices low and the industry suffering from overcapacity, the conditions for building new urea plants are certainly challenging, although there is still an overhang of new capacity developments from the previous investment cycle. This includes several million tonnes of new capacity in the US, as well as Iran, Nigeria, India, Southeast Asia and Russia. Overall, global urea capacity is expected to reach 163 million t/a in 2020, according to IFA. Beyond this timeframe, there are large new projects under development in Russia and Africa – Russia's competitiveness has been aided by the rouble's slide, although sanctions also makes sourcing new technology harder, while Sub-Saharan Africa is the only place where there is still 'stranded' gas on any significant scale – in countries like Mozambique and Tanzania, and there is also still considerable flared gas available in Nigeria, but financing may well depend on urea prices coming back up from their current doldrums.

Urea trade

Table 1 shows the major exporting and importing regions as of 2015, although this masks some intra-regional trade, for example from Indonesia to Vietnam or Canada to the USA. The figure for exports from the Middle East continues to increase, likewise the FSU in spite of more closures in Ukraine. New capacity additions are forecast to exceed consumption growth this year, and prices are likely to remain at levels set by the highest cost producer – in this case Chinese coal-based producers – of around \$270/t. However, next year the outlook is more or less balanced in terms of demand and capacity increases, and thereafter prices should begin to recover.

Table 1: Urea production and consumption and net surplus/deficit by region, 2015, million tonnes N/year

Region	Production	Consumption	Surplus
Western Europe	2.80	4.49	-1.69
Central Europe	1.32	1.64	-0.32
FSU	5.80	2.64	+3.16
North America	4.64	8.04	-3.40
South America	2.05	5.49	-3.44
Africa	2.25	2.12	+0.13
Middle East	9.79	2.52	+7.27
South Asia	14.02	19.84	-5.82
East Asia	37.79	33.23	+4.56
Oceania	0.21	1.13	-0.92

Source: IFA



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Multi-stage scrubbing for granulators and prilling towers

Stamicarbon and EnviroCare have co-developed a multi-stage process for the efficient scrubbing of urea particulate and ammonia from both granulator and prilling tower technologies. These gas scrubbers are designed to achieve extremely high efficiencies and to meet stringent emission levels, while keeping pressure drop low to minimise energy consumption. **W. Dirks** of Stamicarbon and **B. Higgins** of EnviroCare International discuss the key features and performance of the scrubbing technology.

Urea prills and granules are produced from highly concentrated urea melt solutions. When the melt is sprayed into a prilling tower or a granulation unit, there will be evaporation of decomposition products from urea (for instance ammonia and isocyanic acid). Air is used to cool the final product. The off-gas must be cleaned before it is released into the atmosphere because it will contain urea dust, ammonia, and various decomposition products of urea. To reduce air pollution, the off-gas is scrubbed using an aqueous solution that is circulated in the scrubber until it has the desired concentration of urea (e.g., 45 wt-%). The concentrated urea solution is blown down for reuse.

To capture ammonia, sulphuric or nitric acid can be injected to produce and concentrate an ammonium salt, which is sent to OSBL or reprocessed into the urea end-product².

Dust emissions

In both granulation and prilling, substantial submicron dust is generated. Adverse human health effects associated with both long-term and short-term respiratory exposure to fine ambient particulate has made emission reduction a regulatory priority for many governments. While older technology scrubbers easily scrub larger particles, a high degree of submicron dust

capture requires a new approach¹. This need has forced the development of new technologies to remove contaminants from gaseous effluent streams released into the atmosphere. New technologies must both be more effective at pollution control, while simultaneously reaching equally strict financial capex and opex targets. Reducing both capex and opex is challenging because the amount of off-gas (air) is large; e.g., typical gas flow values exceed 750,000 Nm³/h.

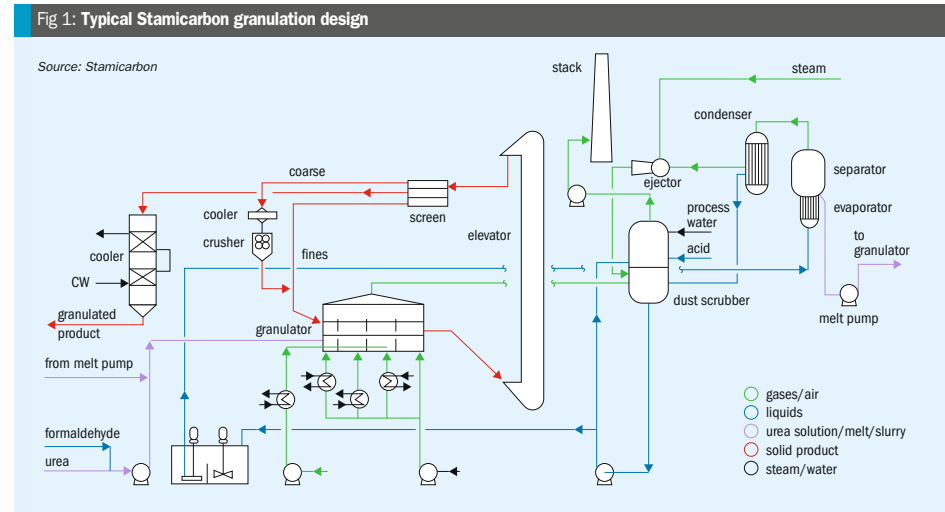
Ammonia emissions

During the solidification of the urea melt in a granulator or prilling tower, the ammonia present in the urea melt is released and emitted. Since ammonia (NH₃) emissions are also regulated, NH₃ has to be removed from the off-gas. The removal of NH₃ from the gas stream is easily achieved by providing intensive contact between the off-gas and an acidic solution, producing an ammonium salt solution. An acid is typically added to the recycled scrubber water using a pH measurement as the feedback control parameter to control the injection of acid².

The NH₃ can be captured in combination with, or separated from, the urea dust capture. There are also various options regarding the selection of the acid, different ammonium salt products will be pro-

duced depending upon the acid selected. For example, if sulphuric acid (H₂SO₄) is selected, the salt product will be ammonium sulphate [(NH₄)₂SO₄]. If nitric acid (HNO₃) is selected, ammonium nitrate [(NH₄)NO₃] will be formed. The ammonium salt product can be cycled up in concentrations, which can be beneficially used separately, or it can be combined with the urea dust and recycled back into the upstream process (so long as the upstream process can accommodate the salt). When processed together, the end product is often abbreviated as UAS or UAN. When processed separately, this changes to U+AS or U+AN. Depending on which of these four combinations is selected, various metallurgy considerations should be considered to prohibit corrosion².

If, for example, the scrubbing solution is acidified with sulphuric acid, the AS produced in the acidic scrubbing stage and the urea solution from the dust scrubbing stage can be concentrated together in a separate evaporator unit and then routed to the urea granulator, in which case the entire urea production then contains approximately 0.05-0.10% S, or it can be processed in a modified multiproduct granulation section to produce UAS fertilizer with a higher AS content as a value-added by-product without producing any waste streams³. The evaporator off-gases pass through condensers, from which the non-



condensable portion is sent to the granulation scrubber. The condensate is returned to the granulation scrubber to close the water loop and to reduce the consumption of external process water (Fig. 1).

Because of an increasing demand for granulated urea containing macro- and micro-nutrients, Stamicarbon has developed a unique and flexible process for the production of granulated UAS with the smoothing of the UAS granules in the final stage of the granulator. A large range of

AS-concentrations (0-50 wt-%) can be handled without the need for any modifications to the granulator. Given the modular build-up of this multiproduct (UAS) granulation, the option to have an evaporation section that is independent of the urea melt section and the versatility of the homogenising and suspension unit, the process can be used to produce plain urea granules or granulated urea containing other macro- and micro-nutrients that are added in the same manner as ammonium sulphate.

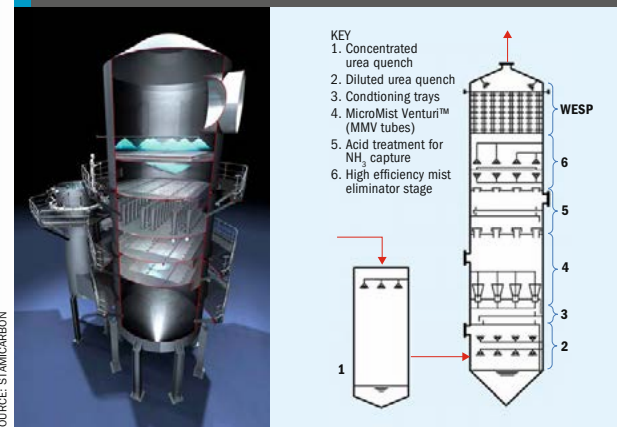
Stamicarbon EnviroCare partnership

Stamicarbon and EnviroCare International (ECI) have partnered to develop scrubber technologies for the urea and fertilizer industry bringing together Stamicarbon's 70 years of urea experience together with ECI's 35+ years of pollution control experience. Together, they have developed a new scrubber technology for the urea industry partially based on a proven technology that has been successfully installed and operated at other industrial applications, such as incineration, pulp and paper, sewage sludge processing, and power.

EnviroCare scrubber technology for granulation

The EnviroCare scrubber contains six stages that progressively treat and clean the off-gas. In the most general terms, make-up water is introduced downstream, contacting the cleanest gases first. The water is then recirculated many times, working its way upstream until it comes into contact with the most dust-laden gases. By the time the water is extracted, it has been allowed to cycle up in concentration with urea and/or ammonia salts. With this applied scrubber technology emissions of 10 mg/Nm³ or lower can be achieved. With an additional integrated wet electrostatic precipitator (WESP) even lower emissions can be obtained⁴.

Fig 2: Representative scrubber 3D (left) and sectional views (right) with six stages schematically indicated



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Fig. 3: View of a typical SpiralMist quench stage.



Fig. 4: Wetted DOI tray, showing intimate gas-water contact.

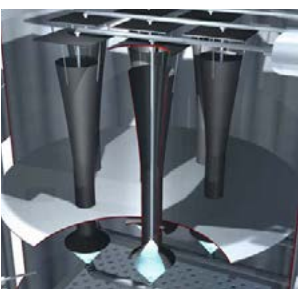
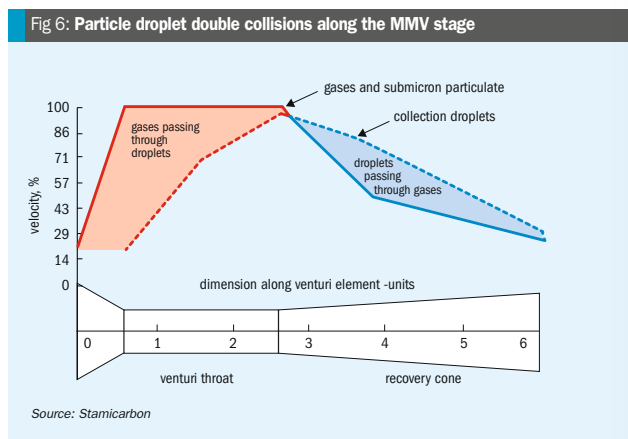


Fig. 5: Multiple MMV tubes shown (flow upward from bottom).



The six stages, represented in Fig. 2, consist of: (1) concentrated urea quench, (2) diluted urea quench, (3) conditioning trays (optional), (4) MicroMist™ Venturi (MMV) tubes, (5) acid treatment for NH₃ capture, and (6) high efficiency mist eliminator stage. There is an optional integrated WESP for very low emission requirements.

Stage 1: Concentrated urea quench

As air is used for removing the heat of crystallisation and for cooling the granules, the off-gas leaving the granulator is relatively dry. To cool and saturate the gas with water, the gas flow is contacted in the SpiralMist™ quench stage (see Fig. 3) with a fine mist of concentrated urea solution. At this stage, most of the coarse particulate urea dust is scrubbed from the gas stream. The concentrated urea solution is typically between 35 wt-% and 45 wt-% urea.

