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IMPORTANT INFORMATION:

Number 358
March | April 2019

nitrogen+syngas

60 YEARS ANNIVERSARY 1959-2019

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India's dream of self-sufficiency

Nitrogen project listing

Product diversification

Multifunctional granulation design

NITROGEN+SYNGAS
ISSUE 358
MARCH-APRIL 2019

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Cover: Sunrise over Gadisar lake at Jaisalmer, Rajasthan.
iStockphoto.com/Roop_Dey

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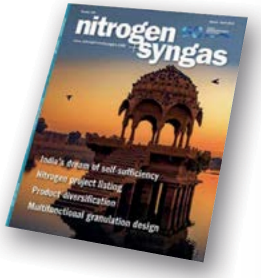
Green ammonia



Producing ammonia from renewable energy sources – so-called 'green' ammonia – seems to be the talk of the industry at the moment. There have been numerous projects announced in the past year, most recently Yara's partnership with Energie to develop solar-based ammonia in Western Australia's Pilbara region, and the South Australian Renewable Hydrogen and Ammonia Supply Chain Demonstrator development at Port Lincoln in South Australia (see Nitrogen Industry News, this issue). At the end of last year, Proton Ventures also announced a collaboration with Yara and Siemens to build a tidal power to ammonia demonstrator plant at Goeree Overflakkee in the Netherlands. It seems appropriate then, that in June, Rotterdam will host the third 'NH3 Event' – an annual European conference on sustainable ammonia development, bringing together members of the energy community, NGOs, policy-makers, delegates from industry and academics. Other conferences on the subject are also beginning to pop up – last November, for example, the first NH3 Energy Implementation Conference was held in Pittsburgh. At this year's Nitrogen+Syngas conference in Berlin, there was a session on 'the role of ammonia in the new energy industry', during which Tobias Birwe of thyssenkrupp Industrial Solutions (tkIS) presented two designs for small-scale electrolysis-based ammonia plants, one of 50 t/d and the other of 300 t/d, which are available 'off the shelf' right now. Pilot plants producing ammonia from renewables started up last year at the Rutherford Appleton laboratory at Oxford in the UK, and at Fukushima in Japan, the first based on wind energy and the second on solar power.

> **At issue, as always, is the cost of producing hydrogen.**

But in spite of all of the industry buzz, the only commercial scale ammonia plants currently capable of running on renewable energy are at Aswan in Egypt and Kwekwe in Zimbabwe, both based on hydroelectric power from river dams, and both are of 1960s vintage. The Kwekwe plant has been idled for four years due to the cost of producing electricity and there is talk of starting up a coal gasification plant to replace it, while the Egyptian plant was recently joined by a second ammonia-urea unit at the site which is currently in start-up, but that second unit is based on natural gas feedstock.

At issue, as always, is the cost of producing hydrogen. The hydrogen-oxygen bond in water is a strong one, and requires a lot of electrical energy to split it by electrolysis. The carbon-hydrogen bond in methane, by contrast, is easily split by oxygen in a reformer. tkIS posited an operating expenditure for an electrolysis-based ammonia plant of about €280/tonne based on an electricity cost of €0.03/kWh. Unfortunately, industrial consumers in Germany currently pay €0.14/kWh. It depends upon how you price electricity from renewables at times of surplus of course, and there are predictions that the cost of electrolysers is coming down. Nevertheless, the cost of hydrogen from electrolysis still has some way to go before it is competitive with hydrogen produced by steam reforming. A recent report by DNV called 'Hydrogen in the electricity value chain' predicted that hydrogen from renewables could become cost competitive with reformer hydrogen by 2035, but the current proposals for green ammonia appear to be anticipating a much faster take-up than that, and that will mean either much heavier carbon taxes than those currently in force, some form of subsidy, or possibly even a straightforward ban on other means of generating hydrogen.

Nevertheless, there is considerable push from some governments to try and achieve a transition to renewable hydrogen over the next couple of decades. The EU has set itself a target of reducing its carbon emissions by 80% below 1990 levels by 2050 – the Dutch government is going further, and pushing for 95%. The German government is looking to a 50% reducing in emissions from industry by 2030. So if the EU is going to carry on producing ammonia and other chemicals, then it would appear that it will need to move to producing hydrogen from renewables. The question appears to be how much and how quickly. ■

Richard Hands, Editor

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Price trends

MARKET INSIGHT

Alistair Wallace, Senior Manager, Consulting, Argus Media, assesses price trends and the market outlook for nitrogen.

Global nitrogen markets reached a period of stability in February 2019 after suffering heavy losses over the prior three months. Middle Eastern urea prices fell by around $100/t from their $330-340/t peak in October 2018, while ammonia is down by almost as much over the same period, settling at around $270/t compared with $360/t in October 2018. Emerging spring demand has helped to prop up nitrogen prices over the last few weeks, and the corn application in the US Midwest looks especially promising for urea and UAN during March and April. But beyond that the market faces significant supply surpluses for urea and ammonia throughout Q2 2019, seasonally its weakest period of the year. We are expecting prices to slide once again in April, continuing their downwards trend into May 2019.

There are numerous drivers of the early oversupply that has gripped the nitrogen market in Q1 2019. One is the poor US fall application seasons, as well as the delays we have seen to the US and European 2019 spring seasons. Poor weather has limited US field work and despite the extremely positive agricultural fundamentals that point towards a bumper year for US nitrogen on paper, we are still waiting for applications to kick off in earnest. EU demand remains lacklustre with German consumption significantly slower this year.

Table 1: **Price indications**

Cash equivalent	**mid-Feb**	**mid-Dec**	**mid-Oct**	**mid-July**
Ammonia ($/t)				
f.o.b. Black Sea	260-280	270-290	335-360	244-250
f.o.b. Caribbean	240	280-290	305-316	270
f.o.b. Arab Gulf	270-285	280-305	340-365	260-280
c.fr N.W. Europe	310-325	330-355	380-387	300-310
Urea ($/t)				
f.o.b. bulk Black Sea	230-240	270-280	280-300	245-260
f.o.b. bulk Arab Gulf*	233-255	280-290	320-340	270-280
f.o.b. NOLA barge (metric tonnes)	245	261	316	220-242
f.o.b. bagged China	260-285	275-290	320-338	270-290
DAP ($/t)				
f.o.b. bulk US Gulf	390	425	458-461	427-430
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	238	268-274	253	n.a.

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

On the supply-side, there have been four significant start-ups of new urea capacity. In December, Acron completed its 0.2 million t/a Urea VI line, and the Garabogaz project in Turkmenistan completed commissioning and added 1.3 million t/a of new urea supply. Soon after, in early January, India's Chambal Fertilizers started its 1.3 million t/a urea plant and Socar commissioned a 0.7 million t/a plant in Azerbaijan. Combined this added almost 4.0 million tonnes of new annual urea supply over the winter holiday season.

The new capacity in Turkmenistan and Azerbaijan also poses a significant problem for the traditional suppliers to the Mediterranean markets. This new supply is certain to target the Turkish market, and along with Iranian suppliers (for whom Turkey is increasingly looking like a market of last resort) this expansion of urea availability from the East will likely start to push Russian Black Sea exporters and the Egyptian suppliers out of the Turkish market. Another important point here is that Iranian urea is available at a significant discount for those buyers willing and able to execute trade with Iran – we would estimate around $50-60/t below the main the price of f.o.b. Arab Gulf supplies.

China has also had a stronger production run this winter. Unlike last year, the government was not surprised by the call on domestic gas supplies and infrastructure. A substantial build-up of gas inventories ahead of the 2018/19 winter heating season meant that availability was higher and that gas rationing on gas-based urea producers was not so severely enforced as the previous year. Higher Chinese winter urea availability and higher international f.o.b. pricing meant that 640,000 tonnes of additional urea shipped this year, much of it leaving China in January 2019. Chinese exports in January 2019 were 590,000 tonnes compared to 140,000 tonnes in January 2018. Chinese ammonia imports are also down, by about 100,000 tonnes between October 2018 and January 2019.

This increase in Chinese export cargos as well as the record export volume set by Iran for the calendar year, has added to the bearish sentiment that has been percolating in the nitrogen market as a poor US fall application season for ammonia turned into a poor northern hemisphere winter pre-buy for urea, and then a late spring for both. If there has been an upside it is that Brazilian urea demand has impressed, and that Brazil has also closed two of its urea factories; potentially increasing this year's Brazilian urea import requirement substantially to replace the loss of ~700,000 tonnes of domestic urea prill production and cover any demand increment. The deteriorating situation in Venezuela also means that that country's urea plants have not exported any significant urea volumes since early summer 2018 and are not likely to do so again this year.

So, with the nitrogen market looking oversupplied until at least July/August, prices are likely to trend downwards towards the industry's cost floor. The worrying thing this year is that the global LNG market looks oversupplied, which is likely to put European gas prices under downwards pressure. Lower gas prices in Europe should translate into lower marginal export costs from Europe, and prices are likely to trend lower in Q2 2019 than they did in Q2 2018. Unless the market tightens before then. At the time of writing, spot hub prices in Western Europe had fallen to $5.60/MMBtu, with further price falls expected as European temperatures rise. At this point last year, the spot price was just over $8.00/MMBtu. ■

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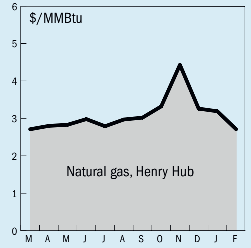
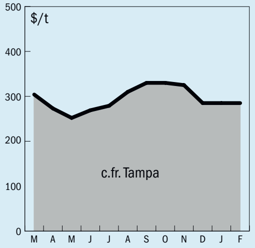
END OF MONTH SPOT PRICES

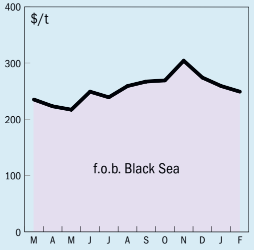
natural gas



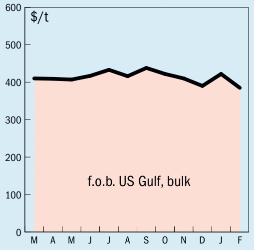
ammonia



urea



diammonium phosphate



MARKET INSIGHT

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

METHANOL

Spot methanol prices fell in Europe and the US in February and rose in Asia. This was due to improved sentiment in China and higher crude oil prices. The official North American reference prices from the major producers for March were $1.30/gal for Methanex and $1.29/gal for Southern Chemical (both rollovers from Feb), equivalent to $432/t and $429/t, respectively. IHS Markit Chemical's contract net transaction price for March is posted at $1.295/gal (nominal $431/t).

The Americas average operating rate was up in February, averaging 88%; 91% in North America and 85% in Trinidad. Methanex's Chilean unit is estimated to have run at around 75% of capacity during January; operations have become constrained as they have in the past due to lower gas availability in the southern hemisphere winter. There is no word on any disruption to Venezuela's plants due to civil unrest in the country. Americas demand into energy-related products remains under some pressure from low crude oil prices. Demand into most other products remained subdued by an extended cold, wet winter which limits construction activity.

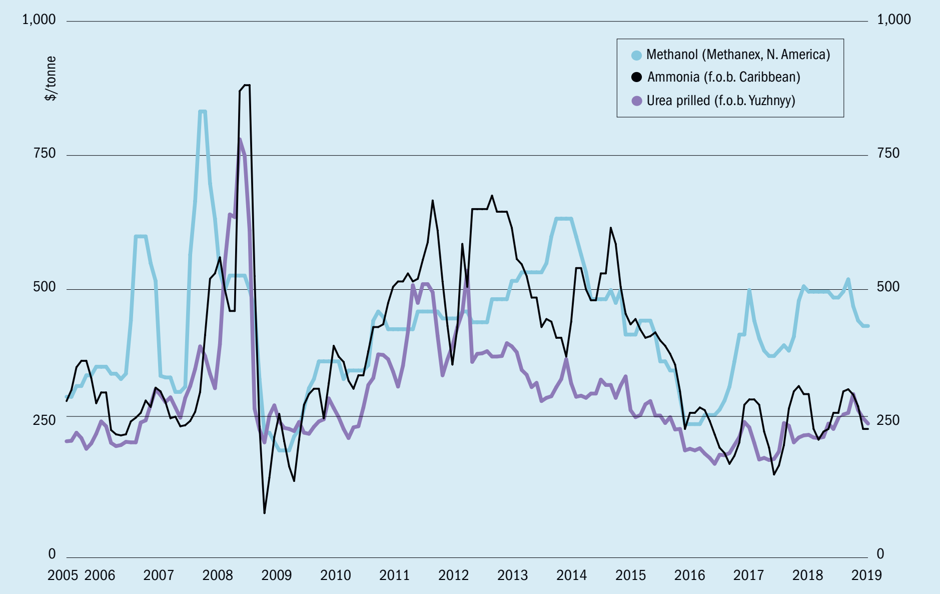
In Europe, European spot prices (T2 f.o.b. Rotterdam) for February were down €2 from January at €279/t over the month. Methanex's 1Q 2019 West European Contract Price was posted at €360/t, f.o.b. Rotterdam T2, down €68/t from the previous quarter. The ongoing suspension of duty on methanol arriving into the EU implemented by the European Commission has been extended and the duty-free allowance will now remain in place. European demand into formaldehyde was stable throughout February. The start-up of a new MMA/PMMA plant in the Middle East this year contributed to an increase in methanol consumption into this segment. Equinor's 900,000 t/a methanol unit in Norway was impacted by a fire at the site on 19 December. It subsequently restarted at the end of January. Zagros in Iran was down for 10-14 days during February for an unexpected issue but has since restarted. Fanavaran will take a short maintenance outage in March. Marjan Petrochemical Co. (1,750,000 t/a) was inaugurated in late September and has sent around five cargoes of methanol to China since that time. The unit shut down at the end of February and will remain offline until early to late March. Indian port prices averaged $293/t in February, up $57 from January due to lower import volumes from Iran during February.

In Asia, Methanex's posted APCP for March was $360/t, up $15 from February. Asian prices in February traded up by $11, in a weekly average low-high range of $275-335/t, c.fr; c.fr China weekly average prices were up $9/t on average in a range of $275-300/t. Chinese capacity utilisation increased in January, averaging around 54% of nameplate capacity or 70% of effective capacity. Boyuan Unichem was offline due to seasonal natural gas restrictions, as was Qinghai Guilu. The major gas-based units in Southwest China resumed normal production with mid to high operating rates in February, although Chongqing Kabeile came offline again in the middle of February due to a technical issue. Shandong Luxi started to sell product commercially in early 2019. Demand into MTO increased in February, with a recovery in olefins prices contributing to improved economics. Zhongyuan PC restarted at the last week of January after three months offline. The MTO margin improved moderately due to the critical increase in olefins prices, although the methanol price increased as well.

In Southeast Asia, regional supply declined significantly. Petronas's large unit (1,700,000 t/a) experienced unstable operations and ran at a reduced for most of February. KMI (710,000 t/a) had a 10-day maintenance outage in the middle of the month. The unit will have its annual turnaround in October/November 2019. BMC (850,000 t/a) ran at typical utilisation rates for most of February but stopped at the end of the month for a 45-50 day turnaround. Spot demand into formaldehyde was healthy. Demand for methanol into the biodiesel sector improved from January's level. The MTBE market was stable. Petronas's second MTBE line (around 150 Kt maximum methanol demand per year) is under construction; it is expected to come onstream in the first half of 2019. ■

Market outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- A poor fall application season has been followed by an equally weak spring application. This has weighed on Caribbean f.o.b. prices and is not expected to be made back as conditions improve.
- The closure of the Magellan pipeline this summer will reduce ammonia availability in the Northern Plains and Midwest Cornbelt. This should help Midwest premiums, but ultimately reduce overall US ammonia consumption.
- Kingisepp has begun commissioning, but is not expected to reach full, nameplate capacity much before June 2019. When it is fully operational, market oversupply looks substantial.
- Increased Chinese nitrogen production this winter has lowered the ammonia import requirement.
- Chinese environmental curbs on downstream industrial production and resulting ammonia consumption were also a feature this winter.
- Prices likely to adjust lower when market feels output from Kingisepp in May 2019. However, we are still forecasting a deficit in Q3 2019 that should trigger a rally back above $300/t f.o.b. Middle East by September 2019.

UREA

- Slow US and European demand have offset early positive sentiment following January MMTC tender. Additional supplies from the Caspian will further dampen sentiment in the near-term.
- Strong US application season expected over the next 6-8 weeks, could trigger a call on urea at NOLA and lift prices in the near-term.
- Election year in India, so strong likelihood of another Indian tender for around 500,000t by April 2019. Current availability for April means the Indian should get a good price and trigger further downwards adjustments into May 2019.
- If EU energy prices continue their slide to significantly below $5.00/MMBtu at NBP/TTF then the market's floor this year could mirror the sub-$200/t lows we saw in 2017.
- Again, supply deficits expected by Q3 2019 and with the closures in Brazil boosting Atlantic trade, we should see a strong recovery back to $300/t by October 2019.

METHANOL

- Various bearish factors are influencing the methanol market in 2019. The primary one is oil prices, which are forecast to continue sliding during the year, and which methanol prices tend to track.
- Another is new capacity – Natgasoline in the US has added 1.8 million t/a of capacity there, and Marjan in Iran another 1.7 million t/a there. Kaveh Methanol in Iran is due to add another 2.3 million t/a of capacity in the Gulf this year, and Carribean Gas Chemical Ltd in Trinidad with another 1.5 million t/a of capacity. Sanctions on Iran do not seem to have so far had an impact on volumes of methanol reaching China and India.
- One bullish factor is the ongoing crisis in Venezeula, which could remove up to 2.5 million t/a of capacity from the market, either via production disruption, or US sanctions. ■

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Nitrogen Industry News

AUSTRALIA

Green ammonia proposal for Pilbara

Fertilizer major Yara has agreed with French energy company Engie to jointly produce a $6 million feasibility study for the construction of a 'green' hydrogen plant. The plant would be integrated with Yara's existing ammonia plant at Pilbara, Western Australia, aiming to convert the 840,000 t/a Pilbara ammonia plant from complete reliance on natural gas feedstock to one where a share of its hydrogen comes from renewable power, dramatically reducing the plant's CO_2 emissions. The study will reportedly consider a 50-60 MW electrolyser powered by more than 100 MW of solar panels to produce enough hydrogen for 28,000 t/a of ammonia. Assuming the feasibility study proves successful, the solar hydrogen plant would be completed in 2021.