Stage 2: Diluted urea quench

Downstream of the first quench zone, a secondary quench is used. In this second quench, a dilute solution of urea (~1%) is used to further cool and humidify the gas

flow. This process is a very important step to assure that remaining submicron particulate is exposed to saturated gas, where particles can substantially grow in size through condensation. Larger particulates, which are mostly surrounded by water, are easier to capture in downstream systems like venturi tubes and WESPs. This second, diluted urea quench makes high-efficiency submicron-particulate capture possible and forms the basis of the intellectual property.

Stage 3: Tray conditioning

Inside the scrubber vessel and after the diluted urea quench stage several dual-orifice conditioning (DOI) trays can optionally be installed to further condition the gas stream. These trays remove lingering coarse particles and promote submicron particle growth through the condensation of liquid onto the particle surface. The water that flows across these trays is provided from the MMV stage above (see Fig. 4).

Stage 4: MicroMist Venturi (MMV) stage

Multiple parallel MicroMist venturi (MMV) tubes are installed vertically on a diaphragm in the vessel (Fig. 5). The diaphragm forces the gas flow to accelerate through the tubes. The diffuser on the outlet side of the MMV tubes is aerodynamically designed to reduce the overall pressure drop, thereby reducing fan power requirements. Each venturi tube includes a converging conical section (the inlet) where the gas is accelerated to throat velocity, a cylindrical throat, and a conical expander where the gas is slowed down and energy is recovered.

A MicroMist atomisation nozzle is located at the entrance of each venturi tube. A second nozzle is coaxially located in the throat of the venturi tube. The throat nozzle is directed upstream, and is primarily used to maintain sufficient pressure drop across the venturi to assure gas/particle interaction when gas flow is low (e.g., winter conditions).



Fig. 7: Construction phase of a MMV scrubber/WESP installation for a urea granulator.



Fig. 8: Construction phase of a rectangular modularized MMV scrubber installation for a 1,000 t/d urea granulator.

Both the inlet and throat nozzles are high-pressure hydraulic nozzles, producing fine droplet sprays. In the MMV tube, gases interact with the particulate and droplets twice (acceleration and deceleration) as shown in Fig. 6.

Stage 5: Ammonia acidic scrubbing

Above the MMV stage, several additional DOI trays are used to capture and sequester the remaining gaseous ammonia. The tray is flooded from above with acidified water. Acid flow rate is controlled based on a pH measurement. Typically sulphuric acid or nitric acid is used to react with NH₃, forming an ammonia salt.

When the urea and ammonia salt capture is intended to be separate, a mist eliminator and chimney hat tray section is installed to prevent contamination between the urea dust scrubbing and the NH₃ capturing section.

Stage 6: Mist elimination

Remaining suspended water droplets are removed from the gas stream in the mist eliminator before the gases leave the scrubber. Fresh (clean) water is continuously sprayed on the mist eliminator to catch and wash away dirty particles. Intermittently, a deluge from above is used to wash agglomerated particulate from the mist eliminator surfaces.

The fresh water used is the source of

the scrubber make-up water for both the urea and ammonia capture systems when combined, or just for the ammonia capture system when operated separately. Due to the small amount of water needed for the ammonia capture system, the mist eliminator water is often designed to be recaptured (across a chimney hat tray) and recycled, with a small fraction bled off to the ammonia scrubbing stage.

Installation experience on granulation

Stamicarbon and EnviroCare have designed this MMV scrubber technology in combination with Stamicarbon's urea melt and fluidised bed granulation technology in more than five greenfield and two revamp projects. For the two projects where the MMV scrubber has been fabricated, this scrubbing technology was preferred due to the very stringent emission requirements necessary for obtaining a new operating permit. Figs 7 and 8 show currently installed projects utilising this new granulator scrubber technology.

Due to the complexity of integrating a large scrubbing system into the urea granulation plant, regular communication is required with the customer's detailed engineering contractor. The workflow, shown in Fig. 9 is representative of the approach Stamicarbon and EnviroCare have agreed upon to facilitate the most

practical method for their respective multidisciplinary project teams. At all phases (i.e., conceptual design, detailed design, fabrication, shipping, erection, and start-up of the system) quality is achieved by continuously having the correct technical specialists available to solve any problems that may arise.

Scope of work is maximised at the shell fabricator's workshop so that quality can be controlled and maintained during fabrication. All internals can be pre-installed and trial fitted such that the total assembly can be inspected and tested by Stamicarbon and EnviroCare before being shipped to site. The customer or the customer's representatives are welcome to witness these activities.

Envirocare scrubber retrofit

The formerly installed granulator scrubber and granulator cooler scrubbers include "Joy" and "Turbulaire D" scrubbers, or simply vertical vessels with multiple tray stages and mist eliminators. Recirculated urea solution enters at the top of the dust removal section and flows down by gravity while the off-gas enters at the bottom of the scrubber and flows upwards in countercurrent. On its way down, the liquid flows horizontally over the trays or downwards through mist eliminators and comes into contact with the off-gas rising through the tray openings, capturing its content of urea dust.

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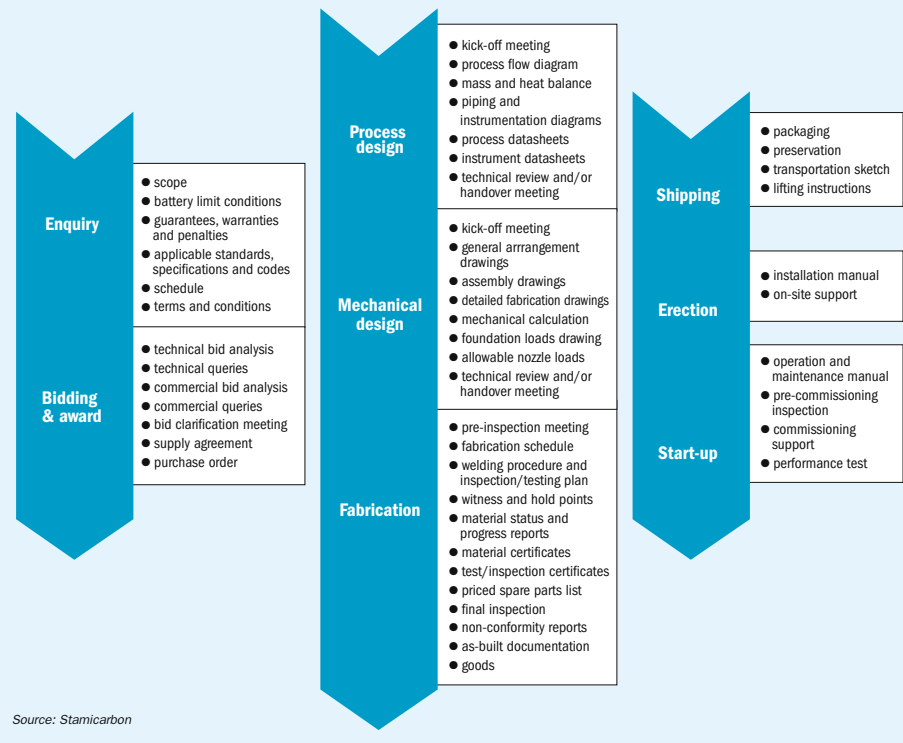
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Fig 9: Stamicarbon and EnviroCare workflow and deliverables



Source: Stamicarbon

The air exhausted from the granulator entrains a certain percentage of the plant output in the form of fine urea dust. That gaseous stream is directed to the granulator scrubber where it is cleaned by urea solution circulated by the granulator scrubber demister is, in practice, flushed continuously.

Some urea dust, though in a much lower quantity and of a more coarse nature than the granulator, is recovered from the fluid bed product cooler and de-dusting lines in the granulator cooler scrubber, which drains to the urea solution tank. This weak urea solution is used as scrubbing makeup liquid to the granulator scrubber. The granulator cooler demister is washed on an intermittent basis.

Often an existing granulator scrubber, as described already and receiving submicron urea dust, can be easily retrofitted with the new MicroMist Venturi scrubbing technology to meet newly requested or

imposed lower emission values. To do this, the existing venturi section is widened and replaced with quench spray nozzles. Then the separator vessel is retrofitted to contain the MMV section, which is installed as a modular insert. Fig. 10 shows a retrofit application.

A retrofit will essentially consist of leaving the base of the existing scrubber and replacing the upper part with a new, MMV section inclusive of internals. The required spool scrubber shell, extra pumps, valves, instruments, and other items, will be provided by the selected contractor or Stamicarbon. The venturi tubes, tray, nozzles, mist eliminator, engineering and design drawings will be provided by Stamicarbon/EnviroCare.

This proposed scrubber revamp guarantees achieving an outlet urea dust emission of less than 10 mg/dNm³. Since no ammonia scrubbing is required, no additional stage is required in this example.

Stamicarbon/Envirocare jet scrubber technology for prilling towers

In a prilling tower, the urea melt is sprayed from a prilling bucket in the centre of the top of the urea prilling tower and is brought in direct contact with the atmospheric air coming from air intakes in the lower part of the prilling tower. The cooled prills fall down towards the bottom of the tower, where a scraper is installed, and a belt conveyor transports the final product to storage.

The off-gas discharged from a urea prilling tower has dust with extremely large surface area. As such, the scattered light makes this dust very visible as a purple-white plume that extends to the horizon. Often, due to the low temperature at the exit (~70°C), the waste gas does not mix well with the atmosphere, resulting in a plume that does not dissipate readily.

For obvious reasons, governmental

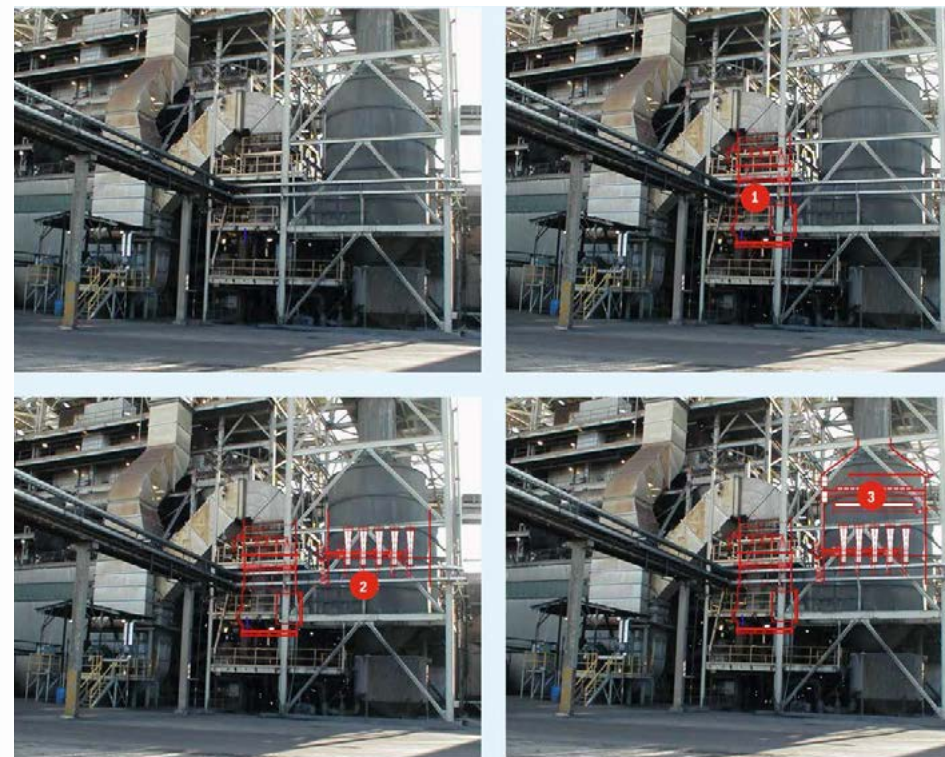


Fig. 10: Retrofit plan showing (upper left) original scrubber, (upper right) new quench section, (lower left) new MMV section, and (lower right) new mist eliminator section.

regulations for prilling tower emissions are becoming stricter. Allowable emission levels are currently maximum 50 mg/Nm³ dust and 50 mg/Nm³ ammonia. Not meeting these requirements might lead to forced plant closure.

When adapting the Stamicarbon/EnviroCare scrubber technology to prilling towers, there are two options: the scrubber can be placed on the ground ("at grade") or it can be placed on top of the prilling tower. When placing the scrubber on the ground, the same technology is used as described above for granulation. While this option is technically sound, it is also an expensive solution due to the required ductwork to bring the flue gas to the ground. Additional expense is required for the fan, structural steel, and the stack.

A less expensive option is to install the newly developed "jet scrubber" on the prilling tower roof. To do this, Stamicarbon and ECI developed a new technology that is

much lighter and does not require an additional fan. A jet scrubber can move the process gas without the aid of a fan or blower. The liquid spray coming from the nozzle creates a partial vacuum at the entrance duct of the venturi tube. This partial vacuum can be used to move the process gas through the venturi as well as through the whole scrubber system. Very high liquid-injection rates can be used to provide the gas-moving capability and higher collection efficiencies.

The Stamicarbon/ECI prilling tower jet scrubber contains three compact stages that progressively treat and clean the off-gas coming from the prilling tower. The three stages are represented in Fig. 11 and consist of: (1) concentrated urea quench and jet scrubber (bottom), (2) lean urea quench and jet scrubber (middle), (3) acid treatment for NH₃ capture (top). A high efficiency mist eliminator is placed between each stage. Each stage is discussed next.

Stage 1: Concentrated urea quench and jet scrubber

As air is leaving the prilling tower, the cooling and condensation of gaseous urea results in the formation of submicron urea dust particles. In order to first cool down and then saturate the gas with water, the gas flow is contacted in the SpiralMist™ quench stage with a fine mist of concentrated urea solution. Then the gases enter multiple jet scrubbers, which use the same urea solution injected into the throat of each venturi tube. The position and selection of the hydraulic nozzle is designed to induce the flow of off-gas through the venturi tube, without the need of a fan. In this stage, most of the coarse particulate urea dust is scrubbed from the gas stream. The concentrated urea solution is cycled up to between 35 wt-% and 45 wt-% urea.

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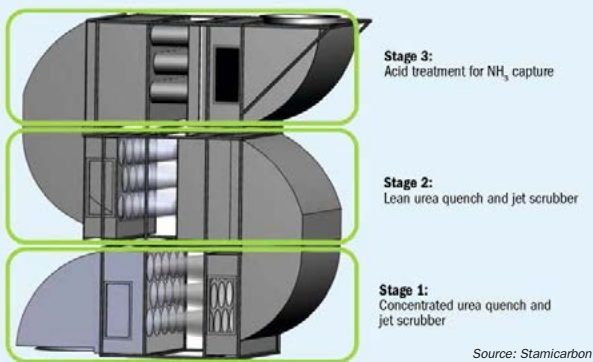
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Fig 11: Representative scrubber cutaway view with three stages indicated



Source: Stamicarbon

Stage 2: Diluted urea quench and jet scrubber

Downstream of the concentrated scrubbing zone and a high efficiency mist eliminator, a secondary quench and scrubbing zone is used, which injects a dilute solution of urea (~1%). This is an important step to assure that remaining submicron particulate is exposed to saturated gas, where particles can substantially grow in size through condensation. Larger particulates, which are mostly surrounded by water, are easier to capture.

Stage 3: Ammonia acidic scrubbing

The last stage in the prilling tower jet scrubber is an optional ammonia acidic scrubbing stage. The nozzle and water flow is smaller than the upstream sections, since NH₃ is much easier to remove. This section is only required for sites that desire low NH₃ emissions (e.g., below 10 mg/Nm³).

Jet scrubber experience on prilling towers

A pilot scrubber test was carried out using a single jet scrubber on the roof of a urea prilling tower. The aim was to make the fumes in the waste gas invisible to the naked eye, the dust content should be reduced at least to less than 20 mg/Nm³, requiring more than 85% of efficiency in the dust collection.

Figs 12 and 13 show pilot testing using a single jet scrubber pilot scale system. Note that the pilot system only included dust capture sections (concentrated urea and dilute urea sections), and not the ammonia capture system (typically the third stage).

A scrubber liquid (40% urea solution) is injected through special nozzles and distributed at the inlet of the jet venturi scrubber to produce a maximum gas/

liquid exchange area and drops with a high relative speed to the gas flow. Due to the high-energy input, the jet venturi scrubber can aspirate and convey off-gases and vapours. This jet effect enables the cleaning of gases without a loss in pressure in the gas flow. Thus, there is generally no requirement for a mechanical ventilator for conveying the off-gases.

At the same time, the quenching effect at the entrance of the jet scrubber leads to cooling of the off-gases or vapours. Water evaporates into the gas stream and the gas stream is cooled to the cooling limit temperature.

This proposed jet scrubber venturi technology is much more advantageous because the operation is not only very simple, lacking movable portions, but also very easy to clean, inspect, and repair, and the concentrated urea blow down solution can also be circulated for reuse, and returned to the urea manufacturing plant.

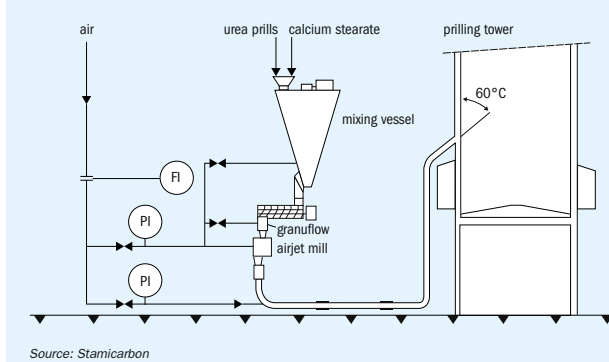
Ammonia and dust emission figures of about 10 mg/Nm³ have been realised, which easily meet the environmental regulations usually applied.

Besides efforts to reduce the off-gas emissions, Stamicarbon can also assist to improve the final product (prills) quality and handling properties. Prilling is still a frequently used finishing technology thanks to the economical investment and simple process operations, however, by nature prills are weak and less suitable for the export market.

To improve prill quality, a number of techniques are readily available such as:

- seeding of urea particles into the prilling tower;
- use of Stamicarbon Advance™ coat on the final product;
- control of the final product temperature.

Fig 14: Schematic flow of seeding system



Source: Stamicarbon

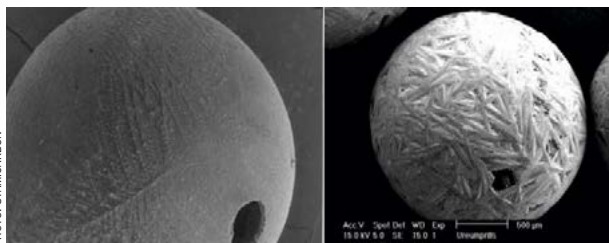


Fig 15: Final result of seeding: urea prill without seeding (left), urea prill with seeding (right).

Seeding

Mechanical- and impact strength are especially important if prilled product needs to be stored after being subjected to a variety of handling operations. Stamicarbon has developed a unique seeding technology to improve the impact strength of the prills and to avoid dust formation during transport and handling.

By blowing small particles (seeds) of a specified flow and diameter into the prilling tower, sub-cooling of the melt droplets is avoided. The seeds act as nuclei for crystallisation, leading to prills with many different crystal orientations and thus a much higher strength (See Figs 14 and 15).

Stamicarbon Advance™ coating technology

Before storage, it is always wise to stabilise the urea prills by using coating additives as demonstrated in Fig. 16⁵.

Easily applied as an additive coating, Advance Coat™ increases the moisture-resistance of urea prills, which dramatically improves their handling and storage proper-

ties. Advance Coat™ is easier and cheaper to apply than formaldehyde, making it a cost-effective, safe and crop-friendly solution.

With its very effective anti-caking and water-repellent properties, Advance Coat™ offers the following benefits:

- allows product storage for several months and the shipping of prills with minimal change in product quality;
- its special formulation allows it to be used in technical applications without the risk of foaming;
- logistic costs are lower due to better granulometry.

Final product temperature

The final product temperature shall be lower than 60°C, which can be achieved by optimising the prilling tower with respect to air flow, prill bucket design and best prilling tower loading. Additionally, by making use of available techniques such as fluid bed cooling or a bulk flow cooler, the final product temperature can be controlled below 60°C.



Fig 16: Stamicarbon Advance™ Coating Technology is applied to stabilise the prills before storage.

In the near future, implementing the Stamicarbon dry finishing technology will allow for a practically emission free environment for ammonia and dust, flexible product specifications and a low biuret number. This technology is also a perfect revamp tool for debottlenecking and lower emissions⁶.

Conclusions

Stamicarbon and EnviroCare have co-developed scrubbing technology for urea granulator and prilling tower applications to achieve very low emissions of urea dust and NH₃. This scrubber technology has been paired with Stamicarbon's urea fluid-bed granulation and prilling technologies, setting a new standard in urea finishing technologies and emission control. ■

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Fig. 12: Pilot Jet Scrubber during fabrication at ECI shop.



Fig. 13: Pilot Jet Scrubber located on top of prilling tower for emissions testing.

Toyo's high efficiency scrubbing systems

K. Sato of Toyo Engineering Corp. reports on Toyo's approaches and latest technologies to reduce ammonia and urea in emissions from urea plants. Case studies for two recent large-scale urea granulation plants are presented.

Nowadays, environmental protection is one of the most important issues for any production facility and the urea plant is no exception. Environmental guidelines and regulations continue to become ever more stringent in response to growing public concern. Toyo Engineering Corporation, a leading process licensor of urea production technologies, has developed and applied its own scrubbing technologies using water and/or acid for the abatement of urea dust and gaseous ammonia emissions from urea plant finishing sections. Typical emission guidelines for urea dust and ammonia applied to the urea plant finishing section are 50 mg/Nm³ urea dust and 50 mg/Nm³ ammonia.

Toyo's water scrubbing system (see Fig. 1) is a proven technology to reduce the urea dust in the exhaust air from the urea finishing section to less than 30 mg/Nm³.

The exhaust air from the prilling tower or granulation plant is introduced into bottom of the tower and rises through the packed bed in countercurrent with a descending stream of circulation water. After elimination of mist carry-over, it is vented to atmosphere.

The system, which has been applied to more than 40 prilling towers and granulation plants, has the following features:

- low pressure drop of only 50-150 mm H₂O;
- efficient recovery of urea as a 45 wt-% solution;
- lower construction cost due to a simple structure and low loading weight of the polypropylene packed bed.

For the abatement of ammonia emissions, Toyo offers three acid scrubbing options:

- single stage acid scrubbing system;
- double stage acid scrubbing system;
- acid scrubbing system with no by-product.

These options are summarised and compared in Table 1.

Single stage acid scrubbing system:

This system is similar to the water scrubbing system shown in Fig. 1 but with acid injected into the circulation water. The system reduces both urea dust and ammonia emission in the exhaust air to less than 30mg/Nm³ and 20mg/Nm³ respectively. The gaseous ammonia is removed as ammonium salt, such as urea ammonium sulphate (UAS) or urea ammonium nitrate (UAN). The urea dust caught by the system cannot be returned to the urea plant for recovery as additional urea product because it is contaminated with the ammonium salt. This scheme is applicable for a plant which needs to minimise by-product or has an ammonium nitrate (AN) or ammonium sulphate (AS) plant.