A separate project, also based in WA's Pilbara region, is pursuing plans to develop between 9-11 GW of wind and solar power for export to southeast Asia via a sub-sea cable, with some of it becoming green hydrogen. The so-called Asia Renewable Energy Hub is led by a consortium of companies including Australia's CWP Renewables, wind turbine manufacturer Vestas, Intercontinental Energy and Macquarie. ■

Generators selected for hydrogen to ammonia project

Australian hydrogen infrastructure developer H2U has selected Baker Hughes to supply the company's *NovaLT* gas turbine generators for H2U's South Australian Renewable Hydrogen and Ammonia Supply Chain Demonstrator plant at Port Lincoln, South Australia. H2U is developing the A$118 million project in partnership with German-based thyssenkrupp, with A$4.7 million in grants and A$7.5 million in loans from the South Australian Government's Renewable Technology Fund. The project will integrate new hydrogen technologies, including a 15MW electrolyser plant, a distributed ammonia production facility, a 10MW hydrogen-fired gas turbine and a 5MW hydrogen fuel cell, which will both supply power to the grid. H2U CEO Dr Attilio Pigneri said *NovaLT* generators were chosen for the green hydrogen power plant facility because they could operate on 100% hydrogen at all times.

"The annular combustor design and dual-shaft configuration will enable the unit to deliver a best-in-class black-start capability while still operating on 100 per cent hydrogen," Dr Pigneri said. "We are impressed by the operating flexibility of the platform and its ability to operate at a low to no-load capacity, then ramp-up very quickly to full load. This means we can use the units to support critical loads within the Port Lincoln facility, while also contributing generation to the grid during periods of low wind or solar output. The hydrogen is also produced by the electrolysis plant on site, so we have a truly self-contained solution to firming renewable energy supply within the South Australia grid."

Dr Pigneri said the cost of hydrogen generated from electrolysis using cheap wind and solar energy was now comparable with the cost of natural gas in South Australia. "The hydrogen and ammonia demonstrator at Port Lincoln is leading the Australian charge to a 100% renewable hydrogen economy with strong export potential," he said.

The project is due for completion in 2020 and will be one of the first commercial plants to produce CO_2-free green ammonia from intermittent renewable resources.

Coal to ammonia/SNG project releases EIS

The A$1 billion Gladstone Energy and Ammonia project has released the terms of reference for its environmental impact statement (EIS). The project aims to convert 1.5 million t/a of coal into 230,000 t/a of ammonia as well as 12 PJ of synthetic natural gas (SNG) per year. Waste gas and heat created in the process will be used to generate the electrical power required for plant operation, with some surplus power exported to the grid when available. Construction is expected to begin in mid-2020, with the first ammonia production proposed in mid-2022.

Gas supply deal for new AN plant

Santos has signed a non-binding 20-year gas supply deal with Perdaman for the sale of 14.5 petajoules per year of gas from the Narrabri gas project - subject to a final investment decision on the project. The gas will go to feed Perdaman's proposed new A$800 million fertilizer grade ammonium nitrate plant near Narrabri, New South Wales. The AN plant is proceeding in parallel with the Narrabri gas development, and both the AN plant and gas production will use a hybrid combination of conventional gas-fired power generation and renewable power generation.

The Narrabri gas project is based on coalbed methane exploitation, and Perdaman says it could produce enough gas to supply up to half of the requirements of the state of New South Wales. In a press statement Perdaman also said that it will also produce competitively priced gas for their AN project, and have stressed the importance of locating new plants close to new natural gas supply sources – LNG projects on the north and west coasts of Australia have driven up natural gas prices there, negatively impacting on nitrogen plant economics. Perdaman says it is hopeful that the Narrabri gas project will proceed to a final investment decision as soon as possible. The Australian-Indian company is also developing a huge $4.3 billion 2 million t/a ammonia-urea project in Western Australia based on gas from the offshore Scarborough field, which it hopes to begin construction on this year. SNC Lavalin was awarded the EPC contract late in 2018.

UNITED STATES

CCS may allow ammonia from coal proposal to proceed

The Indiana General Assembly has passed a bill allowing the State to regulate carbon capture and storage. The aim is to pave the way towards re-starting a shuttered coal gasification plant which was idled in 2016. The Wabash River integrated gasification combined cycle (IGCC) power plant was developed in the 1990s as part of a 'clean coal' initiative, but was shut down after government support for the project ended. It was bought in 2016 by Wabash Valley Resources LLC, who are hoping to convert the plant to produce ammonia at a projected cost of $450 million. However, approval for the plan is contingent on carbon capture from the gasification plant.

EGYPT

KIMA ammonia-urea plant to start up in May

The Egyptian Chemical Industries Company (KIMA) says that its second production train at Aswan is now 95% complete and will start up in May. The 1,200 t/d ammonia and 1,600 t/d urea plants have been built at a cost of $670 million. The ammonia plant is due to start up in early May, according to KIMA, with urea production following toward the end of the month. Full operation is expected by June 25th in time for the anniversary celebrations of Egypt's June 30th revolution. The start-up date has moved back from the original November 2018 due to delays in supply of critical equipment items, held up by customs delays, according to the company.

HUNGARY

Refit complete at urea reactor

Russian nitrogen technology company NIIK says that work is now complete on the relining of a urea synthesis reactor at Nitrogénmuvek's plant at Petrfurdo. Work was conducted between October and December 2018 at the 600 t/d Stamicarbon-designed Urea II plant, which has been operational since 1975. Since 2017 leaks in the reactor lining have increased the number of unplanned shutdowns of the plant, leading to a need for it to be rehabilitated. NIIK says that its specialists developed repair technical documentation for manufacturing liner parts and expanding devices followed by technical assistance for their manufacture, as well as performing a range of assembly and welding works for installing 32 liner belts including non-destructive testing of welding joints. Upon Nitrogénmuvek's request, NIIK also carried out repairs to the carbon steel shell and overflow pipe as well as corrosion inspection of the top and bottom parts of urea reactor, resulting in a report with the list of defects and recommendations for their elimination during the next plant turnaround. The plant started production in early January and has reached full production capacity.

PAKISTAN

Low gas supplies lead to a month of shutdowns

Pakistan's urea stocks fell to just 31,000 tonnes in early March, against a target level of 200,000 tonnes, according to country's National Fertiliser Development Centre. This was due to the low levels of urea production during February, dropping to 350,000 tonnes during the month instead of the usual winter monthly average of 473,000 tonnes, and set against a summer peak production level of 559,000 tonnes per month in July last year. The decline in output is due to shortages of natural gas feedstock, exacerbated by the temporary closure of LNG import terminals in January, as gas is diverted to electrical power production. Technical issues at Engro's urea plant have also impacted upon supply, while a payment dispute between gas supplier SNGPL and two of its clients led to a week-long shutdown for those plants in late February. In spite of government policy to run urea plants on a continuous basis, gas supply to urea companies remains erratic during the winter months, especially during December to February.

IRAN

Masjid Soleiman set for 2019 start-up

The head of Iran's National Petrochemical Company (NPC), Bezhad Mohammed, has said that work on the Masjid Soleiman Petrochemical Company's ammonia-urea plant in Khuzestan province is now 90% complete, and that the plant is expected to be operational by mid-2019. The plant will consume 860 million cubic metres of gas per year to produce 660,000 t/a of ammonia and 1.07 million t/a of urea.

DENMARK

Haldor Topsoe unveils green ammonia research project

Haldor Topsoe is collaborating with academia and industry on the new SOC4NH3 research project. The partners will together develop solid oxide cell electrolysis for CO_2-free 'green' ammonia production. The aim is to demonstrate the technology, bringing it much closer to commercial breakthrough. Topsøe is heading the DKK 26.8 million project, together with the University of Aarhus, Technical University of Denmark, Energinet, Vestas, Equinor and Ørsted Wind Power. The Danish Energy Technology Development and Demonstration Program (EUDP) is backing the project through DKK 15.9 million of funding support.

"We expect that ammonia can be used for transportation and efficient storage of energy. The greatest advantage of ammonia is that it has a high energy density which makes it an effective fuel and energy storage option – and it can thereby solve some of the most important challenges of creating a sustainable energy system of the future," said project leader, John Bøgild Hansen, senior principal scientist at Haldor Topsoe.

"In the Foulum research facility we will demonstrate an especially efficient technology which will enable us to produce ammonia solely by using certified windpower, water and air. The method is much more climate-friendly than conventional ammonia production which today makes up as much as one per cent of the world's total energy consumption and CO_2 emissions," said Lars Ottosen, head of biological and chemical engineering, University of Aarhus.

"We see an interesting potential in using ammonia for creating more stable green energy production," added Bo Svoldgaard, senior vice president, innovation & concepts, Vestas.

ZIMBABWE

Sable Chemicals revises output downwards

Zimbabwean fertilizer producer Sable Chemicals has revised downwards its likely production for 2019, following several months of reduced financial allocations from the government. Since it closed its electrolysis-based ammonia production line because of the expense of paying for the electrical power, the company has been reliant on imports of ammonia from South Africa to operate its ammonium nitrate plant. However, while the company requires $2.7-3.0 million per month to pay for ammonia imports, no funding was reportedly received during January and February, according to the company. Sable argues that this is short-sighted on behalf of the government, as the state is forced to import ammonium nitrate instead, at a higher cost than it can be produced in Zimbabwe, even taking ammonia import costs into account. Sable argues that it saves the government $4 million per month in foreign exchange costs, as well as providing local employment at its Kwekwe site. The ammonium nitrate plant has a notional maximum capacity of 240,000 t/a, although this is currently more like 160-180,000 t/a according to press reports. The company had hoped to raise production to 100,000 tonnes of AN this year, against just 38,000 tonnes last year, and is also engaged in a $25 million programme of refurbishing the AN plant and buying new ammonia rail tank cars to make up for endemic shortages to bring production back up to 200,000 t/a. Longer term there has been talk of a coal gasification-based ammonia-urea unit to be built with Chinese financing. ■

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RUSSIA

PHOTO: HALDOR TOPSOE

The Shchekinoazot site.

Production begins at methanol and ammonia co-production plant

In December, UCC Shchekinoazot successfully completed a test run of their newly completed methanol and ammonia co-production unit. The plant at Schchekino, south of Moscow, is based on Haldor Topsoe's *IMAP Methanol+*™ process, and has a capacity of 450,000 t/a of methanol and 135,000 t/a of ammonia. It is the first green field project to be based on Topsoe's IMAP process. The *IMAP* process design is intended for use where methanol is the main product, ammonia is the co-product, and there is no need to produce urea. Ammonia production capacity ranges from 25-35% of methanol capacity. It also exists in versions that allow flexible co-production of larger shares of ammonia and/or urea.

"We are pleased that the performance test has been concluded with a positive outcome. We opted for the *IMAP* co-production process because of its streamlined process layout with no shift reactors or CO_2 removal unit. Also, the flexibility of this technology allowed us to replace an aging ammonia production unit with the considerably more energy-efficient process, while further expanding our methanol production capacity," saids Anatoly Surba, CEO of Shchekinoazot.

Collaboration between UCC Shchekinoazot and Topsoe dates back to 2007 when the construction of the first methanol plant started – it was launched in 2011. In 2012, a hydrogen unit with the capacity of 26,000 Nm³/hr was built and commissioned. UCC Shchekinoazot is currently implementing their third methanol production plant under a Topsoe license, with a capacity of 500,000 t/a of methanol. ■

Topsoe wins Nizhnekamskneftekhim methanol contract

PJSC Nizhnekamskneftekhim will license Haldor Topsoe technology for the company's new 500,000 t/a methanol plant at Nizhnekamsk. Topsoe will also provide engineering services as part of the contract, which was signed at the headquarters of owning company TAIF. Nizhnekamskneftekhim mainly uses methanol to produce formaldehyde as a feedstock for the company's isoprene production. The company says that the new methanol unit will make its isoprene facilities more efficient and reduce production costs. Construction of the new plant will be carried out by Russian-based NIIK.

UNITED STATES

Construction moving ahead for Yuhuang plant

Chinese-based Yuhuang Chemical Inc says that its methanol plant in Louisiana is making significant progress. The company says that it is moving from foundation laying to above ground construction, and that all major equipment items that have been delivered to the site will be erected during the first half of 2019. Yuhuang is building a 1.7 million t/a methanol plany – YCI Methanol One – in St James Parish, Louisiana, at a cost of $1.85 billion. Construction began in 2017 and the plant is due to begin commercial operation in mid-2020. Yuhuang is partnered in the operation by Koch Methanol, an subsidiary of Koch Industries. As part of its investment, Koch Methanol will receive exclusive methanol offtake rights from the new facility, and will construct, own and operate the methanol terminal assets for the outbound flow of methanol. Around 70% of the plant's output will be sold domestically into the US market, and 30% overseas, according to Yuhuang.

New hydrogen plant for Louisiana

Linde subsidiary Praxair, Inc., has begun work on a new world-scale hydrogen plant in Louisiana to supply a major refinery in the area under a long-term contract. The new plant will be integrated with Praxair's Louisiana production network via its Mississippi River Corridor hydrogen pipeline system.

Praxair will build, own and operate the steam methane reformer (SMR), which will have a capacity in excess of 170 million scf/d of high-purity hydrogen. The new plant, which is planned to start up in 2021, will be one of the largest hydrogen production units in the US. Linde Engineering has been selected to provide process design and fabricate the core components and modules of the plant. Once complete, this project will take Praxair's US Gulf Coast hydrogen capacity to more than 1.7 billion scf/d.

Praxair also recently started up a new syngas plant at Geismar, Louisiana to supply carbon monoxide to customers in the region. The plant incorporates a new CO purification train with more than 13 million scf/d of capacity.

"Praxair has been an integral part of the Geismar chemical industry for over 50 years and with this latest investment, we are demonstrating our commitment to remaining a reliable and efficient source of industrial gases in the region well into the future," said Dan Yankowski, Praxair's president of Global Hydrogen.

CANADA

Alberta government backs new Nauticol methanol plant

The Alberta provincial government has thrown its weight behind a proposed C$2 billion (US$1.5 billion) methanol plant development by Canadian petrochemical developer Nauticol. The project is to be based at Grande Prairie in western Alberta, and envisages three development phases, each producing 1 million t/a of methanol from Albertan tight and shale-based natural gas production. The first phase is aiming to begin construction in 2020, with comple-

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tion in 2022, and will now be backed by the gvernment of Alberta with up to C$80 million in future royalty credits as part of its C$3 billion 'Made-In-Alberta' energy strategy to support energy diversification in the province, currently mainly based around oil sands operations in the north of Alberta.

"Our Made-in-Alberta for Albertans project will be Canada's largest methanol facility. This world-scale project will expand Alberta's petrochemical value chain by transforming the region's abundant natural gas resources into a highly valued product that will reach growing global methanol markets. Nauticol is committed to meaningful, innovative collaborations, smart engineering and sustainable and low-cost production," Nauticol president and CEO Mark Tonner said in a statement.

Nautical has a written agreement with the Western Cree Tribal Council member nations for potential future investment and development. Meanwhile, energy company TransCanada says that it will expand one of its gas pipelines to supply the new plant. It has approved a C$85 million expansion of its NOVA gas transmission system that would connect its natural gas supply to the Nauticol plant.

"Connecting Nauticol's Grande Prairie facility to NGTL increases the reliability of gas transportation and creates a competitive advantage compared to other gas transportation alternatives," said Nauticol president & CEO Mark Tonner. "This allows Nauticol access to multiple natural gas producer options which best serve our operational needs to consume significant volumes of natural gas from Alberta."

TransCanada's plan is to add 28 km of pipe and a new delivery station. It has applied to the National Energy Board to build and operate them in the first quarter of 2020.

NORWAY

Re-start for Tjelbergodden plant

Equinor (formerly Statoil) has successfully re-started its 900,000 t/a methanol plant at Tjeldbergodden on January 20th, following several weeks of unplanned downtime following a fire in December. The fire, at an electricity substation, did not affect the main methanol unit itself or the associated air separation unit. Tjelbergodden represents about 25% of Europe's methanol production. Equinor owns an 82% stake in the unit, with ConocoPhillips holding the rest.

INDIA

Pilot plant for coal-based methanol

India's slow crawl towards coal-based methanol development continues. Researchers and engineers from the Indian Institute of Technology (IIT) in Delhi and Pune-based Thermax have agreed to build a 1 t/d pilot plant to produce methanol from high-ash Indian coal. The plant is expected to be completed in 2021, and will look at potential challenges for a larger-scale roll-out of the technology in areas like catalysis, hydrodynamics and process technology, Thermax will design, install and run the facility. Several other institutions like the Bhabha Atomic Research Centre will also be involved in the project, which will also consider aspects such as carbon capture and storage and develop the blueprint for a larger scale 100 t/d methanol plant.

"This is a multi-faceted project which demands various research and development R&D inputs, which our diverse team is working on intensively," said Shantanu Roy, project lead from IIT Delhi.

ITALY

Sabic and Eni to develop syngas technology

Italian energy major Eni and the Saudi Basic Industries Corporation (Sabic) have signed a joint development agreement to further develop an innovative technology for natural gas conversion into synthesis gas. The partnership will build an industrial demonstration plant within an existing Eni facility to advance the technology, which is based on a process called short contact time catalytic partial oxidation (SCT-CPO). This technology was initially developed by Eni and then coupled with Sabic's short contact time reactor and the company's extensive knowledge of the integration of syngas generation into downstream processes. The companies say that the joint technology will be "a truly innovative way of making syngas and integrating it into higher value applications to achieve lower capex and opex, higher energy efficiency, lower CO_2 footprint and wide feedstock flexibility".

NETHERLANDS

Shell to invest in 'green' methanol plant at Rotterdam

Shell has said that it will join a consortium of other companies developing a €200 million methanol plant at Botlek near Rotterdam. Shell joins Nouryon, the former chemical branch of AkzoNobel, Air Liquide, Canadian waste processing company Enerkem and the port authority of Rotterdam. Each company will have a 20% in the joint venture: W2C Rotterdam bv. The project will convert 360,000 t/a of low grade plastic and biological waste from more than 700,000 households in the area into 220,000 t/a of methanol, using a gasification process. Air Liquide and Nouryon will provide oxygen and 'partially' green hydrogen to help feed the syngas generation process, which aims to produce methanol with 65% lower CO_2 emissions than conventional processes. The developers say that it would be the first facility in Europe to produce chemicals and biofuels from non-recyclable waste.

The project is supported by the Dutch Ministry of Economic Affairs & Climate Policy, which has agreed to develop mechanisms and regulation that will help bring this new technology to full scale to support the low-carbon transition of the Dutch economy. The waste-to-chemicals project is also supported by the City of Rotterdam, the Province of Zuid-Holland and InnovationQuarter, the regional development agency. A final investment decision is likely this year, pending the outcome of financing discussions with commercial lenders. At the moment the plant is still targeting an on-stream date of 2021, although this seems optimistic given the current state of the project.

Equinor's Tjeldbergodden methanol plant.

PHOTO: EQUINOR

Gas infrastructure firm Gasunie and specialty chemicals company Nouryon have also reportedly agreed to supply hydrogen to Dutch methanol manufacturer BioMCN to produce renewable methanol from carbon dioxide. Gasunie and Nouryon are evaluating the possible use of a 20MW electrolysis unit in Delfzijl to produce hydrogen from renewable energy.

TRINIDAD

GTL plant "to be operational by 2020"

Trinidad's Energy Minister Franklin Khan said in a statement to the country's Senate that the ill-fated NiQuan Energy gas to liquids plant should be operational by 2021. The company reportedly completed the first phase of operations necessary for the start-up of the idled plant in December 2018, and a gas supply agreement was signed in June last year. It appears that due diligence and other lingering legal hurdles over the purchase of the plant – which was largely completed but never operational – from previous owner World GTL Trinidad Ltd have been completed and NiQuan now owns the facility outright in return for $10 million in cash and $25 million in shares to the debenture holder, Petrotrin. Now around $100 million of remedial work must be carried out to get the plant back into working order, which is expected to take 18-24 months. Once operational, the plant will produce 2,000 bbl/d of synthetic diesel and kerosene, expanding to 2,400 bbl/d with debottlenecking work.

UNITED KINGDOM

Biomass gasification power plant to be operational soon

A biomass gasification based power plant is set to come onstream in the next few months at Barry Island, near Cardiff. The plant will produce enough power to run 23,000 homes. The plant will use waste wood chippings, mainly from building sites, to generate syngas, and is owned by a consortium of private investors managed by Aviva Investors.

Application for bio-SNG plant

Peel Environmental has signed a deal with Progressive Energy to develop a £150 million ($195 million) substitute natural gas plant at the Protos energy park near Ellesmere Port, Liverpool. The plant would generate gas from up to 175,000 t/a of unrecyclable wood and refuse derived fuel for use in the transport sector, generating enough to power up to 1,000 low carbon HGVs and buses every year. Subject to planning approval and funding, the plant is due to start production in 2022.

GERMANY

Wind-based hydrogen plant to seek permits

German companies Amprion and Open Grid Europe (OGE) have said that they are seeking permits to build a 100 MW power-to-gas plant to convert wind energy into renewable hydrogen. The plant would start operations in 2023 at Lingen in the northwest of the country. The German government has set a target of nearly doubling the country's share of wind and solar power to 65% of electricity generation by 2030. This is likely to necessitate building energy storage solutions close to where green power is produced to avoid overloading transmission capacity.

AUSTRALIA

Coal to hydrogen project generates controversy

A coal gasification project which would use low grade brown coal from the Latrobe Valley in Victoria into hydrogen has been approved by the state's Environmental Protection Authority (EPA). The Hydrogen Energy Supply Chain project, led by Kawasaki Heavy Industries at the head of a consortium of firms, would build a pilot plant to test the feasibility of producing hydrogen from brown coal and shipping it to Japan for use in the domestic market. The facility would begin production in mid-2020, converting 160 t/d of coal to 3 t/d of hydrogen at a plant adjacent to the Loy Yang power station. The hydrogen would be shipped to Japan via a loading terminal in the Port of Hastings, and has received A$50 million in funding from both the Victoria and Australian federal governments. While the project would generate 100 t/a of CO_2 emissions, it would reportedly only move to a commercial stage if a carbon capture option was available. However, the use of government money to generate hydrogen from carbon-intensive coal has drawn considerable criticism from environmental groups, as has the idea of producing clean energy for Japan by polluting Australia.

DUBAI

Work begins on solar hydrogen facility

Ground has been broken on a green hydrogen pilot project for Dubai, being developed jointly by the Dubai Electricity and Water Authority (DEWA), Expo 2020 Dubai and Siemens. The first solar-based hydrogen electrolysis facility in the Middle East, it will be sited at DEWA's outdoor testing facilities in the Mohammed bin Rashid Al Maktoum Solar Park in Dubai. A number of fuel cell vehicles will be powered by the hydrogen generated at the facility as part of a technology demonstration project.

OMAN

Gas development plan to feed new GTL plant

Shell has signed an interim upstream agreement for the development of gas resources to feed a downstream GTL project. The agreement covers an area in the northern part of Block 6 to the west of the existing Saih Rawl gas field operated by Petroleum Development Oman. The project covers investments in gas exploration and production, in partnership with Total and the Oman Oil Company (OOC), aiming to integrate the Shell and OOC share of the upstream project with the development of a gas-to-liquids plant (GTL) currently under discussion, to be developed and operated by Shell in partnership with OOC. Shell has been a pioneer in GTL production via its Bintulu project in Malaysia and Pearl project in Qatar, but had curtailed its GTL development plans due to rising costs and poor economics. Now however it seems to be dipping its toe back into the water, signing an agreement in May last year with Oman to build a plant in the Duqm Special Economic Zone. At the moment the size of the GTL plant is unclear, but with initial gas production from Block 6 put at 500 million scf/d, that would represent about 50-60,000 bbl/d if fully converted to GTL.

Chris Breeze, Shell's Country Chairman in Oman, said: "We hope that the development of gas resources destined for the integrated projects will play an important role in generating in-country value and diversifying Oman's economy. This agreement marks a new chapter in Shell's close partnership with the government of Oman." ■

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People

EuroChem Group AG has announced the appointment of **Petter Ostbo** as its chief executive officer, effective from June 1st, 2019. Mr Ostbo, who has a proven track record in the global fertilizer industry, will take over from EuroChem chief financial officer **Kuzma Marchuk**, who has been serving as Acting CEO since September 2018.

"The Board is delighted that Petter Ostbo is joining the team," EuroChem Group chairman Alexander Landia said. "He is highly regarded in our industry and brings broad experience to the position. Petter's appointment demonstrates EuroChem's commitment to bringing in the best talent to take the company into the next chapter of its growth story. I would like to thank Kuzma for his continuing service as Acting CEO of EuroChem until Petter takes over."

"I am happy to be able to join EuroChem at this exciting time in the company's development," Mr Ostbo said. "The new potash and ammonia production present great opportunities for EuroChem, and I look forward to working with the Board and the management team to accelerate the next phase of growth."

Mr Ostbo's most recent role was as EVP and Chief Financial Officer of Yara International, before which he held the position of EVP Production at the same company, with responsibility for 28 production sites and four mines in 16 countries. Mr Ostbo previously worked at McKinsey & Co from 2003-2010. He holds a Masters in Economics and Business Administration from the Norwegian School of Economics (NHH).

Petter Ostbo.

Darron Page has been appointed as a senior vice president (SVP) at JR Simplot. He will take charge of the company's 'Global Solutions' arm, covering sustainability, procurement, enterprise services and facilities/wheels/aviation, and will report directly to JR Simplot's president and CEO Garrett Lofto. He will also represent Global Solutions within the company as part of the Simplot Leadership Team. Darron takes over Global Solutions from Sue Richardson following her appointment as SVP of Global Business Transformation.

In his 26 years with Simplot, Page has worked as Simplot's procurement VP for from 2014-2017 and supply chain VP from 2012-2014. Prior to taking his current role he was Simplot's vice president (VP) of business development in the Company's AgriBusiness Group from 2017-2019. He has a business degree from Washington State University and an MBA from Boise State University.

"Darron has been a valuable partner and leader within our Company for many years," said Lofto. "His varied experience and innovative mindset will continue to serve the Company well."

Engro has announced the appointment of **Ahsan Zafar Syed** as the new CEO of Engro Energy Limited. Joining Engro in 1991, his experience has been in project management, and the design, construction and execution of large mega-scale projects. In his previous role as Senior Vice President Engro Corporation he was part of the team that executed the $1.1 billion EnVen Project, constructing the world's largest single-train urea plant for Engro fertilizers Limited in 2010. ■

Calendar 2019

APRIL

8-11
IFA Global Technical Symposium,
NEW ORLEANS, Louisiana, USA
Contact: IFA Conference Service,
49 Avenue d'Iéna, 75116 Paris, France
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

JUNE

4-5
IFS 2019 Technical Conference,
BRUSSELS, Belgium
Contact: International Fertiliser Society,
PO Box 12220, Colchester, CO1 9PR, UK
Tel/Fax: +44 (0)1206 851 819
Email: secretary@fertiliser-society.org

11-13
IFA 87th Annual Conference, MONTREAL, Canada. Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

16-19
International Methanol Technology Operators' Forum (IMTOF) 2019,
LONDON, UK
Contact: Polly Murray, Johnson Matthey
Email: polly.murray@matthey.com

19-20
Syngas Nitrogen Russia and CIS,
MOSCOW, Russia
Contact: Milana Stavnaya,
Programme producer, Vostock Capital
Tel: +7 499 505 1 505
Email: MStavnaya@vostockcapital.com

SEPTEMBER

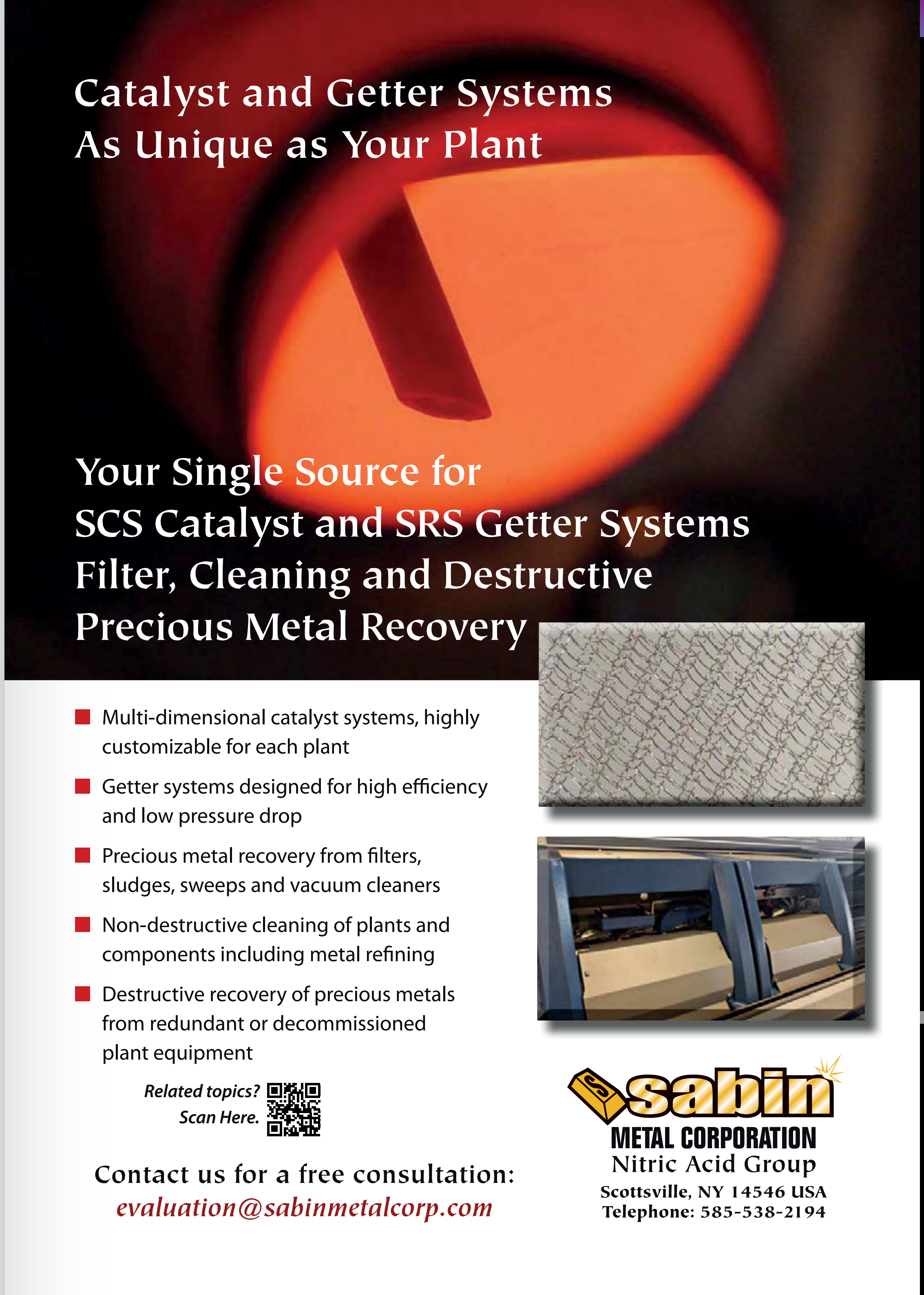
8-12
64th AIChE Annual Safety in Ammonia Plants and Related Facilities Symposium,
SAN FRANCISCO, California, USA
Contact: AIChE Customer Service
Tel: +1 800 242 4363/+1 212 591 8100
Fax: +1 212 591 8888
Email: xpress@aiche.org

8-13
Ammonium Nitrate/Nitric Acid Conference,
VIENNA, Austria
Contact: Hans Reuvers, BASF,
Karl Hohenwarter, Borealis
Email: johannes.reuvers@basf.com,
karl.hohenwarter@borealisgroup.com
Web: www.anna-eu.com

22-24
TFI World Fertilizer Conference,
CHICAGO, Illinois, USA
Contact: Valerie Sutton
Fax: +1 202 962 0577
Email: vsutton@tfi.org

OCTOBER

27-29
Nitrogen+Syngas Middle East,
MUSCAT, Oman
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



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Plant Manager+

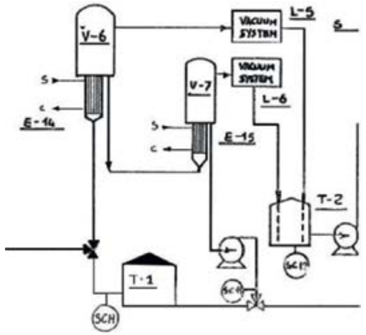
Problem No. 53 Restriction orifices in VOP exchangers and their influence on biuret formation

Vertical one pass (VOP) heat exchangers are used in many urea plants. As the residence time in these heat exchangers is small, unwanted side reactions like biuret formation and hydrolysis of urea are limited. Liquid enters the tubes of the heat exchanger at the bottom side via a control valve. Due to the pressure drop over this control valve some flashing will occur. Furthermore the heat input from the shell side will also result in gas formation. The gas causes a turbulent environment at the tube side increasing the heat transfer co-efficient.

Some phenomena, however, can limit or reduce the performance of these heat exchangers. One problem can be bad distribution of the inlet liquid/gas mixture over the tubes, with some tubes receiving more feed than others, recirculation from the outlet to the inlet may also occur, all limiting the performance. Another problem can be fouling on the tube side, which causes limitations of the heat exchanger.

The more turbulence on the tube side of VOP heat exchangers, the higher the heat transfer coefficient, the higher the performance of the heat exchanger and the lower the risk that fouling can settle on the tube side. It is common experience that orifices at the inlet of the tubes improve the distribution over all of the tubes, increase the turbulence on the tube side, reduce fouling on the tube side and thus increase the performance.

Munirm Munir of Pakarab Fertilizer in Pakistan starts the round table discussion: Can anyone share his/her experience of installation of restriction orifices in vertical one pass (VOP) evaporation heaters (E-14, E-15 or other) in a Saipem urea plant and the reduction in biuret as a result? A sketch of the vacuum and evaporation section of the plant at our site is provided.



Sketch of vacuum and evaporation section.

At present, the biuret content in our final product is 1.1 w-t%. Will the installation of restriction orifices in VOP heaters E-14 and E-15 on the process side help us in reducing the biuret figure in our final product?

Prem Baboo of Dangote Fertilizers in Nigeria responds: In the urea plant I worked for previously, a control valve is provided in the steam supply to E-14 and E-15 for controlling the desired temperature of urea solution to control the biuret. In VOP heat exchangers there is a problem of flashing because the control valve is located at grade level. After that a pressure drop occurs due to the two-phases (gas and liquid) sometimes causing hammering in the vertical line.
The orifices can provide the following advantages:

- LMTD across vertical heat exchanger increases;
- flashing problem will be solved;
- regular and constant flow;
- two-phase (gas-liquid) problem will be solved;
- biuret can be controlled at constant plant load;
- unwanted side reaction can be controlled.

Some more suggestions: The control valve can be relocated to a position closer to the vertical heat exchanger. At variable plant load there is a fixed diameter of orifice. The orifice is suitable at constant load but at variable load, how do you manage the pressure drop with an orifice? For variable loads the control valve can be relocated near the vertical one pass heat exchanger.

Munirm replies: Actually, our plant mostly runs at constant load (i.e. 120% of 300 t/d capacity). If the restriction orifices can help us to reduce the biuret content in the product then we can go for it. Do you know of any references where restriction orifices have been installed? Maybe we can obtain some data from them regarding their performance. The control valve (LV-22) is located down L-3 (LP decomposer holder) and there is about 100 m distance between LV-22 and the E-14 inlet. I believe you mean relocating this control valve? Will it help us to decrease biuret in our final product?

Prem continues the discussion: If you install orifices before E-14 then what is the function of the upstream control valve (LV-22)? The control valve can be relocated near to E-14 and there is no need for orifices anymore. This will help to rectify the problem.

Munirm continues: Relocation of LV-22 is probably an optimal solution. At this point, the biuret content in our final product is ~1.15 wt-%. Will we be able to achieve < 1 wt-% target with this modification? Do you know of any references?

Prem replies again: Yes, relocation of the control valve is proven, but I don't know about the orifices. We have also relocated this control valve to the vacuum section area from the LP holder.