Double stage acid scrubbing system:

This system is a combination of water scrubbing and acid scrubbing (see Fig 2). In the (lower) first stage packed bed, urea dust is

Table 1: Toyo's scrubbing technologies

Scheme	Water scrubbing	Option-1 Single stage acid scrubbing	Option-2 Double stage acid scrubbing	Option-3 Acid scrubbing without by-product (ammonium salt)
Toyo references	43 plants	3 plants	4 plants	1 plant
Required acid (98% H ₂ SO ₄)	none	1 kg/t urea	1 kg/t urea	1 kg/t urea
By-Product	none	45% ammonium salt solution: 90 kg/t urea	40% ammonium salt solution: 5 kg/t urea	None
Urea product	urea	urea	urea	urea + AS (0.2 wt-%)
Recovery of urea dust	as urea product	as by-product	as urea product	as urea product
Recovery of ammonia	None	as by-product	as by-product	as urea product
Ammonia emission	ammonia in urea melt is emitted	< 20 mg/Nm ³	< 20 mg/Nm ³	< 20mg/Nm ³

Source: Toyo



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- Easy installation due to modular design
- Meets new stringent emission regulations
- Demonstrated High Performance Collection of Submicron Particulate
- Best available turnaround ratio
- High quality, low maintenance components
- Suitable for revamping or retrofitting existing scrubbers
- Proven track record

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Fig 1: Dust scrubbing system

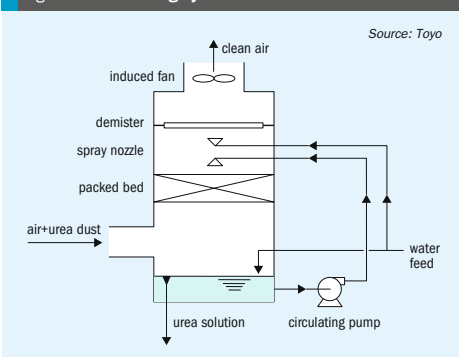
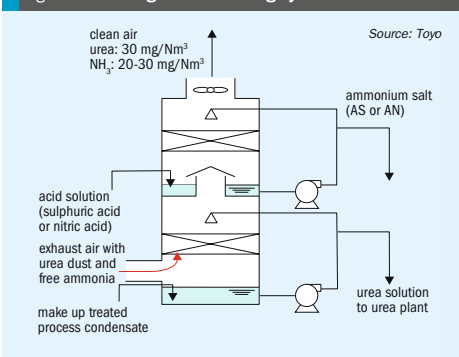


Fig 2: Double stage acid scrubbing system



captured by water scrubbing and recovered as a 45 wt-% urea solution. In the (upper) second stage packed bed, gaseous ammonia is absorbed by acid scrubbing. In this option the urea dust can be recovered as urea product which reduces the quantity of by-product ammonium salt. This scheme is applicable for a plant which needs to minimise by-product or has an AN or AS plant.

Acid scrubbing system without by-product: In this system gaseous ammonia in exhaust air is absorbed in an acid scrubbing system by sulphuric acid and recovered together with urea dust as UAS. An independent small evaporator concentrates the recovered UAS solution which is sent to the urea finishing section where it is mixed with feed urea solution. The final urea product contains 0.2-0.3 wt-% AS as a fertilizer nutrient. By-product AS is eliminated because it will be included in the final urea product. This option is appli-

cable for a plant producing urea product for agricultural purposes, for which 0.2-0.3 wt-% of AS is acceptable, and that does not have the option to produce a by-product besides the urea product.

Large scale projects with dust scrubbing systems

In the late 2000s, Toyo was awarded three contracts for large scale urea granulation plants. This article focuses on Toyo's experience in two of these projects: one is in Indonesia (3,500 t/d) for P.T. Pupuk Kalimantan Timur and another is in Nigeria (4,000 t/d) for Indorama Eleme Fertilizer and Chemicals Limited.

Kaltim No.5 project, Indonesia

In 2011, Toyo was awarded a contract to construct a 2,500 t/d ammonia plant and 3,500 t/d urea plant for P.T. Pupuk Kalimantan Timur (Kaltim). Kaltim is a subsidiary of the state-owned enterprise PT Pupuk Indonesia Holding Company. The urea plant is designed based on Toyo's ACES21® urea process and spout-fluid bed granulation. It is the largest single train ammonia/urea complex in Southeast Asia. A dust scrubbing system is applied for this plant. Toyo provided the EPC for the whole complex on a turn-key lump-sum basis, collaborating with PT. Inti Karya Persada Teknik, Toyo's group company in Indonesia.

The first urea granule was produced on January 24, 2015. The performance test for the ammonia/urea complex was conducted in the same year. The urea dust emission during the performance test is shown in Table 2. As shown in the table, the plant has shown an excellent performance.

Table 2: Urea plant performance of Kaltim No. 5 urea plant

Production capacity, t/d	3,545
Product quality	
Total nitrogen content, wt-%	46.2
Biuret content, wt-%	0.9
Moisture content, wt-%	0.3
Granule size, wt-%	
2 to 4.76 mm	97.2
less than 1 mm	0
1 to 2 mm	3.0
above 4.76 mm	0
Urea dust emission, mg/Nm³	21

Source: Toyo

Indorama project, Nigeria

Toyo and its consortium partner Daewoo Nigeria Limited were jointly awarded the contract to build the world's largest single train ammonia and urea complex for Indorama Eleme Fertilizer and Chemicals Limited (IEFCL) in Nigeria. The facility has a design capacity of 2,200 t/d ammonia and 4,000 t/d of granulated urea from natural gas feedstock employing technology licenses from KBR and Toyo. A double stage acid scrubbing system is applied in this plant and achieved less than 10 mg/Nm³ urea dust in the exhaust air from the finishing section. A general schematic of the double stage acid scrubbing system is shown in Fig. 2.

The urea plant first produced urea granules in May 2016 and started its commercial operation in June 2016. The plant is currently producing more than 4,000 t/d of high quality urea granules. The double stage acid scrubbing system results in extremely low urea dust emissions as shown in Table 3.

Table 3: Urea plant performance of IEFCL urea plant

Production capacity, t/d	4,003
Product quality	
Total nitrogen content, wt-%	46.4
Biuret content, wt-%	0.8
Moisture content, wt-%	0.3
between 2 to 4 mm	93
Urea dust emission, mg/Nm³	7

Source: Toyo

Meeting tougher US emissions requirements

The first large scale urea fluid bed granulation plants utilising a new horizontal scrubbing system, jointly developed by Kimre , tkIS and UFT, are now in operation in the US.

Dr H. Franzrahe of UFT, **M.M. Schmitz** of tkIS and **M. Davidson** of Kimre describe the scrubbing systems and report on the record low emission levels being achieved.

Lower natural gas prices in the US have stimulated the construction of new urea plants and with recent focus on the health impacts of fine airborne particulate, the permitted emission limit values negotiated between plant sites and local environmental authorities are tougher than ever.

Urea dust is characterised as "particulate matter", one of six criteria air pollutants regulated by the US Environmental Protection Agency (EPA) which established requirements for PM₁₀ (particulate matter with aerodynamic diameter of 10 microns or less) and PM_{2.5} (particulate matter with aerodynamic diameter of 2.5 microns or less). PM₁₀ and PM_{2.5} have come under increased scrutiny due to recent studies showing detrimental health impacts of the penetration of these fine particles into the human lung. Requirements of less than 10 mg dust per Nm³ gas on a dry basis were desired for an industry that had previously required no less than 20 mg/Nm³ urea dust.

Opacity regulations have also been introduced as new, separately enforceable emission requirements to particulate matter. With limits as low as zero percent, also known as "invisible stack" conditions, it is the most stringent air permit requirement in the industry.

Ammonia, classified as a precursor to PM_{2.5} which then becomes a regulated pollutant, is another source of emissions from urea granulation plants. It is not particularly difficult to deal with ammonia since the removal is enhanced by an acidic reagent liquid. In most previously constructed plants, however, there was no permitted requirement on ammonia emissions in the air exhausted from the plant.

There are several long-standing technologies that are used to control the emissions from nitrogen fertilizer plants, such as packed beds, impingement and tray scrubbers. However the extremely low emission levels which regulators are now demanding for new plants are difficult to achieve with these technologies. In addi-

tion, the pressure drop of these scrubbers, which is directly related to the power consumption, can be quite high.

For urea granulation, Kimre has partnered with UFT to design highly practical and efficient granulator and cooler scrubber units for new and retrofit installations.

Kimre SXF™ semi-cross flow scrubber

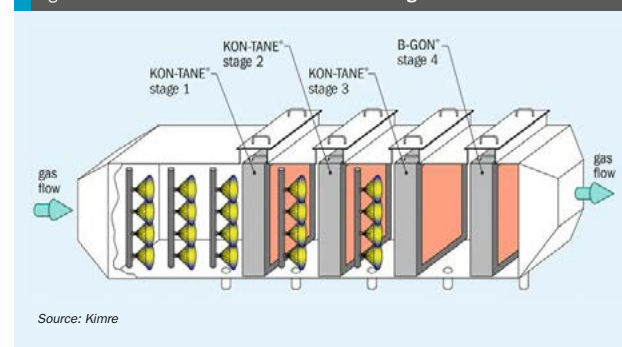
The SXF™ semi-cross flow scrubber combines conditioning spray and downstream mesh pads that operate as KON-TANE® scrubber and tower packing and B-GON® mist eliminator stages (see Fig. 1).

Kimre's uniquely interlaced monofilament structure (referred to as "mesh") is an original invention from 1973 which revolutionised mass transfer operations. It is highly effective in the collection of dust and mist via impaction and interception. Combinations of different styles of mesh allow for customised efficiency removal for any set of gas, solid, and liquid properties.

The term "semi-cross flow" refers to contactors in which the liquid (usually aqueous solutions or slurries) is sprayed co-currently with the gas on the upstream side of the mesh pad, washing the dust off the media. The gas flow is horizontal and the liquid runs down the pad, crossing the gas flow and discharges at the bottom. An added benefit of the horizontal orientation of the scrubber is providing easy access to internal components which, in addition to removable mesh pads, allow for total system flexibility. It is a convenient feature for quickly changing the pad design to increase or reduce the removal efficiency and adapting to changes in the normal operating and design conditions.

Another advantageous design feature is the ability to treat multiple gas contaminants

Fig 1: SXF™ semi-cross flow scrubber internal arrangement



Source: Kimre

Table 1: Urea granulation retrofit installation air permit requirements and results

	Air permit requirements		Test results
Granulator scrubber 1			
Total particulate, lb/h	20.05	8.23 (equiv. to 12.6 mg/Nm ³ dry)	
Opacity, %	< 20		1.2
Granulator scrubber 2			
Total particulate, lb/h	15.2	8.74 (equiv. to 10.2 mg/Nm ³ dry)	
Opacity, %	n.a.		n.a.

Source: Kimre

Table 2: Emission limits and the history of development

Source	Urea dust		NH ₃	
EFMA BAT Booklet (2001)	< 50	mg/Nm ³	< 50	mg/Nm ³
	< 0.25	kg/ton prod	< 0.25	kg/ton prod
EU BREF LVIC (2007)	< 15 – 55	mg/Nm ³	< 3 – 35	mg/Nm ³
US EPA (2014)	< 8.3	mg/Nm ³	< 30	mg/Nm ³
	[< 0.11]	lb/st prod		

Source: UFT

in one common vessel. Through the use of weirs that isolate individual sections of the scrubber, it is possible to separate concentrations and/or chemistries. Each stage in a series of stages can operate as an independent scrubbing system, with its own liquid-to-gas ratio, in a manner similar to that of a distillation tower.

In case of large variations in design mode specifications (i.e. variations in gas, liquid flows, inlet load of contaminants, lack of particle size distribution) and/or superior particle removal requirements, Kimre's AEROSEP® multi-stage aerosol separation system can be added to a typical SXF™ scrubber arrangement. The AEROSEP® provides high efficiency removal of urea dust smaller than one micron, reducing particulate emissions, particularly PM_{2.5}, to the lowest possible levels.

The first retrofit installations to come online were two granulator scrubbers handling off gases from drum granulators. Each of the scrubbers replaced three and four impingement-type scrubbers and were designed to improve the collection of urea dust. An SXF™ semi-cross flow scrubber with three KON-TANE® stages and one B-GON® stage was designed to scrub the particulates from the gas stream with recirculated water and minimum amount of fresh water. The urea was recovered from the scrubber as a 40-45 wt-% solution and recycled back to the process.

Recent test results (Table 1) showed that the scrubbers outperformed the air permit requirements.

New urea granulation plants

thyssenkrupp Industrial Solutions (tkIS), the successor of Uhde GmbH, was awarded the contract for three new urea plants in the US, one located in Louisiana and two located in Iowa. The capacity of the applicable granulation plants is between 1,200 t/d and 3,500 t/d. All three plants utilise the fluidised bed granulation technology of Uhde Fertilizer Technology (UFT) and the scrubbing technology developed by Kimre and UFT.

In addition to the new 3,500 t/d granulation plant completed and commissioned by tkIS, two urea Spheridizer plants at the same site were retrofitted with new scrubbers in order to reduce the emissions and stack opacity and to maintain the overall site emission limits.