Munirm continues: Ok, thank you. We'll be looking to implement this at our site.

Majid Mohammadian of OCI Nitrogen in the Netherlands joins the discussion: Restriction orifices (plugs) are mostly installed in the second stage of evaporation in the inlet of each tube which will increase the velocity, minimise the residence time and therefore reduce the biuret formation of the high temperature and high concentration urea melt.

In Stamicarbon plants the tube diameter of the evaporator heater is usually reduced to 7 mm. Please check with your licensor when selecting the diameter of the orifice plugs.

Munirm continues: The outside diameter (OD) of our VOP tubes is 3/8". The size of the orifice is clear now but it is still unclear how much it will reduce the biuret content in a Snamprogetti urea plant. Can you share the performance improvement achieved at your plant after orifice installation?

Majid replies: If the OD is 3/8" (9.5 mm), I don't think the restriction orifice will be effective in your case. In our case the OD was 20 mm therefore installation of orifices could increase the velocity and reduce the biuret.

Munirm continues: The biuret in the urea melt after the 2nd stage evaporator heater and the prilled product is almost the same which indicates we cannot reduce the size of the melt line to increase velocity. We also took the following measures as operational controls to minimise the residence time, temperatures and holder levels.

- the level in the MP and LP holders is kept as low as possible;
- the pressure drop in the vacuum section is kept at 0.3 to avoid hold up;
- N/C ratio is kept at 3.5 (3.4-3.6) as per design;
- the stripper bottom temperature is maintained at around 201°C;
- the prilling bucket urea melt temperature has been reduced from 140°C to 136°C
- diversion to the urea solution tank and recovery is avoided.

What else can we do to reduce biuret if restriction orifice are ruled out? Any suggestions?

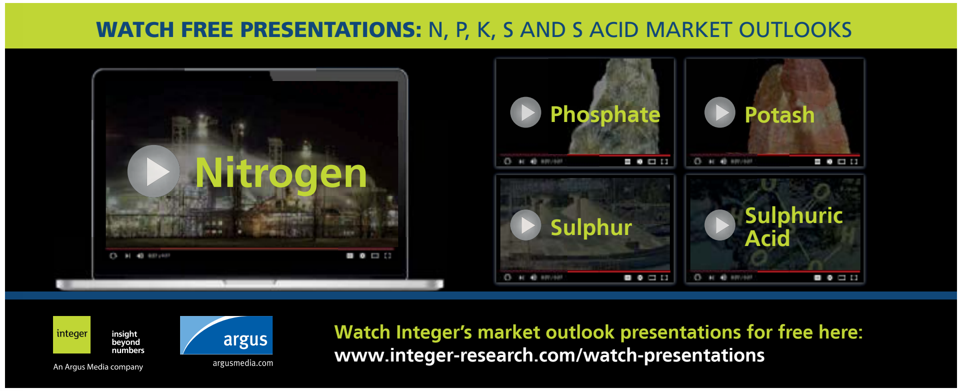
Majid replies: One question: have you been faced with the issue of high biuret issue recently or do you want to improve it to lower than the design value?

Munirm responds: Actually, we want to improve it and bring it lower than the design value. The design value is greater than 1 wt-%.

Majid replies: As you have mentioned you have done all the required process adjustments. If you want to further reduce it to lower than the design value you have to increase the speed of the urea solution/melt or reduce the distances between the preconcentrator, evaporators and the prilling bucket.

Muhammad Kashif of SAFCO in Saudi Arabia shares his experiences: Restriction orifices are used in Stamicarbon urea plants in the rectifier heater and 2nd stage evaporator heater to reduce biuret. However a better solution with respect to mechanical maintenance and reliability is to use an orifice plate with PTFE gasket. ■

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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India's dream of self-sufficiency

Narendra Modi's government has announced its intention to move India back to the self-sufficiency it last enjoyed in urea production in the 1990s. Several urea projects are now under development which could see this goal achieved by 2022.

India's elections begin on April 11th and run to May 23rd, the largest democratic election in world history, with over 900 million people going to the polls. The results are hard to predict – India's polling data can be very volatile. Best guesses put the likelihood of a BJP (via its National Democratic Alliance – NDA – coalition) led government at about 50-50, with the other main likelihood a government led by the Congress party, although a third party led coalition also remains an outside possibility. One of the key battlegrounds will be the economy. Prime minister Narendra Modi has sold himself on tapping into India's economic dynamism, although 2017 and 2018 saw GDP growth rates fall from 8.2% to 7.2%, with the likelihood that this will improve to about 7.3% during 2019 and 7.4% in 2020. There has been some success with spreading the benefits of this growth and tackling corruption and the informal economy, the latter via the Goods and Services Tax, as well as reducing inflation and India's persistent budget deficit, but joblessness remains a problem – unemployment has doubled in the past two years – and lower consumer spending, sluggish investment, and slower growth in agriculture and manufacturing continue to be a drag on the economy.

Agricultural demand

While it now has shrunk to only 15% of GDP, agriculture continues to be a vital part of the Indian economy, employing more than 50% of the working population and supporting 58% of rural households. India is the second largest agricultural producer in the world and the third largest exporter of agricultural products, which represent 10% of India's exports by value. However, while India's growth in agricultural productivity since independence has been a remarkable success story, in the past decade productivity has stagnated or fallen. Lack of irrigation and uncertain monsoon rains remain a problem, as does lack of access to fertilizer by farmers, and this in turn is due to low farm incomes. The government has attempted to maintain food security and enhance farm incomes via minimum support prices (MSPs) for major agricultural commodities, revised and up-rated each year to ensure that there was a rising floor to agricultural prices, helping to stabilise income increases and guarantee farmers a return on investments which help raise productivity.

With its eye on the rural vote, the government has set itself the target of doubling farm incomes over the period 2017-22. A variety of initiatives have been unveiled to contribute to this, most notably the Agriculture Export Policy, approved by government in December 2018, which aims to increase India's agricultural exports to $60 billion by 2022 and $100 billion by 2030 with a stable trade policy regime. There is also a $300 million scheme for computerisation of Primary Agricultural Credit Societies (PACS) to ensure agricultural cooperatives benefit from digital technology, and a $7.7 billion irrigation scheme to provide a permanent solution to droughts. The government also plans to triple the capacity of the food processing sector from the current 10% of agriculture produce.

Most notable is the subsidy system which in theory keeps energy and fertilizer input prices low to farmers. The government has set its sights on moving from a subsidy payment paid to fertilizer producers and energy companies to a direct income subsidy paid to farmers, and has been rolling out its Aadhar identity card scheme to allow farmers to make subsidised purchases across various states. However, there have been rumours that the government is looking to something radical for the upcoming pre-election budget, by using the cards to achieve its ultimate goal of combining all current agricultural subsidies into one single cash payment to farmers – so-called Direct Benefit Transfer or DBT. The aim is to make this revenue neutral – India's farm subsidies currently take about $9.8 billion per year of government cash. The government might also provide low interest or interest free loans to farmers. This would presumably also mean partial or full decontrol of fertilizer prices in India. The effect of this on overall fertilizer consumption is hard to predict at this stage, but ending the dominance of urea as a subsidised product might help to boost use of phosphates and potash and correct the nutrient use imbalance that has dogged Indian agricultural productivity.

Fertilizer consumption

Urea represents virtually half of all India's fertilizer consumption in terms of nutrient tonnes. India's urea consumption rose from 8.8 million tonnes N (19.1 million tonnes product) in 2000 to 12.9 million tonnes N in 2010 (28.0 million tonnes product), but thereafter consumption has risen far more slowly, to 14.1 million tonnes N in 2015 (30.7 million tonnes product), and consumption actually fell in 2016 and 2017 as the government brought in its scheme that all urea had to be coated with neem to provide for controlled release of nutrient, eke out existing supplies of urea, and cut down on black market sales. In 2018 there was a slight uptick of 2% in consumption. Currently India consumes between 30-31 million t/a of urea.

Set against this, Indian urea production has run at about 20-22 million t/a for some years (see Figure 2), leading to imports of up to 8 million t/a. India last went through a major capacity building programme for urea in the 1990s, but new plant building stopped around 1995 for two reasons – firstly, the subsidies being paid to fertilizer companies was starting to spiral out of control and claiming an ever larger share of the federal budget.

Fig. 1: **India's urea and DAP plants**

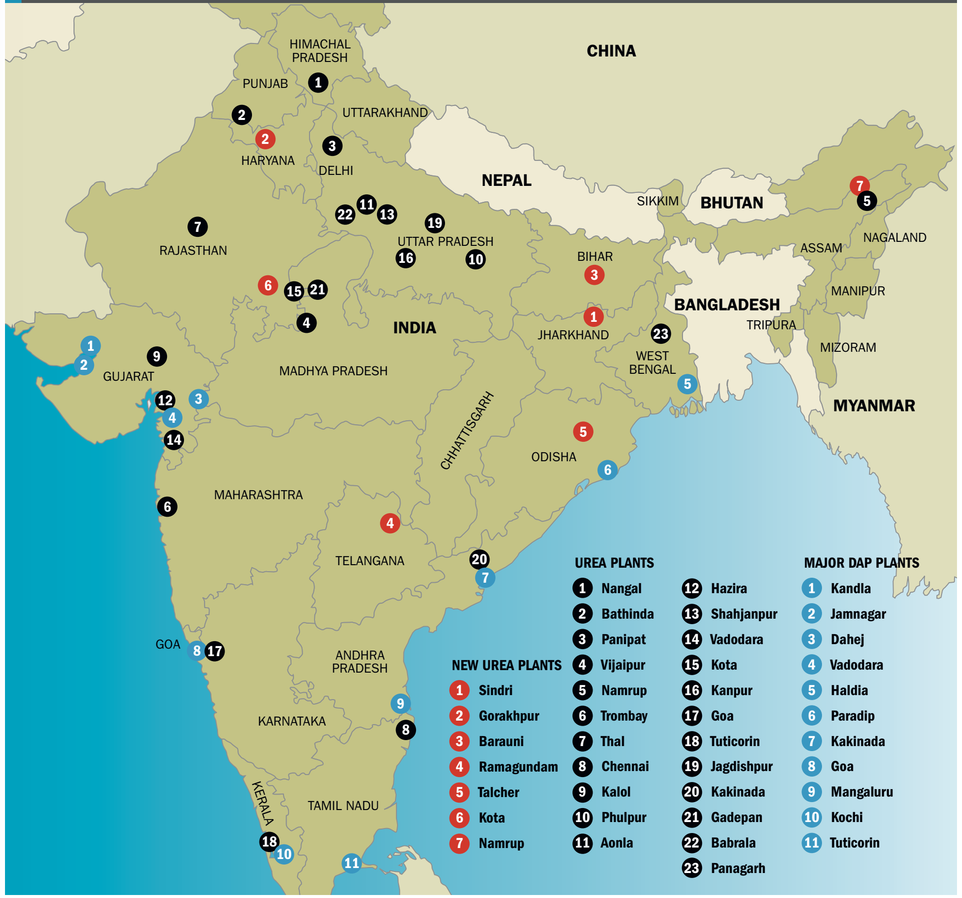

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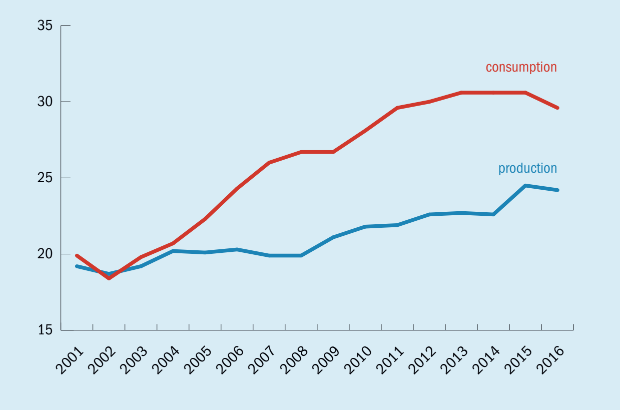
Fig. 2: **Indian urea production and consumption, 2001-2016, million t/a**



Source: IFA, FAI

Secondly, feedstock availability was beginning to become an issue. Most Indian urea capacity was historically based on naphtha feedstock, but high oil prices led to high naphtha prices and consequently a high subsidy bill to keep urea made from naphtha affordable. As a result the government started pressuring plants to switch towards using natural gas feedstock. But India's shortage of natural gas meant that the plants often suffered gas supply curtailments, especially during winter when more power was needed and gas was preferentially given to gas-fired power stations. Gas discoveries in the Bay of Bengal were due to correct this problem, but turned out not to be as extensive as had been believed, and India has had to make up the shortfall by importing liquefied natural gas (LNG), often at high, oil-linked prices (albeit still cheaper than naphtha).

Self sufficiency

The growing reliance on imports of urea led to successive governments trying to encourage the development of domestic urea capacity, but these projects often foundered on gas availability, and most new urea capacity in India over the period 1995-2015 was provided via debottlenecking and upgrades of existing plants. The main exception was the 1.3 million t/a Matix Fertilizer plant in Bengal, which was built to exploit reserves of coalbed methane in the region, and which was the first new urea plant built in India since the 1990s. However, when this facility was completed in 2015, the volume of gas that was able to be supplied was only about 35-40% of the plant's requirement, and the plant has been idle for most of the past three years. The plan is now to connect the plant to the LNG terminal at Dhamra via a new pipeline. Work began last year on this and the plant is due to re-start in 2019.

In spite of this setback, the Modi government has decided to set urea self-sufficiency as one of its targets, and in 2017, the government announced an ambitious $8.7 billion plans to end imports of urea within five years. This would be achieved by reviving five mothballed urea plants and setting up new facilities, bringing 7.5 million t/a of new urea capacity on-stream. Gas import and pipeline schemes to feed the plants also form part of the plan.

'Revived' plants

Current plans call for the re-start of five idled urea plants previously operated by the Fertilizer Corporation of India Ltd (FCIL) and Hindustan Fertilizer Co. Ltd (HFCL). The plants are at Barauni in Bihar state, Sindri in Jharkhand, Talcher in Odisha, Ramagundam in Telangana and Gorakhpur in Uttar Pradesh. Major state utility companies such as Gas Association of India ltd (GAIL) and Coal India Ltd (CIL) are involved in financing and providing feedstock for the units, which will be operated by existing fertilizer firms. Although the projects are described as 'revivals', they are in effect new plants, with most of the old plants being dismantled and new ones constructed at the same site.

At Sindri, Gorakhpur and Barauni, CIL and the Indian Oil Company (IOC) are the lead investors, together with the National Thermal Power Corporation (NTPC), via a special purpose investment vehicle – Hindustan Urvurak and Raysan Ltd (HURL). FCIL and HFCL are the other two partners. Each of the three plants is to be a 1.27 million t/a. Technip FMC was awarded the lump sum turnkey EPC contract in May 2018 for Barauni and Sindri, licensing ammonia and urea technology from Haldor Topsoe and Saipem respectively. Gorakhpur will use KBR and Toyo technology, with contracts awarded in March 2018, and this is expected to be completed first of the three HURL units, in 2020-21, with the other plants following a year later. All three plants will be fed by LNG imported on the east coast at Haldia and supplied along the Jagdishpur-Haldia pipeline.

Ramagundam will be another 1.27 million t/a plant, at the site of an old FCIL coal gasification plant, although the new plant will be gas-based. This is being developed by Ramagundam Fertilizers, a joint venture between FCIL, National Fertilizers Ltd and Engineers India. Gas is being supplied from the Mallavaram LNG terminal in Andhra Pradesh, with a gas supply agreement signed in July 2016. Ramagundam is the furthest advanced of the government-backed projects, and is expected to be commissioned in the next couple of months.

The final plant of the five government developments is at Talcher in Odisha State. Like the other projects, it is to have a final capacity of 1.27 million t/a of urea, although unlike the others the plan is to run it on coal as a feedstock. This is something of a radical development for India, which had an unhappy history with its first two coal-based urea plants, built at Ramagundam and Talcher in the 1970s, which suffered from all manner of production issues and which were finally closed down. The high ash content (35-45%) of Indian coal also means that certain types of gasifier are not suitable. However, the success of China in developing coal-based urea capacity has led to a re-think, and India, with its large coal reserves, is now looking seriously at coal gasification once more. Talcher Fertilizers Ltd is a joint venture between GAIL, Rashtriya Chemicals & Fertilizers, FCIL and Coal India Ltd. The project has made slow progress, but is aiming to award contracts this year for completion in 2022.

Other new urea plants

As well as the five government-backed projects, there are a number of privately funded projects under development, but the only one that has made any significant progress has been the revival by Chambal Fertilizers and Chemicals of its old urea plant at Kota near Gadepan in Rajasthan state, which closed in 2015 due to unfavourable economics. A new 1.27 million t/a replacement plant was completed late last year and commissioned in January 2019.

In addition to this, another government project is under development – the establishment of a new brownfield ammonia/urea complex at the Brahmaputra Valley Fertilizer Corp (BVFCL) site at Namrup in Assam, so-called Namrup-IV – was approved in October 2018. A new 860,000 t/a ammonia-urea plant will replace the two older 220,000 t/a and 270,000 t/a units. The new plant will be 52% owned by Rashtriya Chemicals and Fertilizers, 26% by Oil India Ltd, 11% by the state government of Assam and 11% by BVFCL. No contracts have been awarded as yet.

What is self-sufficiency?

The completion of the six plants under development – two coming on-stream this year, and the others in 2021-22 – will increase India's urea capacity by 7.6 million t/a, assuming that sufficient gas can be imported to operate them all. This, plus the re-start of the Matix plant, should take Indian urea production to a potential 33 million t/a by that time, ahead of current Indian urea consumption and potentially turning the country into a net urea exporter. However, there is an open question as to what extent building these plants actually translates into self-sufficiency. After all, if India has to import LNG to make ammonia, and import phosphate rock to make DAP, is that really self-sufficiency? It might provide greater control over urea pricing in what is a volatile international market, but whether that is worth the $8.7 billion price tag of building the new plants on top of the cost of importing LNG and the subsidy cost for payments to farmers is clearly a political rather than an economic one. ■

Loading urea in the Middle East for shipment to India.

Table 1: **Indian urea production**

Company	**Location**	**Production, 2017-18 FY (million t/a)**
Public sector		
National Fertilizers Ltd	Nangal	0.50
	Bhatinda	0.57
	Panipat	0.54
	Vijaipur	2.20
Brahmaputra Valley Fert Co Ltd	Namrup	0.31
Rashtriya Chemicals & Fert	Trombay	0.41
	Thal	2.14
Mangalore Chemicals & Fert	Chennai	0.47
Cooperatives		
Indian Farmers Fert Coop	Kalol	0.60
	Phulpur	1.62
	Aonla	2.10
Krishak Bharati Cooperative	Hazira	2.35
	Shahjanpur	0.93
Private sector		
Gujarat State Fertilizer & Chem	Vadodara	0.36
Shriram Fertilizers & Chemicals	Kota	0.39
Kanpur Fertilizer & Cements Ltd	Kanpur	0.72
Zuari Agrochemicals Ltd	Goa	0.47
Southern Petrochemical Ind Co	Tuticorin	0.56
Mangalore Chemicals & Ferts	Mangalore	0.38
Indo-Gulf Fertilizers	Jagdishpur	1.16
Nagarjuna Chem & Fert Ltd	Kakinada	1.50
Coromandel Fertilizer & Chem	Gadepan	2.00
Tata Chemicals Ltd	Babrala	1.21
Matix Fertilizers & Chemicals Ltd	Panagarh	0.01
Total		**24.20**

Source: Fertilizer Association of India

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Delfzijl, where AkzoNobel is partnering in renewable hydrogen production.

PHOTO: AKZONOBEL

Hydrogen markets and syngas

Hydrogen production consumption is increasing rapidly as it is increasingly seen as a 'clean' fuel. The future role of syngas in its production however remains uncertain.

Hydrogen appears to be having something of a renaissance. Back in the 1990s there was much talk of the forthcoming 'hydrogen economy'. Hydrogen was seen, for example in the US Department of Energy's 'Green Hydrogen' paper, as a way of reducing dependence on carbon-based fossil fuels. In particular two major roles were foreseen for hydrogen – as a transportation fuel, either burned directly or in fuel cells, overcoming the problems of battery power for vehicles; and as a way of storing energy from renewable fuel sources at times of low demand and high production.

In the subsequent years and decades, however, practical issues managed to intervene and hydrogen became a fuel that has, in the words of the Royal Society of Chemistry, "promised much but delivered little". Nevertheless, as the future effects of climate change continue to be a major issue for the world (the current US administration possibly excepted), and as societies look for a way to decarbonise their energy production and use, hydrogen seems to be coming back to the forefront of discussion again. At the moment, current forecasts are for 8% year on year growth for hydrogen markets over the next five years, but large scale adoption in the transportation and energy sectors could change this rapidly over the years and decades that follow.

Hydrogen's main role today is in breaking down larger molecules into smaller ones in refinery processing of crude oil and other feedstocks, and in desulphurising refinery feeds. The refining sector is the primary consumer of hydrogen (outside of ammonia production, which represents about 30 million t/a of hydrogen generated). But the long term objective of many in industry and government remains, as it was 25 years ago, hydrogen's penetration into energy and transportation uses – although for the transportation route the development first of hybrid cars and regenerative braking systems, and then more efficient on-board battery systems, has begun to make electric cars look more like the future of transport than hydrogen-powered vehicles. Nevertheless, some end uses remain hard to electrify, such as long-distance transport including aircraft and heavy goods carrying road vehicles, energy-intensive industries, and some residential heating cases. Energy will also still need to be traded between countries and regions, on a large scale, and it is inefficient to do this using electrical transmission lines.

Fuel cells

One application which does seem to be making some headway is hydrogen as a source of electrical power in fuel cells. While use of fuel cell passenger cars appears to have been overtaken by battery-powered vehicles, fuel cell car numbers are nevertheless growing, and at an exponential rate. A recent survey by consultants KPMG found most automotive executives around the globe thought the rise of fuel cell electric vehicles would be the number one trend in the sector until 2025. From around 200 being in operation in the US in February 2016, there were 1,600 on the road in February 2017, and 5,900 in January 2019, almost all of those in California. Worldwide, fuel cell manufacturer Ballard Power estimates that there are now 10,000 fuel cell passenger cars in service, with Japan the second largest user after California – the Japanese government intends Japan to become a 'hydrogen society' with plans for 40,000 hydrogen-powered cars on the road by 2020, growing to 800,000 by 2030. At the moment most fuel cell cars on the road are the Toyota Mirai, which has been the first mass production fuel cell vehicle that can be owned (previous fuel cell vehicles such as the Honda Clarity existed on a leasable basis). Hyundai has said that it will invest $7 billion in fuel cell vehicles and its Nexo model will go on sale this year, and Daimler BMW is now leasing its GLC F-CELL cars in Germany.

Aside from passenger vehicles, fuel cell buses carried 15 million passengers in 2017, and fuel cell forklifts have made some inroads into the market. Fuel cell trucks are now moving from demonstrator programmes into commercial service. Perhaps the biggest development has been that in 2018 China has begun commercialising fuel cell buses and trucks, with around 1,500 now in service. China has recognised alternate fuel vehicles as one of the solutions to its city pollution problem, and as numbers begin to ramp up, China could end up a very large consumer of hydrogen for fuel cell vehicles indeed. The Chinese government is looking at 50,000 fuel cell vehicles in service by 2025 and 1 million by 2030. Overall, Ballard estimates that there could be 100,000 commercial fuel cell trucks and buses in service by 2025, 150,000 forklifts, and that fuel cell vehicles could represent 3% of all new car sales by 2030. Around 80 million cars are sold per year at present, with that number relatively flat from 2016-2019, so at current numbers that would represent 2.4 million vehicles per year.

Outside of fleet uses (where fuelling can be centralised), the numbers of hydrogen filling stations are also rising rapidly, with 21 in the greater Los Angeles area by mid-2018 out of a total of 39 nationwide. There are now dozens in Europe, and an estimated 330 worldwide by early 2018. California has set a target of 100 hydrogen fuelling stations in service in the state by the end of 2020, although it looks as though this target may be missed. China has 21 stations in operation and 41 under construction. As the fuelling infrastructure grows, so the prospects for hydrogen powered vehicles becomes brighter. The average fuel cell car consumes – assuming an average drive of 12,000 miles per year – 0.2 tonnes of hydrogen. A heavy vehicle can at least double that. That means that by 2025 fuel cell vehicles could be consuming 250,000 t/a of hydrogen, and by 2030 a total of 1 million t/a.

In the meantime, the greatest application so far for fuel cells seems to be stationary fuel cells for backup power generation in critical locations or for remote areas away from the grid – numbers of these installed are also rising rapidly, with 670MW of generating power shipped to clients in 2017, up from 500MW in 2016.

The Hydrogen Council

Perhaps one of the biggest developments in the world of hydrogen in the past couple of years has been the formation of the Hydrogen Council, unveiled at the World Economic Forum in Davos in 2017. It is a group of 39 companies within the energy, transport and industrial sectors who are working to promote hydrogen as a key component of an energy transition from fossil fuels. Its members include "leading companies that invest along the hydrogen value chain, ranging from hydrogen production, infrastructure, and retail to end users in the residential, industrial, and transportation sectors", and cover some big names like Air Liquide, Linde, Shell, Total, BMW, Honda, Toyota and Hyundai. In total, the group's members account for total annual revenues of over $2.0 trillion and close to 3.8 million jobs around the world, so it is no ordinary pressure group. Its goal is, according to its own mission statement, to "seek to define and implement a specific action plan with appropriate supporting tools that will help accelerate major investment into large-scale commercialisation of hydrogen solutions across industries worldwide." To this end, it has so far produced two studies to date; 'How hydrogen empowers the energy transition' (January 2017) exploring the role of hydrogen in the energy transition, including its potential, recent achievements, and challenges to its deployment, and 'Hydrogen, scaling up' (November 2017), presenting a comprehensive vision of the long-term potential of hydrogen as well as a road map for its employment.

The Council envisages that hydrogen will provide 18% of global energy demand by 2050, reducing global CO_2 emissions by 6 gigatonnes. It proposes doing this by focusing on seven key areas in which hydrogen can make an impact;

- enabling large-scale renewable energy integration and power generation
- distributing energy across sectors and regions
- acting as a buffer to increase energy system resilience
- decarbonising transportation
- decarbonising industrial energy use
- helping to decarbonise building heat and power
- providing clean feedstock for industry.

Transportation

In the transportation sector, hydrogen-powered fuel cell vehicles could complement battery electric vehicles to achieve applications with longer range requirements, heavier payloads, and a high need for flexibility (shorter refuelling times, for example). These segments consume a large share of total energy – the Council argues that while trucks and buses might account for only 5% of all fuel cell vehicles in 2050, they could achieve more than 30% of hydrogen's total CO_2 abatement potential in the transport sector. Environmentally, fuel cell vehicles produce 20-30% lower emissions than conventional cars even when hydrogen is produced from natural gas without carbon capture, but of course produce essentially zero emissions when using hydrogen from renewable sources.

The Hydrogen Council is aiming for 1 in 12 cars sold in California, Germany, Japan, and South Korea to be powered by hydrogen by 2030, when sales start ramping up in the rest of the world. This would involve more than 350,000 hydrogen trucks and 50,000 hydrogen buses, as well as potentially thousands of trains and passenger ships. Further out, the aim is for hydrogen to become a feedstock for renewable fuels for commercial aviation and freight shipping.

Chemicals

Large amounts of hydrogen are used as feedstock for refining and the production of ammonia and methanol. Here the Hydrogen Council argues that "with the right regulatory framework, the first oil refineries and ammonia plants could produce hydrogen from clean sources in 2030". It also proposes using hydrogen with captured carbon or carbon from biomass to replace fossil fuels as feedstock for the chemical industry, with 10-15 million t/a

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of chemicals being produced by renewable feedstock by 2030. In the iron and steel industry, where hydrogen can be used to reduce iron ore to iron, it expects the use of clean hydrogen to be demonstrated by 2030 and gain momentum by 2035.

Heat and power

For heat and power for buildings and industry, hydrogen can make use of existing gas infrastructure and assets. Indeed, hydrogen has long been used as a domestic heating fuel – the 'town gas' that municipal gasworks produced in the first half of the 20th century from coal was a mixture of roughly 50% hydrogen by volume, 30% methane and the remainder mostly carbon monoxide and dioxide. The Council is arguing that this kind of blending of hydrogen into existing natural gas networks can be done with no need for any infrastructure upgrades. Alternatively, entire cities could be converted to pure hydrogen heating. Both processes have already started and could start scaling up around 2030, with the equivalent of more than 5 million households connected to a gas network with blended or pure hydrogen. A second wave of commercialization could start once the costs of producing hydrogen have fallen enough to drive uptake in more cost-sensitive industry segments. While hydrogen penetration may not reach the same rates in industry as in other segments, industry's large energy consumption implies substantial hydrogen demand beyond 2050. By 2030, up to 200 steel, chemical, and automotive plants could be pioneering the use of hydrogen for heat and power.

Of course the Council also assumes that hydrogen will play a role in the storage of renewable electricity and the production of clean electricity. By 2030, it envisages 250-300 TWh of surplus renewable electricity being stored in the form of hydrogen for use in other segments.

How to get there

This plan is an ambitious one. Building the hydrogen economy would require annual investments of $20-25 billion (a total of about $280 billion) until 2030. About 40% ($110 billion) of this investment would go into the production of hydrogen, about one third ($80 billion) into storage, transport, and distribution, and about a quarter ($70 billion) into product and series development and scale-up of manufacturing capacity. The remainder, some $20 billion, would go into new business models, such as fuel-cell-powered taxi fleets and car sharing, on-demand transportation of goods, and contracting of combined heat and power units.

However, the Hydrogen Council also acknowledges that industry would have to bring down the cost of hydrogen production from renewables through scale. Significant cost reductions have already been achieved in some areas; the cost of refuelling stations and fuel cell stack production have been cut in half in the last ten years, for example (fuel cells have actually come down in price by 80% since the turn of the century). However, further cost reductions are also necessary to bring down the cost of hydrogen itself. These are possible through cost reductions in the hydrogen production and renewable power generation for electrolysis.

Cost of hydrogen

The vision is a grand one, to be sure, but is it achievable? Producing renewable hydrogen at a reasonable cost is the key to decarbonisation strategies. At the moment, the cost of hydrogen from renewables can be up to 6-7 times as expensive as producing it from steam reforming. However, there are signs that this may be changing. A recent article in *Nature* argues that the recent sharp decline in the cost of renewable energy suggests that the production of hydrogen from renewable power will become more economical. The authors argue that renewable hydrogen is already cost competitive in niche applications and, within a decade will also become so at an industrial scale, with the cost of hydrogen falling to €2.50/kg, or around 6.3 Euro cents per kWh.

> **"At the moment, hydrogen is not commercially competitive in most potential applications.**

DNV, in a recent research paper called 'Hydrogen in the electricity value chain' also found that hydrogen produced from electrolysis will be competitive with natural gas by 2035, due to continuing reductions in the cost of electrolysers, the rise of time periods when low or zero cost prices for electricity are available due to the rise of renewables, and increases in carbon taxes and other emissions penalties. The company's previous Energy Transition Outlook forecasts that solar photovoltaic, wind energy and hydropower will account for 80% of global electricity production in 2050.

However, in the interim, costs remain high, and if the Hydrogen Council's ambitious targets are to be achieved, governments may need to provide the bridge from the present to the future. The UK's Parliamentary Committee on Climate Change concluded in November 2018: "At the moment, hydrogen is not commercially competitive in most potential applications. This is likely to continue unless and until costs can be driven down, including through deployment at scale. Continuation of an incremental approach that relies on isolated, piecemeal demonstration projects may lead to hydrogen continuing to remain forever an option 'for the future'.

"Without taking near-term action to deploy hydrogen, it is difficult to see how the infrastructure and costs challenges will be addressed to enable it to play an important part in decarbonisation by 2050. This means starting deployment of hydrogen in a 'low-regrets' way in the 2020s, recognising that even an imperfect start is likely to be better in the long term than a 'wait-and-see' approach that fails to develop the option properly."

The role of syngas

Currently 95% of hydrogen produced (outside of the ammonia and methanol industry) comes from fossil fuels, about 50% of this is produced from natural gas, 30% from partial oxidation of crude oil and 18% from gasification of coal and other heavy feedstocks. Only around 4% of hydrogen production currently comes from water electrolysis. But how will this change in future? For the next decade or more steam reforming will continue to be the dominant factor in hydrogen production. Even Japan's move to a 'hydrogen economy' – the country is looking at importing 900,000 t/a of hydrogen by 2030 – is currently still financing a coal gasification-based project in Australia. Small scale gasification of biomass and municipal waste are growing applications, and no doubt will form part of the mix going forward. In the long term, it seems likely that most hydrogen will be produced from electrolysis. But how we get from here to there is still not clear, and in spite of the financial muscle of the Hydrogen Council, it is likely to require concerted governmental level action if it is to be achieved in the next couple of decades. ■

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Nitrogen project listing 2019

Nitrogen+Syngas's annual listing of new ammonia, urea, nitric acid and ammonium nitrate plants shows that the key areas for new project developments are India, Nigeria, Russia and central Asia, while the surge of new capacity in the United States is now coming to its end. Iran's considerable pipeline of new projects must now face renewed US sanctions, while Chinese capacity faces gas supply restrictions and pollution controls. New projects have also been announced in Australia, with feasibility studies in several countries including Nigeria, Oman and the Republic of Congo.


PHOTO: OCI NITROGEN

OCI Nitrogen's Geleen site.

Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
AUSTRALIA							
n.a.	n.a.	Australian Future Energy	Yarwun, QLD	Ammonia	1,000	P	2022
SNC Lavalin	Haldor Topsoe	Perdaman	Karratha, WA	Ammonia	3,500	CA	2023
SNC Lavalin	Stamicarbon	Perdaman	Karratha, WA	Urea	6,000	CA	2023
AZERBAIJAN							
Samsung	Haldor Topsoe	SOCAR	Sumgait	Ammonia	1,200	C	2019
Samsung	Stamicarbon	SOCAR	Sumgait	Urea	2,000	C	2019
BANGLADESH							
MHI, CNCIC	Saipem, TKFT	BCIC	Polash	Urea	2,800	BE	2022
BELARUS							
thyssenkrupp I.S.	thyssenkrupp I.S.	Grodno Azot	Grodno	Nitric acid	1,200	UC	2019
thyssenkrupp I.S.	thyssenkrupp I.S.	Grodno Azot	Grodno	UAN	3,395	UC	2019
BRUNEI							
thyssenkrupp I.S.	thyssenkrupp I.S.	Brunei Fertilizer Ind.	Sungai Liang	Ammonia	2,200	UC	2021
thyssenkrupp I.S.	Stamicarbon, TKFT	Brunei Fertilizer Ind.	Sungai Liang	Urea	3,900	UC	2021
CHINA							
n.a.	Casale	Hubei Yunhuaan Chem Co	Wuxue	Ammonia	1,200	UC	2020
n.a.	Casale	Hubei Sanning Chem Co	Yichang, Hubei	Ammonia	2,020	UC	2020
n.a.	Casale	Yichang Xingjiang	Yichang, Hubei	Ammonia	1,250	UC	2019
n.a.	Casale	Hubei Yihua Fert	Yichang, Hubei	Ammonia	1,820	UC	2019
n.a.	Casale	Henan Jindadi Chem	Luohe, Henan	Ammonia	1,800	UC	2019
Wuhuan Engineering	Stamicarbon	Inner Mongolia Huajin	Panjin	Urea	2,860	C	2018
China Chengda	Stamicarbon	Inner Linggu CICL	Jiangsu	Urea	n.a.	RE	2018
Hualu Engineering	Stamicarbon	Jiujiang Xinlianxin	Jiujiang, Jiangxi	Urea	2,330	UC	2020
Wuhuan Engineering	Stamicarbon	Hubei Sanning	Hubei	Urea	2,330	UC	2021
EGYPT							
Tecnimont	KBR	Kima	Aswan	Ammonia	1,200	C	2018
Tecnimont	Stamicarbon	Kima	Aswan	Urea	1,575	C	2018
thyssenkrupp I.S.	thyssenkrupp I.S.	Egypt Hydrocarbon	Suez	Nitric acid	850	C	2018
thyssenkrupp I.S.	thyssenkrupp I.S.	Egypt Hydrocarbon	Suez	Ammonium nitrate	1,050	C	2018
GERMANY							
SKW Piesteritz	Stamicarbon	SKW Piesteritz	Lutherstadt	Urea	960	RE	2018
HUNGARY							
n.a.	Casale	BorsodChem	Kazincbarcika	Nitric acid	660	UC	2020
INDIA							
TEC	KBR	Chambal Fert & Chem	Gadepan	Ammonia	2,200	C	2019
TEC	TEC	Chambal Fert & Chem	Gadepan	Urea	2 x 2,000	C	2019
Engineers India Ltd	Haldor Topsoe	RCFL	Ramagundam	Ammonia	2,200	UC	2019
Engineers India Ltd	Saipem	RCFL	Ramagundam	Urea	3,850	UC	2019
n.a.	Casale	Zuari AgroChem	Goa	Ammonia	1,050	RE	2020
TechnipFMC/L&T	Haldor Topsoe	HURL	Sindri	Ammonia	2,200	DE	2021
TechnipFMC/L&T	Saipem	HURL	Sindri	Urea	3,850	DE	2021
TechnipFMC/L&T	Haldor Topsoe	HURL	Barauni	Ammonia	2,200	DE	2021
TechnipFMC/L&T	Saipem	HURL	Barauni	Urea	3,850	DE	2021
n.a.	KBR	HURL	Gorakhpur	Ammonia	2,200	DE	2021
n.a.	TEC	HURL	Gorakhpur	Urea	3,850	DE	2021
n.a.	Casale	Deepak Fertilizers	Paradip	Nitric acid	970	BE	2021
n.a.	KBR	Deepak Fertilizers	Taloja	Ammonia	1,500	UC	n.a.
n.a.	n.a.	Talcher Fertilizers	Talcher	Ammonia	2,200	P	2022
n.a.	n.a.	Talcher Fertilizera	Talcher	Urea	3,800	P	2022
INDONESIA							
TEC	KBR	PAU	Sulawesi	Ammonia	1,900	C	2019
n.a.	thyssenkrupp I.S.	Bakrie	Kalimantan	Nitric acid	750	DE	On hold
n.a.	thyssenkrupp I.S.	Bakrie	Kalimantan	Ammonium nitrate	900	DE	On hold
IRAN							
Hampa	Casale	Lordegan Petrochemical	Lordegan	Ammonia	2,050	C	2018
Hampa	Stamicarbon	Lordegan Petrochemical	Lordegan	Urea	3,250	C	2018
PIDEC	Casale	Masjid Soleyman	Masjid Soleyman	Ammonia	2,050	UC	On Hold
PIDEC	n.a.	Masjid Soleyman	Masjid Soleyman	Urea	3,250	UC	On Hold
Hampa	Casale	Zanjan Petrochemical	Zanjan	Ammonia	2,050	UC	2020
Hampa	Stamicarbon	Zanjan Petrochemical	Zanjan	Urea	3,250	UC	2020
Namvaran	KBR	Kermanshah Petchem	Kermanshah	Ammonia	2,400	UC	On Hold
Namvaran	Stamicarbon	Kermanshah Petchem	Kermanshah	Urea	4,000	UC	On Hold
PIDEC	Haldor Topsoe	Hengan Petrochemical	Assaluyeh	Ammonia	2,050	UC	2021
PIDEC	Saipem, TKFT	Hengam Petrochemical	Assalyueh	Urea	3,500	UC	2021
ISRAEL							
n.a.	KBR	Haifa Chemical	Mishor Rotem	Nitric acid	240+147	RE	2019
MEXICO							
Proman	KBR	GPO	Topolobampo	Ammonia	2,200	CA	n.a.
NETHERLANDS							
OCI Nitrogen	Stamicarbon	OCI Nitrogen	Geleen	Urea	n.a.	RE	2019

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P: Planned/proposed
RE: Revamp
UC: Under construction
Conversion:
1 t/d of hydrogen = 464 Nm^3/h
1 t/d of natural gas = 1,400 Nm^3/d

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Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
NIGERIA							
TEC	KBR	Indorama	Port Harcourt	Ammonia	2,400	UC	2021
TEC	TEC	Indorama	Port Harcourt	Urea	4,000	UC	2021
Saipem	Haldor Topsoe	Dangote Fertilizer Ltd	Agenbode	Ammonia	2 x 2,200	UC	2019
Saipem	Saipem/TKFT	Dangote Fertilizer Ltd	Agenbode	Urea	2 x 3,850	UC	2019
OMAN							
SNC Lavalin	Linde/Haldor Topsoe	Salalah Methanol	Salalah	Ammonia	1,000	UC	2020
POLAND							
thyssenkrupp I.S.	thyssenkrupp I.S.	Grupa Azoty	Pulawy	Nitric acid	1,000	UC	2021
thyssenkrupp I.S.	thyssenkrupp I.S.	Grupa Azoty	Pulawy	Ammonium nitrate	1,300	UC	2021
RUSSIA							
Tecnimont	Stamicarbon	KuibishevAzot	Togliatti	Urea	1,500	BE	2020
GIAP	Casale	KuibishevAzot	Togliatti	Nitric acid	1,350	BE	2021
GIAP	Casale	KuibishevAzot	Togliatti	Ammonium nitrate	1,500	BE	2021
NIIK	Casale	JSC Metafrax	Gubakha	Ammonia	1,000	UC	2020
NIIK	Casale/MHI	JSC Metafrax	Gubakha	Urea	1,700	UC	2021
Tecnimont	KBR	EuroChem	Nevinnomyssk	Ammonia	2,700	BE	n.a.
Casale	Casale	EuroChem	Nevinnomyssk	Urea	1,600	RE	2019
Casale	Casale	Togliatti Azot	Togliatti	Urea	2,200	UC	2021
Tecnimont	KBR	EuroChem	Kingisepp	Ammonia	2,700	UC	2019
n.a.	KBR	Acron	Dorogobuzh	Ammonia	2,100	RE	2019
n.a.	Stamicarbon	Uralchem	Perm	Urea	+770	RE	2019
n.a.	KBR	Kemerovo Azot	Kemerovo	Nitric acid	500	DE	2021
NIIK	Stamicarbon	Acron	Novgorod	Urea	2,000	UC	2020
n.a.	Stamicarbon	EuroChem	Novomoskovsk	UAS	600	UC	2019
SAUDI ARABIA							
Al Jubail Fert Co	Stamicarbon	Al Jubail Fert Co	Al Bayroni	Urea	n.a.	RE	2019
Daelim	thyssenkrupp I.S.	Ma'aden	Ras al Khair	Ammonia	3,300	UC	2022
TURKMENISTAN							
MHI/Gap Insaat	Haldor Topsoe	Turkmenkhimiya	Garabogaz	Ammonia	2,000	C	2018
MHI/Gap Insaat	Saipem/TKFT	Turkmenkhimiya	Garabogaz	Urea	3,500	C	2018
UNITED KINGDOM							
n.a.	JM	CF Industries	Billingham	Ammonia	1,500	RE	2020
UNITED STATES							
IHI	Stamicarbon	Dakota Gasification	Beulah, ND	Urea	1,000	C	2018
Black & Veatch, KBR	Stamicarbon	Koch Nitrogen	Enid, OK	Urea	2,200	C	2019
KBR	KBR	BASF/Yara	Freeport, TX	Ammonia	2,270	C	2018
PCS Nitrogen	Stamicarbon	PCS Nitrogen	Geismar, LA	Urea	+250	RE	2019
thyssenkrupp I.S.	KBR	Cronus Chemical	Tuscola, IL	Ammonia	2,200	CA	n.a.
thyssenkrupp I.S.	Stamicarbon	Cronus Chemical	Tuscola, IL	Urea	3,850	CA	n.a.
UZBEKISTAN							
MHI	Haldor Topsoe	NavoijAzot	Navoij	Ammonia	2,000	UC	2019
MHI	Saipem, TKFT	NavoijAzot	Navoij	Urea	1,750	UC	2019
n.a.	Casale	NavoijAzot	Navoij	Nitric acid	1,500	UC	2020

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Platinum catalyst deactivation

Sumit Rao, **Dr. Jürgen Neumann** and **Sachin Balip** of Hindustan Platinum Ltd discuss processes leading to the deactivation of precious metal catalyst gauzes in nitric acid plants, and ways of remediating them.

Under extreme operating conditions in the ammonia oxidation process, platinum alloy catalyst gauzes are exposed to a number of destructive influences, including temperature, pressure, the presence of impurities, etc. During operation, the wire surface is morphologically and chemically altered after a short period, resulting in considerable precious metal losses. These factors result in the ageing process, i.e., the decline of the activity of the precious metal catalyst.

Apart from the usual ageing process, wherein the formation of precious metal oxides eventually lead to the decline of the catalytic yield, this phenomenon could have manifold representations, e.g.:

- Interaction of alloy constituents during process ambient changes resulting active site alterations
- Interaction with impurities/inhibitors that may result in the alteration/blanketing of active sites
- Interaction with contaminants/poisons that causes increase in the rate of the side reactions
- Interaction with certain substances which make the catalyst surface mechanically weak

Most of the above undesirable changes in the catalyst occur frequently and increase in severity during operating period, finally leading to deactivation. The decrease in the catalyst working life is a subject requiring thorough investigation, especially owing to the limited availability/high cost of precious metals.

Catalyst deactivation

All catalysts may become deactivated by certain substances that chemisorb on to their active sites more strongly than the molecules that are intended to react there.

Fig. 1: **Catalytically active surface (magnification x300)**

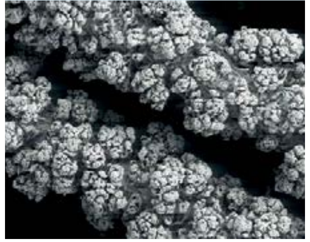
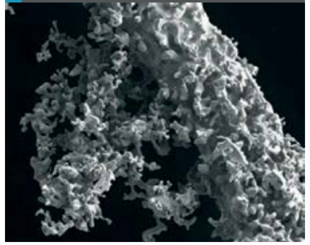


Fig. 2: **Catalytically deactivated surface (magnification x300)**



Like all catalysts, platinum gauzes are sensitive to catalytic contamination. When the catalyst surface is chemically attacked by contaminants present in the reactants, the rate and yield of the reaction will decline or even diminish to nil. It is therefore very crucial to exclude any potentially harmful contaminants from the reactants.

The mechanism of catalyst deactivation is therefore the retardation of the activation process, and/or the alteration/blocking of active sites, mechanically or by chemical processes. Figure 1 shows a catalytically active surface, and Figure 2 a similar deactivated surface.

Alteration/blanketing of active sites

The activity of platinum gauzes used in ammonia oxidation may drastically decrease in the presence of impurities such as, Fe, Zn, Au, Cu, Mg, Mn, etc., which act as catalyst poisons and adversely affect the active sites, rendering the ammonia conversion selectivity and in turn the product yield abnormal; while certain contaminants may cause blanketing of the active gauze surface.

Even with optimum alloying, prudent design and robust morphological structures, the catalyst system would be able to resist the harsh effects of the poisoning elements only for a certain operating period up to a certain level of contamination. Thereafter as the ageing progresses, the negative effects of the contaminants adversely affect the chemical processes by irreversibly binding with the intermediate products of reaction and/or with the alloying material itself, and thus accelerate the catalysis process towards its end of campaign earlier than designed. Therefore, the source of the contaminants must be addressed for the optimum performance of catalytic systems.

The main source for iron contamination can probably be traced back to the ammonia feed, received from an upstream manufacturing process or a reservoir where ammonia is stored. Iron oxide, in the form of plant scale blown onto the gauze pad by the rapidly flowing gases, has also been shown to be responsible for a decline in nitric oxide yield. Ammonia produced from non-synthetic sources, such as coke oven liquors, can contain high concentrations of sulphur, arsenic and other base metal impurities.

Aluminium, calcium, magnesium, and silicon most frequently come from filter and gasket materials. During removal of the gauzes from the converter, particles of the gasket material may fall down and accumulate in the basket or on the downstream heat exchanger/equipment. In the case of pressure variation, these particles could enter the catalyst when there is back flow. On the other hand, in case of damage to the heat exchanger downstream of the catalyst, the steam pressure may be high enough to allow impurities to reach the catalyst plane against the direction of reactant flow, probably leading to alteration to or blanketing of a gauze catalyst surface.

Fig. 3: **Scanning electron micrograph of reconstruction of the wire surface during operation (magnification x800)**

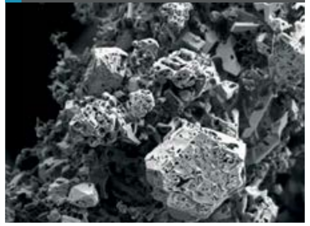


Fig. 4: **Scanning electron micrograph of Rh_2O_3 needle crystals (magnification x200)**

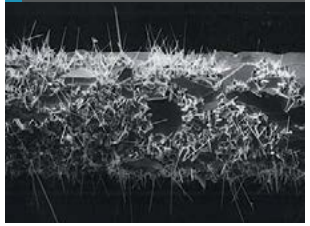
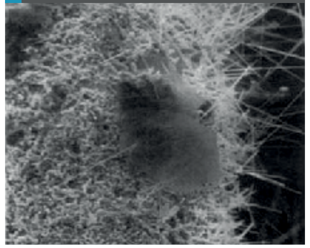


Fig. 5: **Section of Figure 2 (magnification x2000)**



A gradual decrease of NO-selectivity can likely be traced back to insufficient filtration. Often this situation is observed after the filters have been changed. In front of and/or behind the filters there are often dead zones for the gas stream where particles can accumulate. Sometimes, due to insufficient sealing across the filtration system, particle entrainment can be observed. These particles could enter the reactor with the pressure surge during start-up of the converter.

Besides these, operating under too low a temperature, especially during start-up, may lead to alteration in the catalyst's structural composition; for example, the formation of Rh_2O_3 has been widely documented. This in turn – in the presence of certain contaminants such as iron – could lead to the formation of so-called Fe-/Rh-agglomerates, which are a cause of catalytic deactivation.

Uncommon processes and common contaminants

Some uncommon processes, in the presence of common contaminants, can result in alteration/blanketing of the active sites during plant operations.

Fig. 6: **Section of Figure 2 (magnification x4000)**

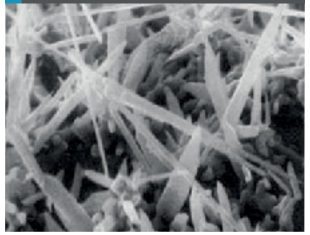
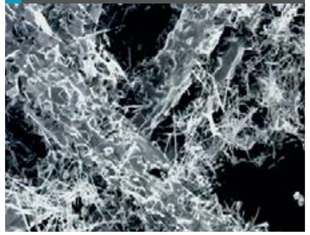


Fig. 7: **Section of Figure 2 (magnification x4000)**



a) Platinum/rhodium surface reconstruction and rhodium oxide (Rh_2O_3) formation

When the gauzes are fully operating at their normal working temperature, the surface of the gauzes is strongly roughened after a short period, resulting in considerable platinum losses. This metal loss rate contributes significantly to plant operating costs and is highly dependent on the gauze temperature. A tenfold increase in the metal loss rate occurs when the operating temperature rises from about 820°C to 920°C. Oxygen is firmly believed to play a role in this, since the losses increase with increasing oxygen partial pressure. The interaction of oxygen molecules with the surface of the metal is believed to be the major cause of the restructuring of the surface. The formation of gaseous PtO_2 is regarded as the major source of losses.

Ammonia oxidation gauzes undergo extensive surface restructuring during their operating lifetime. For the restructured surface of the catalyst wires two types of different crystalline phases are distinguishable; an octagonal crystal structure can be seen in Figure 3, as well as the development of nodules with extended faceting and highly porous particles. Rhodium enrichment of catalyst gauze occurs as a consequence of the loss of platinum from the catalyst surface. Platinum oxidises and volatilises at high temperatures in oxidising atmospheres. Rhodium also oxidises, but does not volatilise as readily, thus resulting in a natural enrichment of rhodium, which is mainly responsible for the deactivation of the gauze.

Extensive formation of Rh_2O_3 is a highly undesirable situation because it may lead to complete deactivation of the catalyst. Whiskers and grain-like structures of Rh_2O_3 become visible at the core of the wire. A Pt-Rh catalyst gauze with a large concentration of needles have been examined using x-ray diffraction and scanning electron microscopy and confirm the presence of rhodium oxide, as shown in Figure 4. Figure 5, 6 and 7 are closer views of different aspects of the needle structures which can be seen on deactivated gauzes at high magnification.

Rhodium oxide formation on a Pt/Rh-alloy is known to be likely to occur between 550-750°C, and varies depending on plant operating conditions. Research studies have shown the effect of rhodium additions to platinum on catalytic activity, and observed that pure rhodium by itself only gives 80% conversion efficiency. It

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Fig. 8: **Deactivated catalyst surface by iron contamination**

Fig. 9: **Energy-dispersive x-ray spectroscopy/mapping (EDX) of a surface deactivated by iron**

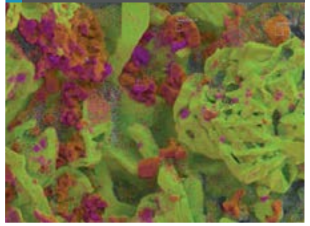

Fig. 10: **EDX spectroscopy/mapping of a surface deactivated by carbon**

Fig. 11: **SEM of Ca-contaminated Pt-Rh wire (magnification x200)**

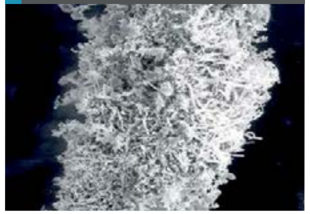

Fig. 12: **SEM of Mg-contaminated Pt-Rh wire (magnification x200)**

is inferred that the large amounts of non-volatile oxides which form will probably obstruct the active chemisorbed layer of oxygen and thus strongly inhibit the reaction of ammonia with oxygen.

When running at low temperatures, diffusion processes will ensure that the surface composition moves automatically towards pure rhodium; the rhodium oxidised at the surface being continuously replaced from inside the wire by diffusion. A rhodium oxide layer of sufficient thickness will act in the same manner as a pure rhodium surface and prevent access to the catalyst surface for the reactants and give a reduced yield.

b) Iron contamination and effects

In the manufacture of nitric acid, one of the most common causes of low catalyst performance is the deposition of iron on the gauze surface. Iron oxide is used as an ammonia synthesis catalyst and is therefore equally capable of catalysing the reverse reaction; the decomposition of ammonia to nitrogen and hydrogen. Iron/iron oxide is also formed as a result of the presence of iron in the mild steel components within the flow stream, which are prone to oxidation and rust formation.