For the new plants, the dust emission limits required by the EPA were extremely challenging (Table 2) and well below previous requirements. For the first time visibility limits of the stack plume (low opacity) had to be guaranteed. While the permits did not regulate the ammonia emissions from the urea granulation stacks, overall site ammonia limits had to be fulfilled. This indirectly required a limitation of the

ammonia emission from the new urea fluidised bed granulation plants.

The operating permits for the US plants require emission limits for dust down to 0.1 lb/st, which corresponds to a concentration values of below 9 mg/Nm³. As described in a previous publication⁴, the existing technologies for emission reduction were not adequate to meet these stringent requirements.

In a fluidised bed granulation process the opacity or plume visibility of the stack is largely determined by the aerosols formed by urea isomers and the amount of fine particles below PM_{2.5} in the off-gas from the granulator. Although only present in small quantities their influence on the visible emissions from the stack is high due to the large surface of the particles.

The challenge of the new emission limits is that these very small particles (PM_{2.5}) and aerosol particles must be removed from the off gas.

Urea dust particles are fully soluble in water. The current EPA emission methods do not adequately apply to this situation – they are based on the determination of insoluble particles. As there is no reliable emission test method for determining the PM_{2.5} particles of urea in the saturated off-gas of a scrubber UFT assumes that all particulates emitted from the stack are below PM_{2.5}.

Scrubbing systems for the removal of coarse dust particles, the removal of NH₃ and the integration of the ammonium salts in the urea granulation process have been published previously^{2,3,4}, therefore this article focuses on a new advanced scrubbing system that is being used to meet the new permit limits for PM_{2.5} and opacity/visibility with a pressure drop that is comparable or even lower than that of existing emission reduction technologies.

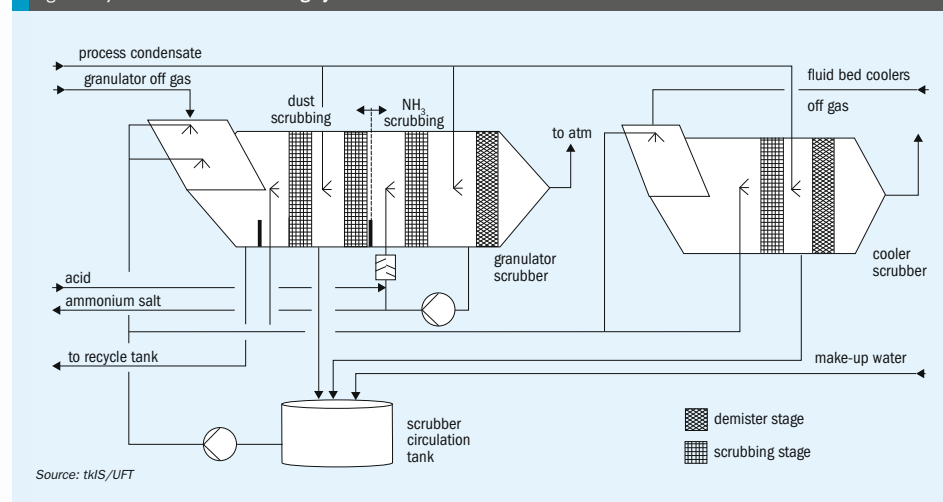
The horizontal scrubbing systems installed in the three new plants in the US were jointly developed by Kimre, tkIS and UFT.

New advanced scrubbing system

A horizontal cross flow scrubber (Fig. 2) consists of:

- quench stage;
- one to two dust stages (depending on the emission limits);
- acidic NH₃ removal stage (optional);
- separation stage;
- AEROSEP® stage (if required to reduce the visibility).

Fig 2: UFT/Kimre advanced scrubbing system



The scrubber system shown in Fig 2 is for a large plant which requires separate granulator and cooler scrubbers. Smaller plants, particularly those which use bulk flow product coolers, can be designed with just one scrubber using the same simple process design.

In this scrubbing system the dust laden gas flows horizontally through the scrubber. The off gas is initially wetted by a set of water sprays which saturate and cool the off gas and at the same time already reduce the coarse particle loading of the inlet gas stream. This is called the quench stage.

In the subsequent dust removal stages the off gas comes in contact with a sequence of wetted pads which remove the remaining dust. The number of dust removal stages is determined by the emission limit – a low emission limit requires two stages, for less stringent emission limits a single stage might already be sufficient.

If required, an acidic stage for the removal of NH₃ is added downstream of the dust scrubbing section. The ammonia removal stage requires a separate liquid circuit for the acidic solution and the scrubber bleed which contains an ammonium salt. The horizontal gas flow through the scrubber ensures that there is no cross contamination of the upstream dust stages with ammonium salts or acids. This

must be prevented as the scrubber bleed from the dust removal stages is normally returned to the evaporation section of the synthesis unit.

The recently commissioned plants use nitric acid as a medium to remove ammonia. This is available at site and the resulting urea-ammonium nitrate bleed from the scrubber is processed in a UAN plant.

Alternatively sulphuric acid can be used to remove the ammonia. The resulting ammonium sulphate solution in the scrubber bleed cannot be returned to the urea synthesis plant. To process an ammonium sulphate solution UFT has developed its ACT (Ammonia Convert Technology) system⁴.

The final stage of the scrubber is a separation stage which consists of a demister to remove any droplets before the off-gas is discharged to the stack via the scrubber exhaust fan. The demister must be flushed by clean process condensate. To maintain the water balance the demister cleaning is done sequentially.

AEROSEP® scrubbing stage

In order to meet the requirements of “zero opacity” or “no visible emissions” additional measures are required to reduce the emissions of sub-micron particles. For this application Kimre's AEROSEP® system is added as shown in Fig. 3.

This system is preferably installed

between the acidic stage and the final demister.

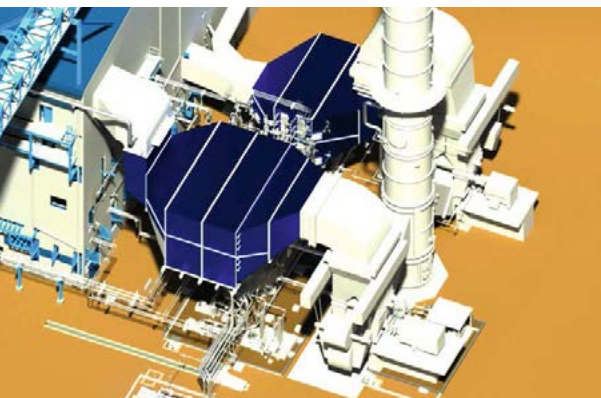
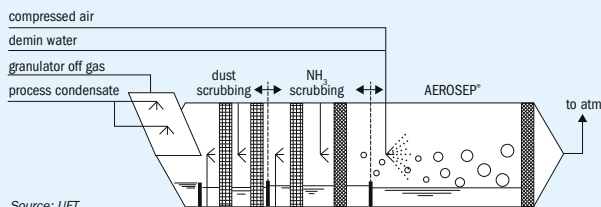
The AEROSEP® multi-stage aerosol separation system utilises a stage-wise approach to remove mist and particulates. It is specifically designed for the collection of submicron particulates, or aerosols, by a combination of particle growth and particle removal. The off-gas is supersaturated and the water condenses on the aerosol particles. These grow very rapidly to 1 µm in size and can then be easily coalesced and entrained in a mist eliminator comprised of a special selection of Kimre™ media.

The AEROSEP® stage in combination with the horizontal cross-flow type scrubbing system allows compliance with all known requirements for dust, ammonia, PM_{2.5} and plume visibility.

Application in a fluid bed urea granulation plant

Before finalising the detailed design of the granulator and cooling scrubber system for the new CF Industries, Donaldsonville plant site in Louisiana, tkIS, together with Kimre, carried out pilot plant tests. In these tests the optimum arrangement of media pads and the irrigation rates were determined. They also confirmed that the required efficiency for both, dust and ammonia removal, required to fulfil the

Fig 3: Horizontal cross-flow scrubber with added AEROSEP® stage



PDSMS MODEL: KNS

Fig. 4: Computer view of the horizontal cross-flow scrubbers for a 3,500 t/d granulation plant.

Table 3: CF Industries urea granulation installation air permit requirements and results

	Air permit requirements		Test results
Particulate matter (filterable), lb/h	29.67	1.63 (equiv. to 12.6 mg/Nm ³ dry)	
Opacity, %	< 20		3.8

Source: Kimre

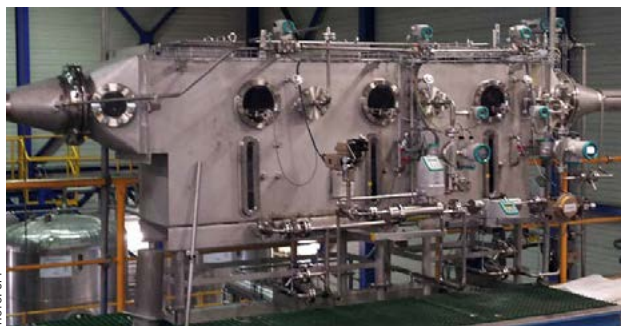


PHOTO: UFT

Fig. 5: Horizontal cross-flow scrubber installed in the UFT pilot plant.

challenging requirements of the commercial plant could be met.

For the test trials, which were conducted at an industrial urea granulation plant and with the University of Florida, Kimre supplied a mobile scrubber test unit and a variety of media pads.

The removal processes for dust and ammonia are totally different. The dust entrainment is achieved by impacting the larger dust particles on the filaments and by growing the very small particles to a size which can be caught by the filaments. The ammonia is absorbed in the water phase and reacts with the acid to form an ammonium salt. This process is known as chemisorption.

The reaction between ammonia and the acid is spontaneous and the chemisorption of the ammonia from the gas phase is not problematic. The challenge for the efficiency of the ammonia reduction is to bring together the reaction partners ammonia and acid.

In the gas phase the reaction surface can be increased by reducing the droplet size produced by the spray nozzles. However, a significant part of the chemisorption takes place in the water film on the pad filaments therefore a uniform liquid distribution is essential to achieve high reaction efficiencies.

Commissioning of commercial plant

Despite the positive results from the pilot plant tests there was still the challenge of significant scale-up of about a factor 100 to the dimensions of the commercial plant. The air flow of the large scale granulation plant is about 800,000 cubic meters per hour and the inlet contamination is in the range of 90 kg/h ammonia and more than 5 t/h urea dust. The dimensions of the granulator scrubber are impressive: 11.3 x 6.8 x 16 m (H x W x L), (see Fig. 4).

Due to the large cross section of the granulator scrubber the challenge was to design an acidified water spraying system which achieved an equal distribution over the whole cross section to minimise any by-passing of the ammonia gas.

Achieved emission results

Three plants with Kimre horizontal scrubbers were completed during 2015 and 2016. Emissions tests for the EPA were conducted after start-up when operations had been stabilised. Table 3 summarises

the results of the emission tests; they have been published and are publically available.

The particulate matter content of 1.63 lb/h is an average of three test runs of 1.45 lb/h, 1.71 lb/h, and 1.73 lb/h and is equivalent to 0.87 mg/Nm³ on a dry basis, ten times lower than the most stringent emission requirement to date, 10 mg/Nm³.

The two smaller plants in Donaldsonville are urea Spherodizer plants. For these plants the existing scrubbers were replaced with Kimre horizontal scrubbers. These scrubbers are equipped with a dust stage and an AEROSEP® stage.

Despite the extremely low emission figures achieved and the huge air flow in the recently commissioned granulation plant the total pressure drop over the granulator scrubber (including inlet and outlet) is only 670 mm WC, a very low value when compared to other emission reduction systems.

Further development

The excellent results achieved by the plants in the USA confirmed that the scrubbers designed by UFT and Kimre can meet and even exceed the lowest current emission limits.

The experience from these scrubbers is now being applied to further reduce the pressure drop by optimising the liquid flows and the pad arrangements while maintaining the separation efficiency. These developments are being jointly done by Kimre and UFT.