Iron promotes the formation of rhodium oxide in its non-volatile form, Rh_2O_3. Iron compounds also combine with the Rh_2O_3 formed on the surface and result in the formation of isolated agglomerates. Figure 8 shows a catalyst surface deactivated by iron contamination.

In Figure 9, platinum, rhodium and iron compounds are colour coded, with platinum being green, rhodium orange and iron characterised by a violet colour. The EDX mapping shows a significantly presence of Fe-/Rh- agglomerates on the wire surface, mainly in the recesses of the faceted surface.

Such an accumulation of agglomerates along the grain boundaries in the initial stage of the development of the catalyst surface means that the migrating platinum accumulates at less exposed, energetically unfavourable sites and cannot form an optimally active surface structure. The distribution of the agglomerates of the iron/rhodium mixed oxides shows a relatively high accumulation at the cauliflower crystal growths and this also suppresses the re-crystallisation of the wire surface.

As a result, the NO-selectivity remains at a relatively low level and decreases at an accelerated rate as the campaign progresses. The lower NO-selectivity results in higher heat generation by side reactions, in particular on the iron/rhodium agglomerates at which so-called ‘hot spots’ occur. This in turn leads to a higher formation of volatile platinum oxide. However, during decomposition in the gas phase, it is not possible to deposit these on the cauliflower-like growths, since these growths could develop only later.

c) Carbon contamination and effects

Another example is given below in Figure 10, where it becomes obvious from the EDX spectrum that in addition to the iron/rhodium mixed oxide agglomerates, partial coverage of the surface with carbon occurs. In the Figure, as in Figure 9, platinum, rhodium, iron and carbon compounds are colour coded, with platinum being green, rhodium orange, iron violet and carbon characterised by a blue colour. Although, the effects of carbon contamination have not been researched and studied in detail, as they are uncommon, they are believed to temporarily raise the gauze temperature by way of exothermic reactions to form CO_2. Thereafter, the gauze surface is assumed to have recovered with partial loss of active sites in the vicinity.

d) Aluminium, calcium and magnesium

Oxides of aluminium, magnesium and calcium are frequently considered to be present as dust in the combustion air which can deposit on the catalyst gauze. It is quite possible that these oxides cause damage not only as a result of their partially covering the catalyst surface, but also as a result of them combining with the Rh_2O_3 formed on the surface of the wires. In this way they may substantially reduce the oxygen potential of the Rh_2O_3 and perhaps lead to a reduction in yield (Figs. 11 and 12).

e) Silica/silicates contamination

Silicon is known to be troublesome contaminant when present in the platinum alloy. Silicon is seen to drastically reduce the melting point of platinum, to a minimum of 830°C, by way of the formation of a eutectic composition between platinum and silicon. The practical implication of this is that even at low silicon content; a liquid phase will be present in the platinum at its normal operating temperature and can lead to premature failure. Scrupulous care is therefore necessary to avoid contamination by siliceous material.

General remedial measures

The further use of poisoned gauzes always depends on the degree of contaminations. A defined recommendation without an analysis of the gauzes is hardly possible, but analysis and any corresponding recommendation can be carried out immediately after receiving a gauze sample of the affected area. Included below is some more general information about a few of the methodologies as damage control measures. It must be considered that these procedures probably result in higher primary losses, making them economically non-viable; however, they can be promising for short term emergencies.

a) Gauze cleaning

If a new set of gauze pack is not immediately available, carefully brush the gauzes to remove particles from the surface. On examination of the gauzes, if the top few layers are found to be brittle and weakened they may have to be removed from the pack. The rest of the pack is then to be pickled in dilute hydrochloric acid (20%) for approximate 30 minutes up to two hrs and at a temperature of 60°C, depending on the degree of contamination, to remove catalyst poisons, particularly ferric oxide which will have accumulated on the gauze during operation, in a special room set aside for the purpose. After washing with distilled water to remove all acid/salts deposited on the surface, the gauzes must be carefully dried.

Examination of used and Rh_2O_3 contaminated gauzes after the gauze cleaning procedures has shown that the fusion mixture normally used removes iron oxide, but has little effect on rhodium oxide. Similarly, rinsing in hydrochloric acid will not change the behaviour of this type of surface since the oxides of rhodium are insoluble even in the boiling acid. Since the Rh_2O_3 coating arises by rhodium oxidation, the process should be theoretically reversible. Indeed for certain cases, this was accomplished by carefully heating to avoid damage to the gauzes, in hydrogen to reduce the oxide to metal, or in nitrogen to dissociate to metal and oxygen. However, for cases with suspected metal-/Rh- agglomerates, the contamination effects may not be reversed.

b) Replacement of the top gauze catalyst

In case of a scenario where impurities are entering the reactor and catalyst pack through the feed gas flow, the contaminations will be found with a decreasing gradation on the top gauze layers of the catalyst pack. Under these circumstances, replacement of a number of gauzes from the top of the catalyst gauze pack may result in mild to distinct improvement in the product yield, depending upon the effectiveness of the layer replaced. The replacement of the number of layers may depend on the degree and type of contamination and/or plant operating conditions.

c) Inversion from top to bottom

In case of low grade contamination, a distinct improvement of catalytic performance might be reached by inverting the complete pack of catalyst gauzes. However, owing to advances in the gauze pack designs, where the pack is customised/tailored for optimum performances, the flipping process may prove more detrimental rather than a boon. ■

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PGM prices impacting primary gauze technology

Johnson Matthey demonstrates its expertise in optimisation of PGM based ammonia oxidation catalysts for current market conditions. By developing more sophisticated gauze pack systems, it has been possible to reduce PGM metal weight and therefore nitric acid productions costs, whilst lowering N_2O emissions and increasing conversion efficiency.

Nitric acid catalysts, used for ammonia oxidation, are made from platinum group metals (PGMs). PGMs are used in bespoke gauze pack systems that are made to meet specific customers' requirements, providing excellent conversion efficiency and optimum weight, whilst minimising N_2O emissions and metal losses.

In 2016, Johnson Matthey celebrated its 100th year of manufacturing platinum-based catalytic gauzes for use in the production of nitric acid by the Ostwald process. Advances in technology and on-going development have resulted in a complex catalyst system, which uses a blend of binary and tertiary alloys of platinum, rhodium and palladium. Using gauze systems made of these alloys, ammonia oxidation takes place as ammonia is combusted across the gauze at the nitric acid plant burner.

Fig. 1 shows a HICON™ (a Johnson Matthey trademark) corrugated PGM gauze pack that has been specifically designed for a nitric acid plant operating with a high burner pressure. HICON corrugated systems are proven to improve gauze performance and reduce pressure drop on arduous duties with high nitrogen loading.

Depending on customer drivers, each bespoke gauze pack is made to meet specific requirements, providing excellent conversion efficiency and reduced pack weight whilst minimising N_2O emissions and metal losses. As shown in Fig. 2, by developing more sophisticated gauze pack systems, it has been possible to reduce PGM metal weight, to lower N_2O emissions and to increase conversion efficiency – this allows customers to achieve and maintain high levels of efficiency thus helping to reduce production costs.

Effect of platinum and palladium prices

In recent years, market pressures have resulted in a change in the relative prices of platinum and palladium. In late 2017, the price of palladium overtook platinum. Since then the price differential between the two metals has continued to increase (see Fig. 3).

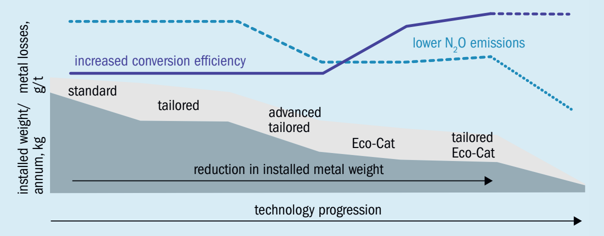
In 2018, global platinum demands declined and although there was no large growth in primary mined supplies of platinum processed from fresh ore there was significant growth in supplies of recycled platinum, with larger volumes of spent autocatalysts being collected and reprocessed. This resulted in the market moving further into surplus. The outlook for 2019 is that the market will remain in surplus.

In contrast, the palladium market remains in deficit, fuelled by record levels of autocatalyst demand. The deficit in the palladium market looks set to widen dramatically in 2019, with stricter emissions legislation forecast to stimulate double digit rises in palladium demand from European and Chinese car manufacturers. Although recoveries from autocatalyst scrap should rise again, the rate of growth in recycled secondary supplies of palladium is likely to be lower than in 2018, while it is expected that availability of fresh mined palladium supplies are expected to be flat. At the time of writing, the palladium price has continued to breach a series of all-time highs and lease rates remain exceptionally high.

PHOTO: JOHNSON MATTHEY

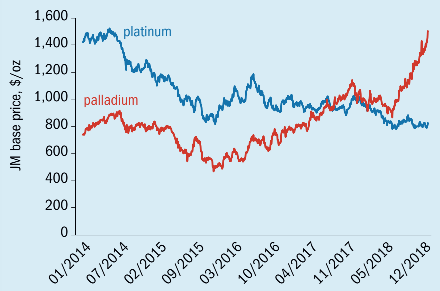
Fig. 1: HICON – PGM gauze pack for HP nitric acid plant.

Fig. 2: **Technology progression for PGM gauzes**



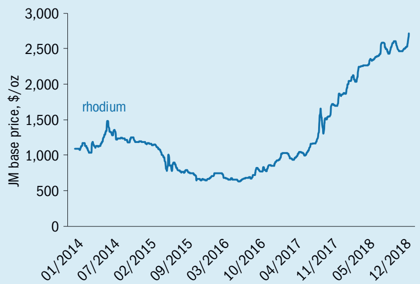
Source: Johnson Matthey

Fig. 3: **Five year PGM price trends for platinum and palladium**



Source: Johnson Matthey

Fig. 4: **Five year PGM price trends for rhodium**



Source: Johnson Matthey

Johnson Matthey's ECO-CAT™ technology offering, which is recommended for the majority of nitric acid plants, uses palladium in a controlled manner to replace some of the platinum in the gauze. Exploiting its metal recovery properties, the palladium catches lost platinum without compromising ammonia conversion efficiency. This improves overall performance – an increase in campaign length without any reduction in conversion efficiency and a reduction in N_2O emissions.

ECO-CAT packs are tailor-made for each individual plant, utilising in-house modelling to select the optimal blend of alloys and knit structures to suit both plant operating conditions and prevailing PGM prices. A successful design combines the properties of platinum and palladium to maintain high conversion efficiency and minimise N_2O emissions, with prevailing PGM market conditions and N_2O emission legislation influencing the final installed weight.

Catchment/getter efficiency

A fundamental component of the gauze pack is the palladium-based catchment or getter system. Through sacrificing palladium, volatilised platinum lost from the primary catalyst gauzes can be recovered. Recovery rates are dependent on the mass of palladium installed and vary from about 30% for high pressure plants to more than 90% for lower pressure plants.

Understanding the price differential of platinum and palladium and the ratio of platinum gained against palladium lost is critical for designing a profitable getter system. JM uses in-house modelling systems alongside empirical models of metal loss to calculate the most efficient getter system for each plant. The uppermost palladium layers are the most efficient in terms of the trade-off between platinum recovery and palladium loss. The overall ratio is dependent on catchment layer placement and primary platinum loss from the gauze (which in turn is dependent on plant operating pressure, temperature and nitrogen loading).

Even though palladium currently costs more than platinum, getter systems remain profitable for the majority of plants and are an effective way of reducing the cost of nitric acid production.

Effect of rhodium price

In addition to platinum and palladium, rhodium plays a key aspect in gauze design and performance. Despite the rhodium market being in surplus, the rhodium price climbed to an eight-year high of $2,600 in December 2018, with the trend continuing into 2019. Because rhodium is a small, illiquid market, any short-term misalignment between supply and demand can have significant consequences for the price and physical availability of the metal. In 2019, rhodium use in autocatalysts is forecast to grow strongly, as emissions limits and in-use testing become more stringent. Primary supplies will be flat, but further growth in recycling could again leave the market in surplus. This, however, masks the underlying tightness in the rhodium market.

Rhodium is installed primarily to increase the strength of platinum and palladium alloys but has been demonstrated to improve performance over that of a pure platinum ally. Due to the small proportion of rhodium installed in a typical gauze pack the increase in rhodium price (Fig. 4) has less of an impact than that of palladium. Nonetheless, development work is ongoing to introduce new alloy blends to reduce metal loss in addition to minimising the installed weight of rhodium and palladium.

Future development

There is a constant drive to maximise nitric acid plant efficiency which includes the challenges brought about by changing PGM prices. Through targeted R&D projects, Johnson Matthey remains committed to improving the performance of its catalyst and catchment systems.

Topics of focus include:

- improvements to the structure of our catchment systems;
- better prediction of metal losses;
- Increasing conversion efficiency;
- reducing N_2O. ■

Information on PGM market trends courtesy of Johnson Matthey Precious Metals Marketing Market Research. For further information on the PGM markets, please refer to JM's PGM Market Report published February 2019, available at www.platinum.matthey.com/services/market-research/pgm-market-reports.

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Expansion from the conventional to a multifunctional granulation design

Over the last 20 years Stamicarbon has been awarded 29 granulation plants covering a wide range of capacities. Today's challenge is the further expansion of the technology to a multi-functional granulation design, which is able to produce urea as well as specialty products like urea ammonium sulphate. **B. Cuchiella** of Stamicarbon recounts the history of the Stamicarbon urea granulation technology and describes the latest technology innovations.

The original Stamicarbon fluid bed granulation process and the film spraying nozzle were developed in the late 1970s. After the initial development activities, the technology was first implemented in a commercial test facility in 1998 at Grodno Azot plant, Belarus, where a small granulation unit was completely converted to the Stamicarbon process. After this successful introduction of the Stamicarbon granulation process, scaling up took place at the Agrium urea complex in Fort Saskatchewan, Canada, where two existing granulation lines of 625 t/d were converted to the Stamicarbon granulation process. The plant commenced granulation production in 2003 and is still performing very well to the satisfaction of the customer today. Following these successful revamps, the first grass root plant was started-up in June 2006 in Egypt. Originally designed with a capacity of 2,000 t/d, the plant was later revamped and currently runs at a capacity higher than 2,500 t/d.

Stamicarbon granulation features and advantages

Fig. 1: **Stamicarbon's film spraying nozzles**

The key to the success of the Stamicarbon urea granulation technology are the film spraying nozzles (Fig. 1), which build up the granules layer by layer. Before a new layer of liquid melt is applied on the seed particle, the previous layer on the particle is completely solidified.

Due to the characteristics of the film spraying nozzle, together with the fact that the Stamicarbon granulation process applies a 98.5% melt concentration, the granulation process results in an end product with excellent quality and properties.

Compared to other fluidised bed granulation processes, considerable opex savings are achieved due to a reduced formaldehyde content in the final product and the low dust formation which results in a granulation plant that can be operated for two to three months without any interruption for cleaning. The original Stamicarbon granulation process is shown in Fig. 2.

The product leaves the granulator at a temperature of 95°C and, after passing a lump screen, the remaining granules flow into a fluid-bed cooler, which reduces the temperature to 70°C. The product is then lifted by a bucket elevator to the classification section, which consists of a number of double-deck screens and a crusher.

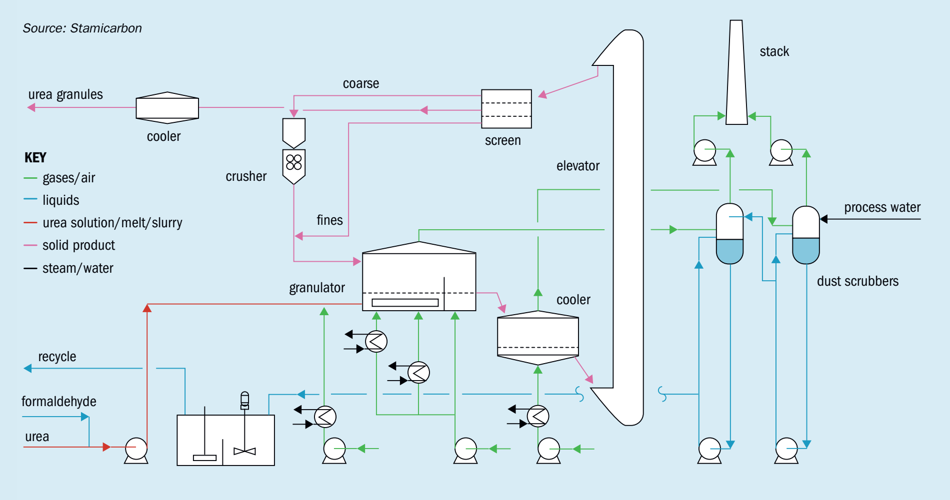
The fine recycle is combined with the crushed material, and the on-size product is sent to storage after further cooling to the storage temperature in a fluid-bed cooler. All air flows are treated to remove urea dust in two scrubbers: a granulator scrubber and a cooler scrubber. The wet recycle flow is concentrated to about 45% urea and recycled to the melt plant.

New developments

Simplified design

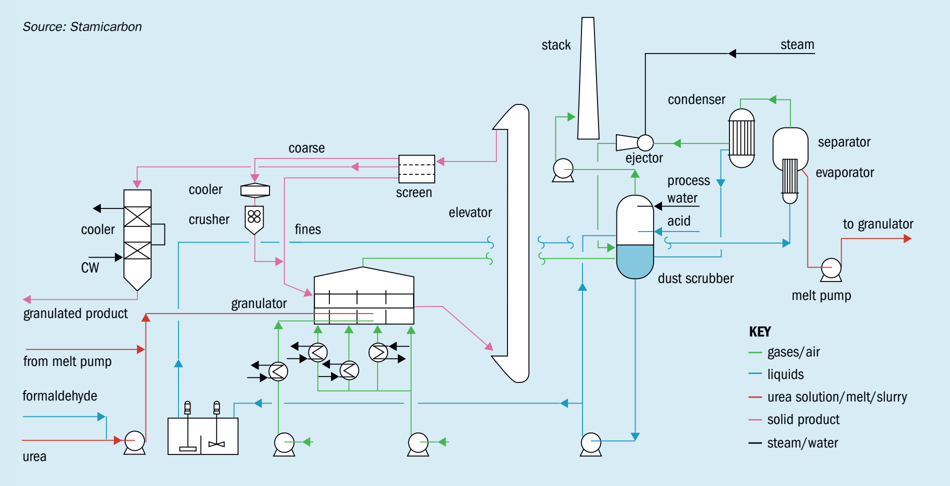
In 2008, Stamicarbon introduced a simpler granulation plant design concept without sacrificing the reliability of the Stamicarbon granulator with its high on-stream time. The simplified design is characterised by minimal number of equipment items, a reduced footprint (10-15%), and a reduction of capex and opex costs. The cost saving in power consumption of about 20% is mainly due to the omission of three fans.