Since 2013 UFT operates its own batch pilot plant in Germany. This pilot plant was recently fitted with a horizontal scrubber (Fig. 5) and is fitted with the same Kimre pads as used in the commercial plants. The pilot plant scrubber has two stages and a demister stage. The second stage can be operated either as a dust stage or as an acidic stage.

Currently the UFT pilot plant scrubber is used to extend the emission reduction technology to the newly developed urea with elemental sulphur products (Urea-ES), which are a joint development of Shell Thiogro and UFT. During the production of Urea-ES the dust from the granulation plant will contain insoluble elemental sulphur. Therefore the scrubber system must be able to separate the insoluble sulphur particles without blocking the pads. During trial production of Urea-ES with sulphur contents up to 30 wt-% sulphur the scrubber operated without any major problems.

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NITROGEN+SYNGAS
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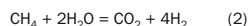
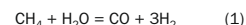
Steam methane reformer improvements

Today's state-of-the-art reformers are considerably different to their original predecessors that were established in the 1930s. Factors such as the availability of new materials, improved methods of catalyst manufacture, developments in reformer design, advances in computational modelling and improved operational regimes have all contributed to the vast improvements that have been realised.

Steam methane reforming is a critical operation and can be considered as the heart of any ammonia, hydrogen or methanol plant. The conversion of methane, or other hydrocarbon feedstocks, into a synthesis gas mixture is a challenging operation, both chemically and physically. Due to the complex nature of steam methane reforming there are many conflicting demands, hence ensuring that the process is accomplished both efficiently and reliably is something that involves continuous improvements that reflect the latest technological capabilities.

Basic design criteria of a primary reformer

A steam methane reformer is dedicated to the production of syngas from a methane feedstock and steam. This catalytic process results in a mixture of hydrogen, carbon monoxide, carbon dioxide and water. The main equations governing the process are:



These reactions are carried out in nickel catalyst-filled tubes in metallic reactors at a temperature of 800°C to 1,000°C, and a pressure in the range 10 to 50 bars. Outlet components collect the syngas from the various catalyst tubes and convey it to the transfer line. Both catalyst tubes and outlet components are operated at over 800°C. Their typical failure mode is governed by creep damage, upon which core design calculations are based.

Catalyst tubes are commonly designed according to API Standard 530 (Calculation of heater-tube thickness in petroleum refineries). They must be thick enough to resist the constant thermo-mechanical loading arising from the process pressure and temperature. Therefore, catalyst tube wall thickness must be higher than a minimum value, defined by equation 3:

$$\delta_{\min} = \frac{P_r D_i}{2\sigma_r P_r} + f_{\text{corr}} \delta_{\text{CA}} \quad (3)$$

where δ_{\min} is the minimum wall thickness, P_r is the design pressure inside the catalyst tubes, D_i is the tube inside diameter and σ_r (the rupture allowable stress) is the stress leading to tubes creep rupture in a given period of time (commonly 100,000 h). The corrosion allowance contribution is usually not considered ($f_{\text{corr}} \delta_{\text{CA}} = 0$). From equation 3, it can be easily derived that the higher the creep resistance of the chosen material (the higher σ_r), the thinner the catalyst tubes can be.

Outlet components of a primary reformer, which are not exposed to the flame, are designed according to ASME B31.3 §304.1 (equation 4), which takes into account additional security factors:

$$\delta_{\min} = \frac{P_r (D_i + 2C_d)}{2(\sigma_r E W P_r (D(1-Y)))} \quad (4)$$

where E is a casting quality factor, W is weld joint strength reduction factor and Y is a security factor which depends on the steel grade and on the temperature. Therefore, similar to what has been described for catalyst tubes, an improvement in material properties for outlet components also leads to higher flexibility in terms of manufacturing and design. Enhanced material

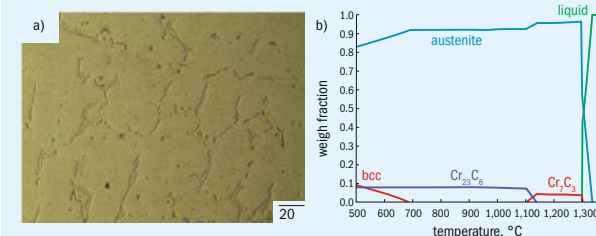
creep properties enable the thickness of these large components to be reduced, resulting in multiple beneficial effects.

Primary reformer heat-resistant grades

Heat resistant steels are essentially stainless steels with high creep properties. These alloys consist of iron, nickel, chromium, silicon and some carbide-forming elements such as niobium and titanium. Carbon content usually varies between 0.1 wt-% to 0.5 wt-%, depending on the required balance between creep resistance and ductility. A deeper insight into the contribution of each of these elements to the global material properties is provided below.

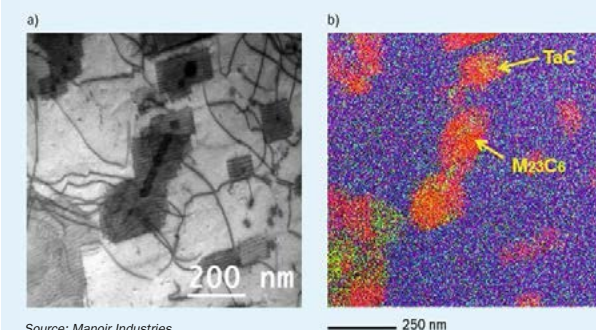
As heat resistant steels are designed to work at high temperatures (800°C-1,000°C), a high amount of nickel is necessary in order to guarantee an austenitic matrix well known for its good mechanical properties at high temperature (i.e. creep strength, yield stress, ultimate stress). An additional benefit is that no phase transformation ($\alpha \rightarrow \gamma$) is expected during the temperature fluctuations, limiting the thermal fatigue. The high amount of chromium (20%-35%) provides oxidation and corrosion resistance in severe environments. In addition, chromium combines with carbon, forming chromium carbides, which increase the creep strength of the grades. Silicon increases the hot corrosion resistance. The contribution of additional carbide forming elements such as niobium and titanium that bind with carbon atoms also results in increased creep strength, through subsequent inhibition of deformation mechanisms such as grain boundaries sliding and dislocation gliding.

Fig 1: a) As-cast microstructure of Manaurite® XM (HP Nb MA grade)
b) Thermocalc simulation of phases during the cooling of an HP grade



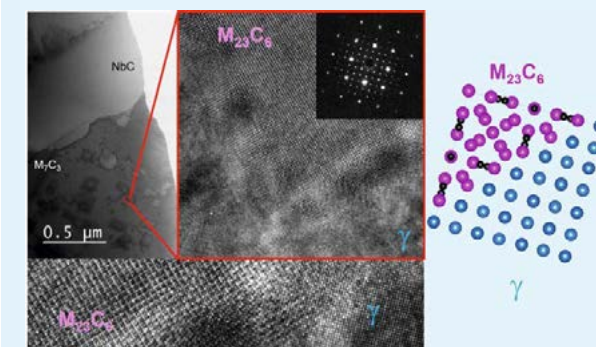
Source: Manoir Industries

Fig 2: a) TEM image of chromium carbides which precipitates on smaller carbides
b) EDX Energy-dispersive X-ray spectroscopy mapping of the TEM image



Source: Manoir Industries

Fig 3: HRTEM images of the coherent interface between the austenitic matrix and a secondary carbide. The associated diffraction pattern and the schematic representation of the crystal lattices are given in the inset.



Source: Manoir Industries

Catalyst tubes are centrifugally cast in metallic moulds, resulting in a high cooling rate. Cast tube sections are up to 6 m long, therefore tube-to-tube welding is required to produce the standard 10 to 15 m length of catalyst tubes. Due to the high solidification rate, the as-cast material is not in a thermodynamic equilibrium stage. Standard grade used for catalyst tubes is HP Nb MA (e.g. Manaurite® XM), which stands for a grade with 25% chromium, 35% nickel, with the addition of niobium and micro-additions (MA) of other carbide forming elements. Fig. 1a shows the as-cast microstructure of Manaurite® XM, which essentially consists of carbides embedded in an austenitic matrix.

Fig. 1b shows microstructural evolution within an HP grade, based on a thermodynamic simulation. At 1,200°C, chromium carbides consist of Cr_7C_3 , which is the structure of chromium carbides in as-cast material. At lower temperatures, the stable form for these carbides is the Cr_{23}C_6 structure. Therefore, at typical service temperatures, carbide transformation into the stable form occurs, i.e. $\text{Cr}_7\text{C}_3 \rightarrow \text{Cr}_{23}\text{C}_6$ accompanies the precipitation of new carbides during service exposure (secondary precipitation).

Since creep strength depends on the carbide distribution, it is all the more crucial for these new carbides (secondary precipitation) to be finely and homogeneously distributed. In order to obtain the optimum carbide nature and distribution, some elements can be used as nucleating agents, where secondary precipitation will occur; the correct balance and distribution of these elements will produce the highest strengthening effect. In order to achieve this precise control of the melting process is necessary. Fig. 2 shows chromium carbide secondary precipitates nucleating on smaller carbides, therefore contributing to creep strength enhancement. Fig. 3 shows HRTEM (high-resolution transmission electron microscopy) images of the coherent interface between the austenitic matrix and a secondary carbide.

Further thermal ageing leads to subsequent evolution of secondary precipitation: some of the smallest carbides will disappear while larger ones will grow and coalesce, leading to a reduction in the strengthening effect. The driving force for this phenomenon is the minimisation of global surface energy. Acting on the atomic structure of carbides allows the coalescence of carbides to be delayed.

Table 1: Development of reformer tube material

Timeline	Tube material	Cr/Ni	CFE*	Wall thickness
1960 –	HK-40	25/20	-	> 30 mm (1.2 inch)
1976 –	HP-modified	25/35	Nb	> 17 mm (0.67 inch)
1984 –	Micro-alloy	25/35	Nb, Ti, Zr	14 mm (0.55 inch)
2008 –	new Micro-alloy	25/35	Nb, Ti, Zr	12 mm (0.47 inch)

Basis: 100,000 h tube lifetime, constant design parameters (T, p, Di=127mm);
CFE*= carbide forming elements Source: tkIS

The generic principles mentioned for catalyst tube creep resistance also apply to the heat-resistant grades used for outlet components. However, for the latter, additional considerations must also be taken into account, since ductility after ageing is also an important consideration for these components.

Reformer tube metallurgy and performance

Recent metallurgical developments for primary reformer grades are based on an advanced understanding of creep processes. The latest material developments are characterised by a significant increase in creep resistance, which enables lower investment, increase in lifetime, increase in process temperature and/or increase in throughput. Such design flexibility allows engineering companies to take advantage of these advances by challenging their design of the

steam methane reformer. Table 1 shows the most important reformer tube materials and a comparison of the resulting wall thicknesses for the same design conditions.

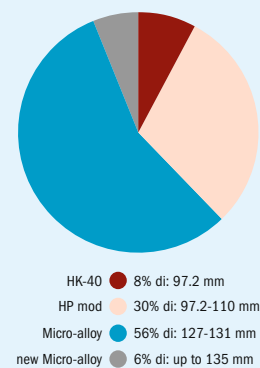
For the older tube materials, such as HK 40, only smaller tube diameters have been realised in order to keep the wall thickness at a reasonable level.

In most cases tube inner diameters are in the range between 97.2 mm and 110 mm for HK-40 and HP modified material. With the introduction of the Micro-alloy material the reformer tube inner diameter could be increased to 127 mm (5") which boosts the capacity of one tube by up to 70%.

Fig. 4 shows the distribution of materials used in tkIS plants (formerly Uhde).

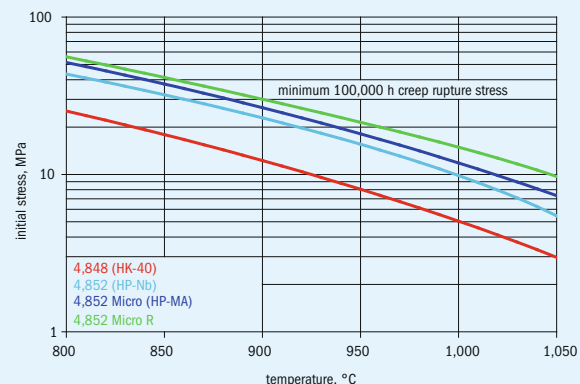
While the Micro-alloy material has been used for steam methane reformers and ethylene crackers, the new Micro-alloy material has been developed especially for steam methane reformers, which have a lower design temperature, which makes

Fig 4: Distribution of material use in tkIS plants



Source: tkIS

Fig 5: Parametric stress rupture strength of Micro-alloy (Centralloy® 4852 Micro) and new Micro-alloy (Centralloy® 4852 Micro R)



Source: Schmidt+Clemens

it possible, for example, to reduce the silicon content.

The new Micro-alloy materials promise another approximately 20% increase in creep rupture strength within the typical operating range of a steam methane reformer tube (see Fig. 5), thus providing designers of steam methane reformers new opportunities for new plants and revamp projects, for example:

- **Tube dimensions unchanged**
The higher creep strength of the new Micro-alloy allows for a significantly longer lifetime or an increase of the operating temperature by approximately 20°C which leads to an increased methane conversion rate.
- **Keeping the ID constant, wall thickness reduced**
This option results in a slightly reduced fuel gas consumption since the heat transmission through the tube wall is more efficient; consequently the stresses within the wall thickness are reduced. Additionally, there is a commercial advantage because thinner wall of tubes means less weight and less cost, especially when nickel prices are at a high level.
- **OD unchanged, ID increased**
This option allows for either a reduced pressure drop or an increased flow rate through each tube; e.g. tkIS offers reformer tubes with an ID of 135 mm and corresponding optimised operating concepts, which represents a capacity boost of approximately 16%.

Table 2: Chemical composition of Manaurite® XMR and Manaurite® 900X

		C	Mn	Si	Ni	Cr	Nb	Ti	Fe
Manaurite® 900X	min	0.10	-	0.50	30	19	0.80	add.	bal.
	max	0.18	1.50	1.25	35	23	1.20		
Manaurite® XMR	min	0.40	0.30	0.60	32	23	-	add.	bal.
	max	0.50	1.00	1.20	35	27	1.0		

Source: Manoir Industries

Advanced metallurgy from Manoir Industries

Manoir Industries, a world-class supplier of heat-resistant steel components for steam methane reformers, has developed two grades specifically for steam reforming: Manaurite® XMR, for catalyst tubes, and Manaurite® 900X, for outlet components. They have been designed in order to provide the optimum creep resistance, ductility and microstructural stability for both applications. Typical chemical compositions are highlighted in Table 2.

Metallurgy for better process performance

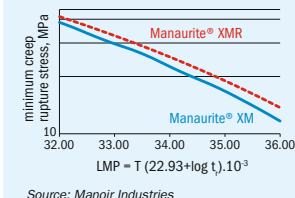
Design criteria used for catalyst tubes and outlet components, together with proper quality control during manufacturing, ensure that reformer parts will be resistant to steady creep for 100,000 h. It is however worth noting that other considerations, such as creep-fatigue resistance, ductility over time and weldability, are also of great importance, especially for thick components like outlet manifolds that undergo high stress gradients during thermal transients, and may occasionally have to undergo repair work. The use of advanced metallurgies, such as Manaurite® XMR for catalyst tubes or Manaurite® 900X for outlet components, ensures the highest reliability for these critical parts.

The use of a higher creep resistant material like Manaurite® XMR also enables the catalyst tube wall thickness to be reduced. Such additional design flexibility can be used to:

- increase throughput by increasing catalyst volume;
- decrease capital expense by maintaining reactor volume but decreasing tube outer diameter and therefore tube weight;
- extend tube lifetime;
- increase service temperature.

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Fig 6: Larson Miller curves of Manaurite® XM and Manaurite® XMR



Source: Manoir Industries

Consider, for example, the following case study where the catalyst tube has an outside diameter of 130 mm, a design temperature of 966°C and a design pressure of 31.9 bar (3.91 Mpa). Assume that for previous tube replacement, reformer tubes were manufactured with standard grade Manaurite® XM. Fig. 6 compares the creep properties of Manaurite® XM and Manaurite® XMR, which can be used to assess possible improvements. For a temperature of 966°C, the rupture allowable stress for Manaurite® XMR is 14% higher (18.4 MPa vs 16.1 MPa), which allows the tube wall thickness to be reduced by 11% (12.5 mm vs 14.0 mm). This higher design flexibility enables the catalyst volume to be increased by 6% or the tube weight to be reduced by 1.1%. If no change is made to the tube wall, upgrading from standard material to advanced Manaurite® XMR will enable the tube lifetime to be increased by a factor of 2.2 (from 100,000 h to 220,000 h) or the operating temperature to be increased by 15°C (from 966°C to 981°C). A compromise between all four options can also be chosen to achieve the optimum results based on various operational, maintenance and investment constraints.

Material upgrades, switching from standard 20Cr32NiNb material to micro-alloyed Manaurite® 900X, for outlet components have similar benefits. Besides an

increase in operating temperature or lifetime allowed by such an upgrade, the most interesting option might be the possibility to manufacture lighter components (by up to 20%). Constraints associated with the manufacturing of these large components, their welding, and especially their in-service behaviour, will be positively affected. The creep-fatigue contribution to their damage will be drastically reduced by lowering thickness, and issues arising from the heaviness of these outlet components will also be significantly reduced.

KBR primary reformer advancements

To fully understand the advancements made to the KBR primary reformer it is necessary to briefly describe the differences between a conventional ammonia plant and the KBR Purifier™ plant.

A key feature of the KBR Purifier™ process is to allow higher methane levels exiting both the primary and secondary reformers. The residual methane is ultimately removed in a cryogenic separator and sent to the primary reformer as fuel. By not driving the methane slip to minimum levels in the primary and secondary reformers considerable energy savings are achieved.

The heat release in the secondary reformer is 100% efficient since all heat is transferred, primarily as reaction duty. The Purifier process shifts more duty to the secondary reformer and reduces the load on the primary reformer. The air flow to the secondary reformer is approximately 50% above the stoichiometric value used on conventional plants allowing for heat release to be increased and the reforming exit temperatures to be cooler. With the shift of reforming duty to the secondary reformer the primary reformer firing is significantly reduced and the SMR outlet temperature is approximately 700°C compared to over 800°C for the conventional process.

For Purifier plants KBR's primary reformer features two designs; the applied design is based on the need for steam export for urea manufacture or other reasons. If steam export is required then the flow sheet features a gas turbine driven process air compressor which sends exhaust gas to the primary reformer furnace as combustion air. Steam that would have been used to drive the air compressor can then be exported. Start-up steam requirements are also reduced. Virtually all the heat from the gas turbine exhaust is recovered in the reformer

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Fig 7: KBR Purifier process air compressor scheme featuring GTE integration with primary reformer furnace

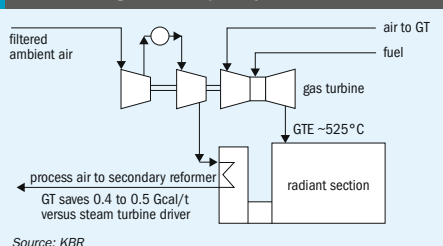


Fig 8: KBR Purifier gas turbine integration scheme at CNOCC, Dongfang, Hainan Province, P.R. China (began operation in 2003).

convection section within practical limits. If steam export is not required, the process air compressor is driven by a steam turbine. In this case, the reformer is fired with pre-heated air using a combustion air preheater to achieve the same high furnace efficiency.

Improved mechanical life and increased efficiency

The milder primary reforming used by the KBR Purifier plant provides the following benefits over a conventionally designed reformer:

- The number of primary reformer tubes and burners is significantly reduced, resulting in lower capital and operating cost.
- The primary reformer catalyst tubes, the outlet manifold, the transfer line and the convection section operate at lower temperatures, increasing mechanical reliability.
- The life of the primary reformer catalyst and tubes is increased, which reduces operating and maintenance cost.
- The lower reforming temperatures result in lower radiant tube skin temperatures increasing radiant section efficiency.

Integrated primary reformer furnace and gas turbine

The radiant duty of the primary reformer furnace in the Purifier process is only about two-thirds of a conventional reformer, while power requirement of the process air compressor is about 1.5 times more than a conventional ammonia plant. Due to this unique combination, the oxygen quantity in the gas turbine exhaust is a good match with the oxygen requirement of the primary reformer furnace burners. The exhaust of the gas turbine driver of the process air compressor is integrated with the primary reformer furnace as shown in Figs 7 and 8.

Figs 7 and 8 illustrate the actual integration of the process air compressor,

gas turbine and primary reformer furnace. In Fig. 8 the gas turbine and process air compressor are located in the building on the left and the gas turbine exhaust flows to the right. For start-up, there is a turbine exhaust vent stack between the two. The hot exhaust flows directly into the primary reformer burner ducting system. The heat from the exhaust gas is recovered in the convection section and then flows through the ID fan to the stack. KBR has over 16 operating Purifier plants and an additional five in construction or commissioning using gas turbine integration with the primary reformer furnace.

Environmental improvements

Recent KBR Purifier plants in the US have required best available control technology (BACT) for NOx emissions. BACT for the primary reformer furnace is selective catalytic reduction (SCR) which can reduce NOx from the burners by approximately 90%. The SCR systems are designed by KBR and integrated into the cold leg of the convection section. Ammonia plants have the unique benefit of having the NOx reductant, NH₃, readily available. The ammonia may be taken from storage or the refrigeration compressor discharge, mixed with heated dilution air on a specially designed skid, and then sent to an ammonia injection grid located above the catalyst in the cold leg. Start-up and operating experience on a new 2,300 t/d North American KBR Purifier plant will be presented at the 62nd Annual Safety in Ammonia Plants and Related Facilities Symposium, September 10-14, 2017, New York, NY. Based on performance testing results at the same facility the SCR system is completely effective at reducing NOx to 10 ppmv (dry basis) levels while holding ammonia slip from the SCR catalyst to the same 10 ppmv (dry basis) value.

Johnson Matthey catalyst and technology developments

For many decades Johnson Matthey has been at the forefront of steam reforming catalyst and technology developments, pioneering and supplying advanced products and services that have provided operational and performance improvements for the steam methane reforming industries.

Modelling improvements

Significant advances in computing power and availability over the last thirty years have had a large impact on the methods available for catalyst design and process simulation, both of which are highly influential when considering optimal steam methane reforming performance.

Catalyst simulation

Computer aided design (CAD) has been widely exploited during recent years for the optimisation of pellet design. CAD allows for detailed pellet designs to be reviewed both accurately and quickly without the need for physical prototypes to be constructed. Another advantage of CAD is that it allows for finite element analysis (FEA) to be performed. FEA allows for stress patterns of pellet designs to be evaluated, highlight areas of concern and allowing for design modifications to be made prior to manufacture. FEA performed by Johnson Matthey has improved its catalyst designs and has helped lead to its world class QUADRALOBE™ pellet that is stronger than the previously manufactured Johnson Matthey 'four-hole' pellets (see Fig. 9).

In addition to reviewing pellet designs individually there is significant merit in having the capability to see how pellets interact when loaded into reformer tubes.

Fig 9: FEA of QUADRALOBE pellet showing surface stress patterns, during pellet compression

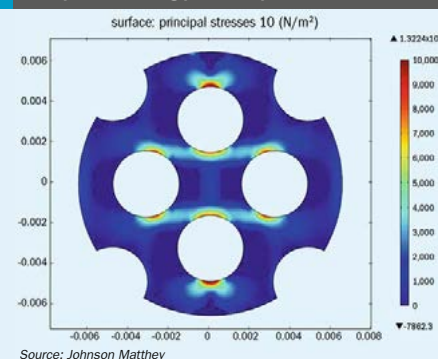
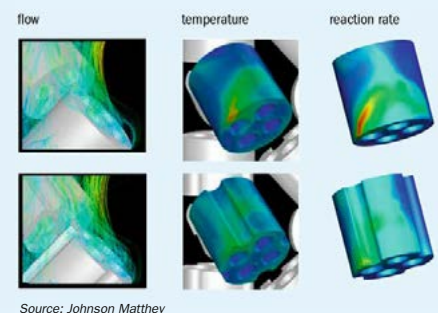


Fig 11: CFD modelling of four-hole vs QUADRALOBE catalyst using the same packing conditions



Pellet interactions during the 'packing' of catalyst into reformer tubes has a substantial impact on performance of the reformer as a whole, in particular the pressure drop and heat transfer characteristics. Johnson Matthey has sophisticated modelling capability to allow simulation of the packing characteristics for any size or shape pellet into any size or shape vessel. Fig. 10 shows simulation results of QUADRALOBE catalyst being loaded into a standard reformer tube. This simulation demonstrates pellets packing randomly, showing few large voids and good tube wall contact, enabling excellent heat transfer.

Process simulation

Another tool that has been widely adopted is computational fluid dynamics (CFD). CFD

Fig 10: Packing characteristics of QUADRALOBE catalysts

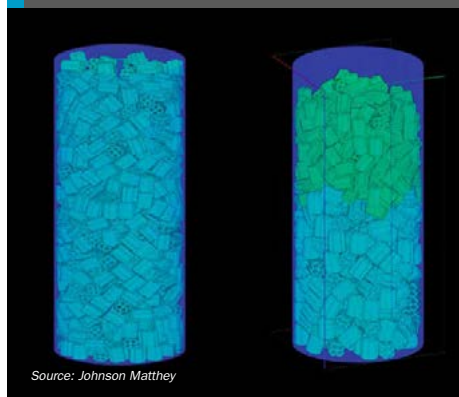
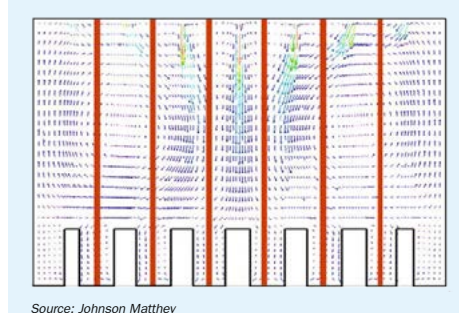


Fig 12: CFD results highlighting issues with flue gas flow patterns in a primary reformer heated box



allows for accurate prediction of flow patterns, this can provide valuable insight into the conditions both inside and outside of reformer tubes. Johnson Matthey has its own in-house ability and has used CFD to simulate the flow across pellets contained within reformer tubes allowing for prediction of characteristics such as the pellets surface reaction rate profile. As can be seen in Fig. 11, Johnson Matthey's QUADRALOBE catalyst offers superior uniformity in surface temperature and reaction rate, this minimises hot spots and hence prolongs catalyst life.

Another example of where CFD has provided significant advantages is allowing for the ability to model flue gas flow patterns within the heated box of a primary reformer, this can help to highlight maldistribution of flue gas which can lead

to reduced tube life and loss of process efficiency (Fig. 12).

The improvements in computer processing have allowed for far superior capability regarding the modelling of reformers. The modelling of a reformer allows for accurate prediction of many different process outputs that influence the performance of the whole chemical plant it is positioned within. An accurate model can allow for prediction of tube wall temperatures, methane slip, pressure drop, carbon margin etc. Johnson Matthey has developed an advanced in-house simulation program called PRIMARY, which has been validated against operational steam reformers. PRIMARY is based on a set of rigorous models that include:

- combustion on the furnace side of the reformer;

Fig 13: Cross section of KATALCO_{JM} 57-6Q compared to traditional QUADRALOBE catalyst

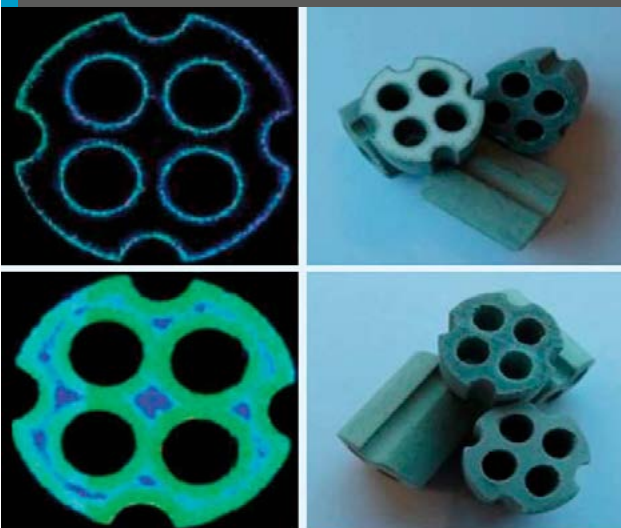


PHOTO: JOHNSON MATTHEY

- heat transfer by both radiation and convection;
- heat transfer through the tube wall and catalyst;
- reaction of methane, ethane, propane, butane and higher hydrocarbons including aromatics and cyclic compounds;
- methane/steam and water gas shift equilibrium;
- pressure drop calculation;
- tube design calculation;
- carbon formation predictions.

Catalyst improvements

The temperatures, pressures and duties placed on steam reformers have changed significantly over the last eight decades. This has required an improvement in catalyst design to match the increased demands.

Composition

Composition of the catalyst selected for use in a steam reformer is of paramount importance as this has a large influence on the performance of the unit. Typically, a robust nickel alumina catalyst is used, the precise composition is something that has been refined over decades of continual development and varies depending on the exact duty the catalyst is to be supplied into.

Due to the temperatures at which steam reformers operate carbon formation will

occur. In a well operated reformer with an appropriate catalyst composition carbon will also be removed, hence resulting in no carbon accumulation. It is well known that both the rate of carbon formation and carbon removal can be influenced by the use of promoters. Johnson Matthey pioneered the addition of potassium as a promoter into their KATALCO_{JM} series catalyst, this has now been adopted as an accepted solution for controlling carbon formation across the catalyst industry. The KATALCO_{JM} range of catalysts available today has been designed with a variety of promoter concentration to best suit the needs of the customer's application. The incorporated potassium is held within ceramic phase reservoirs with a precise stability to regulate the release rate and minimise any adverse effects on the steam reforming ability of the catalyst.

Recent developments within Johnson Matthey regarding catalyst composition have been focused on where the nickel is located within its steam reforming products. Traditionally, during the manufacture process nickel is penetrated deep into the centre of a ceramic support where its effectiveness is lost at high temperatures as it is not accessible for the reforming reaction. Johnson Matthey has recognised this issue and has since used patented technology to apply the nickel on the periphery of the catalyst where it is required.

This has led to the creation of KATALCO_{JM} 57-6Q, which allows for an enhancement of the steam reforming reaction that occurs on the outside of the pellets (see Fig. 13).

Pellet shape

As the temperature has increased in steam reformers the shape of the pellets has become increasingly important, in particular the geometric surface area. As the temperature rises the reactions are increasingly taking place on the outside of the pellet, due to the diffusion rate being slow in comparison to the reaction rate.

Detailed studies regarding pellet shapes including the number of holes and aspect ratio have been undertaken by Johnson Matthey. The aim of newly developed shapes has always been to increase activity and heat transfer while maintaining a low pressure drop. The continued innovation resulted in KATALCO_{JM} QUADRALOBE steam reforming catalyst available in multiple sizes to allow for a catalyst solution to be tailored to suit customers' individual requirements. Typically, the smallest size, MQ, is used at the top of the tube to help prevent carbon formation and the largest size, XQ, can be used at the bottom of the tube to reduce pressure drop.

Next generation catalysts

For many years, catalyst-impregnated ceramic pellets have been the default product of choice for steam reforming duties across the globe. As already discussed these products have been developed significantly over the years to reach the advanced

Fig 14: CATACEL_{JM} SSR Individual fan



PHOTO: JOHNSON MATTHEY

Fig 15: CATACEL_{JM} SSR flow patterns

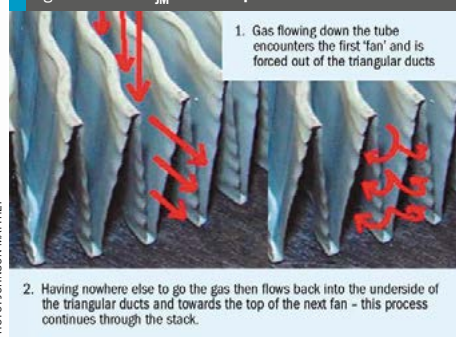


PHOTO: JOHNSON MATTHEY

level they are at today. However, due to the nature of pelleted products inherent limitations will always be present.

During the last decade a new approach has been commercialised that allows coating of active catalyst material on to thin metal foils. This new Johnson Matthey proprietary technology permits a complete deviation from pellets and their inherent limitations. The coating process results in metal foils that can be structured in 'fan' arrangements with a large degree of flexibility (see Fig. 14).

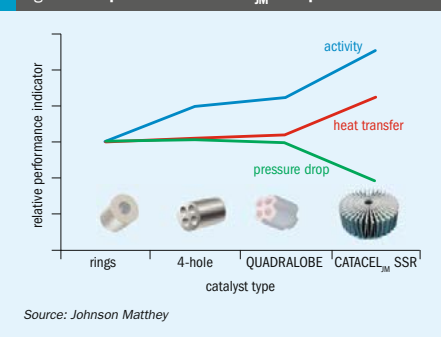
The stacking of multiple individual fans results in Johnson Matthey's commercialised CATACEL_{JM} SSR™ product. The stacked 'fans' of catalyst coated material work by directing the gas flowing down the reformer tube ensuring adequate contact with the extended surface area that CATACEL_{JM} SSR provides and also creating flow patterns that cause the gas to impinge directly onto the inside of the reformer tube wall improving the heat transfer of the process (Fig. 15).

CATACEL_{JM} SSR is fundamentally different and can therefore exceed the performance of pellet products significantly. As such it offers improved activity and heat transfer while giving significant pressure drop savings. Fig. 16 shows a relative performance indication of CATACEL_{JM} SSR compared to other pelleted steam reforming technologies.

Clariant's new steam reforming catalysts

Nickel based steam reforming catalysts have been manufactured and marketed by Clariant for over 60 years and Clariant's ReformerMax® series catalysts are commercially proven to be highly effective for any process feed or process design.

Fig 16: Comparison of CATACEL_{JM} SSR performance



Source: Johnson Matthey

Steam reforming catalysts have to satisfy several basic requirements in service, like high activity, good heat transfer, low pressure drop and high physical strength. The performance of a reforming catalyst is mainly determined by the catalyst shape and its resulting geometric surface area (GSA) as well as pressure drop in the reforming tubes. Every shape parameter (e.g. size, aspect ratio, internal and external channels) influences both the geometric surface area and the pressure drop.

Following this approach, Clariant has developed a new generation of reforming catalysts with a unique and optimised flower-like LDP Plus shape with eight holes (see Fig. 17).



PHOTO: CLARIANT

Fig. 17: Unique 8-hole floral design of ReformerMax® LDP Plus catalysts.

The new ReformerMax® LDP Plus catalysts build on the success of Clariant's previous 10-hole ReformerMax® LDP series (LDP stands for low differential pressure). Compared to its 10-hole predecessor, the new 8-hole floral design of ReformerMax® LDP Plus allows a pressure drop decrease of up to 20%. This allows plant operators to significantly reduce energy costs and/or increase the reformer gas throughput in existing plants.

The new catalysts retain the very high geometric surface area of the ReformerMax® LDP 10-hole shape, thus maintaining high activity for the steam reforming reaction. Heat transfer is improved thanks to the increased hole diameters. Particularly when used together, ReformerMax® 330 LDP Plus (standard) and ReformerMax® 210 LDP Plus (lightly alkalisied) effectively suppress carbon formation in the process.

Table 1 shows the chemical composition and physical properties of the new catalysts.

Acknowledgement

Nitrogen+Syngas would like to thank Manoir Industries, thyssenkrupp Industrial Solutions, KBR, Johnson Matthey and Clariant for their contributions to this article.

Table 1: Chemical composition and physical properties of ReformerMax® LDP Plus catalysts

Nominal content	ReformerMax® 330 LDP Plus	ReformerMax® 210 LDP Plus
Nickel, wt-%	11	14.5
K ₂ O, wt-%	-	1.5
Carrier	calcium aluminate	potassium calcium aluminate
Shape	8 holes	8 holes
Size, mm	20 x 17	20 x 13

Source: Clariant

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