Fig. 2: **Original Stamicarbon granulation process**



Source: Stamicarbon

Fig. 3: **Simplified Stamicarbon granulation process**



Source: Stamicarbon

The fluid-bed granulator cooler was omitted by increasing the length of the cooling zone in the original granulator and the fluid-bed product cooler was replaced by a solids flow cooler. In addition, the respective granulator cooler scrubber with all necessary pumps and fan were omitted.

The omission of this equipment leads to the simplified process flow diagram shown in Fig. 3.

The liquid melt is still fed to the granulator with a temperature of 140°C and a concentration of 98.5% urea plus biuret and, in the granulator, the bed temperatures in the compartment where liquid melt is injected are still maintained in the range 102-110°C, however, it differs from the original Stamicarbon design in the last stage where the end product is cooled down to 85°C.

After passing the lump screen, the product is lifted with a bucket elevator to the classification equipment. The complete solid product flows via gravity flow through the main screens. The coarse product is fed to the crusher after

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PHOTO: STAMICARBON

Fig. 4: Shahjalal melt and granulation plant in Bangladesh

PHOTO: STAMICARBON

Fig. 5: Large scale granulation plant

cooling to a temperature of 70°C. The crushed product and the fine recycle flow are combined and recycled to the granulator as so-called seeds. The on–spec product in the outlet of the main screens is cooled to storage temperature in a solid flow cooler which makes use of cooling water instead of cooling air.

The dust-loaded air from the granulator and all the de-dusting points is collected and fed to a single granulator scrubber.

The reduction of equipment items resulted in a significant reduction of the overall capital cost of the plant. The total capex cost reduction is not only achieved by eliminating equipment, but there are also savings in transportation (shipping) cost, cost of insurance, effect of reduced footprint, construction, etc.

Less equipment will also result in a reduction in maintenance costs and opex savings.

Furthermore, to reduce the amount of fluidisation cooling air, a water injection system is provided in the discharge of the fluidisation air fan. This is only operated on exceptionally hot days, to increase the relative humidity and to reduce the total air consumption as well.

The first granulation plant with this new design concept was a 1,760 t/d plant in Bangladesh, commissioned in 2015.

The Shahjalal experience

In 2011 Stamicarbon signed a 1,760 t/d melt and granulation licensing contract for the Shahjalal plant close to the city of Sylhet in Bangladesh, where the new simplified granulation design was implemented for the first time. The plant was successfully started up and was commissioned in 2015 (Fig. 4).

This granulation plant with minimum equipment demonstrates an investment saving of minimum 20%. It started up very easily and shows a very reliable and smooth operation with minimal operator attention required. The power consumption meets expectations and is 20% lower than in the conventional design and the maintenance costs are reduced by the elimination of three fans and all the other equipment. The product exceeds the standard commercial quality, even at formaldehyde levels lower than 0.30% in very humid ambient conditions.

After the experience in Bangladesh, several other plants with this simplified design have successfully been put in operation with different capacities all over the world.

Stamicarbon is continuing to focus on further improvements to lower capex and opex of the granulation plant.

Large scale granulation plant

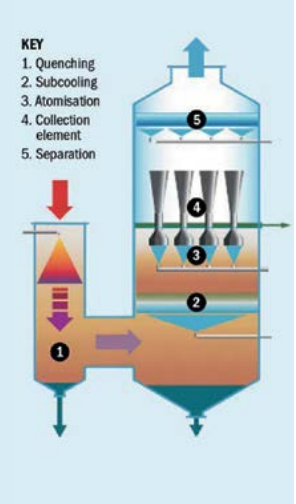
The next milestone was the start-up of Stamicarbon's largest licensed granulation plant in Assaluyeh, Iran with a capacity of 3,250 t/d (Fig. 5). The plant reached more than 100% capacity in a short time. The client, who has experience with other urea granulation technologies, is really satisfied with the Stamicarbon technology, which operates in difficult ambient conditions.

Despite the large scale, the plant proves the typical performances of the Stamicarbon granulation plant. An on-stream time of more than two months was achieved during the summer period.

The MMV scrubber technology

To meet more stringent particulate matter emission regulations, Stamicarbon together with EnviroCare have developed a multi-stage process for the effective and efficient scrubbing of urea particulate matter and ammonia from the granulation plant.

Fig. 6: **MMV scrubber**



Source: Stamicarbon

With this technology emissions of less than 10 mg/Nm³ for dust and ammonia can be achieved.

The high emission values in granulation process are caused by the generation of submicron dust. Older technology scrubbers easily scrub larger particles but are not focused on the reduction of ammonia.

A new capture approach focuses on submicron dust and on efficiently removing ammonia through use of an acid solution is applied.

In the MicroMist™ Venturi (core of the scrubbing technology) lean urea solution is sprayed as a fine mist into the airflow. The mist of urea solution collides with the submicron dust particles on the way in and out of the MicroMist™ Venturi and separates them from the air flow (Fig. 6).

The first application of the scrubber technology is for a client with very stringent requirements for urea dust emissions coming from a granulation plant. The project realisation and the application of the multi-venturi technology has resulted in an important achievement in terms of emission limitations. Another Stamicarbon plant where this technology has been applied went into operation last year. Testing at the second plant recorded urea dust emissions lower than expected and more than 50% below the permitted amount.

Waste stream integration

Sulphuric acid (H_2SO_4) and nitric acid (HNO_3) are the most commonly used acids for reducing ammonia emissions. As result of the reaction with ammonia, ammonium sulphate or ammonium nitrate salts are generated.

Based on the type of acid applied, the configuration of the scrubbing system and how the salt leaves the plant, different options are possible to utilise the waste streams.

Stamicarbon has developed several options featuring no extra waste streams during the required emission control process.

Ammonium nitrate (AN) can also be reused by feeding it to a urea ammonium nitrate (UAN) or ammonium nitrate (AN) plant. The ammonium nitrate (AN) preferably leaves the plant as an aqueous solution. This solution is sent to a neighbouring AN/UAN plant for further processing.

In a standard configuration, the AN solution is not recycled to the urea granulation plant. For this reason, the final urea product will be pure.

Fig. 7 shows the plants within an industrial complex that can accommodate a certain level of integration.

Based on how the liquid and the gas waste streams are integrated within the plants, two different concepts are described:

- liquid waste stream integration
- liquid and gas waste streams

In the first concept, acidic salty condensate from the off-gas treatment section of the AN/UAN plant is used in the scrubbing system as make-up water, reducing the amount of process condensate needed. Conversely, a recycle from the granulation is routed into the AN/UAN plant. In this way, no liquid waste streams are sent to battery limits.

In the second concept, a further simplification is introduced that completely eliminates the emissions coming from the AN/UAN plant. The idea is to route the ammonia off-gas coming from the AN/UAN synthesis section directly to the scrubbing system of the granulation plant.

Another possible option is the production of UAN directly from the scrubbing system of the finishing section. The by-product (AN salt solution) is routed to a dedicated evaporation section to be further concentrated and mixed with urea solution.

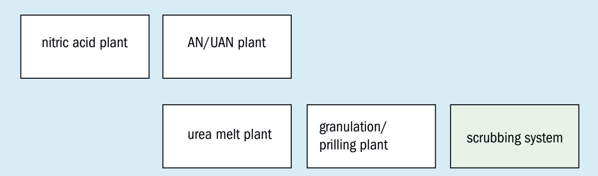
This allows for emissions abatement and UAN production in one step. The generated salt from the scrubber is used for UAN production. In this way no liquid waste streams are sent to battery limits and UAN production is performed without the need for an AN/UAN plant. The entire site has only one single emission source and no extra ammonia emissions are generated, at the same time the feedstock requirement for acidic scrubbing is made redundant by smart integration.

Modular UAS granulation / multiproduct granulation

Nowadays, as a result of flue gas desulphurisation, the use of cleaner fossil fuels, increased reliance on chemical fertilizers and a shift to higher-concentration phosphate fertilizers containing no sulphur, large agricultural areas are not receiving anything like their former sulphur input. At the same time, the need for nutrient sulphur has actually increased because of more intensive cropping.

To address the increased need for sulphur as a plant nutrient, one typical configuration to utilise waste streams ammonium sulphate is to recycle and concentrate the liquid urea ammonium sulphate (UAS) in order to have the salt leaving the granulation plant in a solid form after combination with melt urea.

Fig. 7: **Available plants for ammonium nitrate waste stream integration**



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Multifunctional granulation design

NITROGEN+SYNGAS
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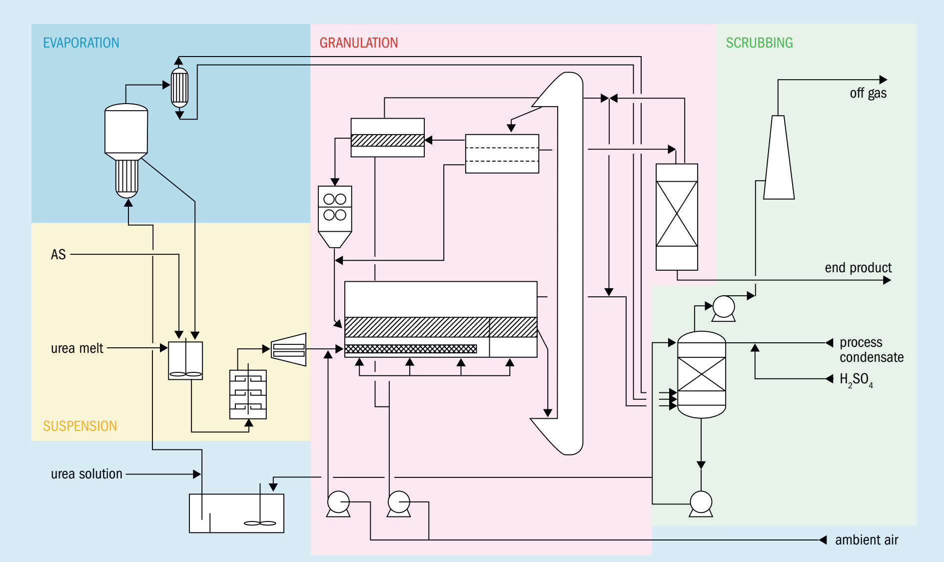
Fig. 8: **A modular analysis of the Stamicarbon UAS fluid bed granulation plant**



Source: Stamicarbon

Sulphur can be made available to plants as sulphate or as elemental sulphur.

Stamicarbon has given priority to the development of ammonium sulphate as a sulphur source instead of elemental sulphur.

Properties of elemental sulphur make the application of elemental sulphur in a urea granulation plants less desirable. It is more complex, more difficult to develop and engineer, more expensive, and it has a lot of side reactions. Furthermore, according to agronomic studies, bacteria need minimum two years to convert elemental sulphur to AS, so it becomes available for take-up by plants.

Stamicarbon has developed a unique and flexible modular process for the production of granulated urea containing higher ammonium sulphate concentrations.

In the UAS-granulation process there are four main modules (Fig. 8):

- **Suspension module:** Granulation is suitable for production of UAS with an ammonium sulphate content ranging from 0 to 50 wt-%. The additional solid ammonium sulphate is homogenised, milled (size less than 1 mm) and suspended in urea melt.
- **Granulation module:** The UAS granules are produced by using the standard granulation process.
- **Evaporation module:** The liquid effluent from the scrubber is concentrated and recycled back to the melt feed to the granulation. The process is optimised to prevent fouling in the evaporation section.
- **Scrubbing module:** The off-gases from the entire granulation plant are cleaned and treated as described above.

The same modular granulation process can be used to add many other macro and/or micro-nutrients (for examples zinc, boron, copper, etc…) to produce urea granules.

The first Stamicarbon UAS plant started-up this year at EuroChem's Novomoskovsk site in Russia. The 600 t/d plant is able to produce urea, as well as UAS, with concentrations up to 50% AS.

Existing granulation plants can also be adapted to this new design after some modifications and additional equipment

Conclusions

Finishing technologies have been used on a large scale for a long time. Changing markets and business situations and stricter environmental requirements and legislation are drivers for Stamicarbon to continuously innovate finishing processes. The latest technologies described:

- decrease opex and capex;
- improve product quality;
- exceed environmental requirements and;
- lead to better and more diverse products.

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Highly efficient vibrations for urea granules

Pardis Petrochemical Company (PPC), Iranian owner of one of the world's largest urea granulation plants, uses RHEWUM direct excitation screening technology to achieve the desired high process efficiency, availability, reduced energy consumption and high quality urea granules.

Increasing world food and energy consumption has led to growing demand for fertilizers and the need to save natural resources. For these reasons, a major producer of high quality urea in the Middle East decided to set up a third urea plant with the world's latest urea granulation design. The aim of the producer for this long-term investment was to achieve the highest possible efficiency paired with reduced energy consumption.

At the heart of the new plant, RHEWUM screening technology ensures the desired efficiency of the process as well as the purity of the urea product. The producer selected RHEWUM for design, manufacturing and commissioning of the extractor lines and main screens with the proven direct excitation technology for the production of granulated urea.

As the pioneer in directly excited screening technology RHEWUM has been successfully developing, designing and manufacturing screening machines for new and existing urea granulation plants for many decades. Since 1956, RHEWUM has supplied more than 1,800 machines to fertilizer plants which are installed in more than 60 different countries.

Screens for urea granules

For urea granulation, the combination of vibrating extractors with linear motion screens guarantees the level of the fluidised granules in the granulator and additionally protects the process by screening out the lumps. Downstream in the granulation unit the main screens ensure the quality of the final product. RHEWUM extractor lines, diverters, special chutes, distributing feeders, safety and process screens ensure a consistent process.

The feed capacity of the main screens is 4 x 65 t/h. The screening task is to separate the lumps (>15 mm) in a separate outlet and the coarse particles (4 to 10 mm) in the second outlet while the product (2 to 4 mm) and the fines (<2 mm) flow into separate inlets of the product diverter. The steady product requirement for 95% purity with minimum product loss in the coarse and fine fraction is essential for high performance screening.

Efficient screening

Step 1: Distribution

To make use of the complete screening area requires a constant and uniform distribution of the urea directly at the inlet of the screening machine. The distribution feeders are pre-positioned to the screens and guarantee the continuous quality of the product in following steps.

The moving inner distribution plate which is vibrated by two outer out-of-balance motors and a static housing allows a firm and dust-tight flange connection without flexible sealing. The static housing further permits inspection of the distribution feeder and adjustment with guiding plates during operation. The low weight of the vibrating inner distribution plate reduces the energy consumption to 0.68 kW per motor and the dynamic loads to a maximum of 0.25 kN in vertical and 0.125 kN in horizontal direction per support point.

Step 2: Screen cloth

The most important contact part of the screening machine with the urea is the screen cloth. Choosing the right mesh opening will create a high quality product. In addition, a constantly open screening area will increase the plant capacity and reduce the costly recirculation of material. Easy and fast maintenance of the screen cloths will lead to high availability. All these points have been incorporated into the design of the main screen cloths.

Fig. 1: RHEWUM SV feeder for constant and uniform distribution of screening materials.

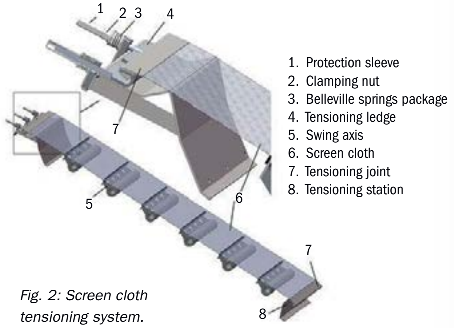
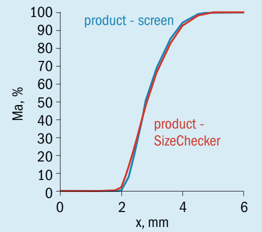


Fig. 2: Screen cloth tensioning system.

Fig.3: RHEWUM WAU screening machine with direct excitation of the screen cloth.

Fig. 4: **Comparison Product Screen-SizeChecker**



Source: RHEWUM

The mesh openings were optimised during test trials in the RHEWUM pilot plant in Remscheid. Directly excited screen cloths with an automatic cleaning cycle keep the screen cloths free from clogging. Every screen cloth can be changed individually without removing any of the others, which is very useful considering that different wear of the screen cloths can lead to individual maintenance intervals. The screen cloths are tensioned by tensioning ledges with only four clamping nuts. Between the tensioning ledges and clamping nuts Belleville spring packages are installed to make the screen mesh more flexible and self-tension itself in case of wear or high temperature. A protection sleeve keeps the dust away from each screw and ensures easy replacing. In total there are only four screen cloths installed and each can be replaced within just ten minutes.

Step 3: Screening technology

Requirements for urea granules are quite challenging: continuous and economic production of well-defined products in reproducible qualities. By choosing advanced technology the objective to efficiently operate the plant with lowest operation cost can reliably be achieved.

WAU type directly excited screening machines employ the vibration effectively into the screen mesh, thus directly into the urea granules. The required energy consumption is only 0.036 kW/ton of screened urea. Availability of each component in the urea granulation process needs to be as high as possible. One weak point in the process will create a bottleneck and in the worst case a shutdown of the whole granulation plant. To guarantee 100% availability, the screening machine is equipped with 15 small out of-balance motors which keep the performance stable till the next scheduled maintenance period in case of one motor failure. The motors are flange connected to the vibrating axes which transmit the vibrations through knocker shaft profiles and screen cloths to the urea. The WAU's high number of motors increases the performance and allows the screen decks to have different amplitudes. As a result the amplitude remains uniform over the complete width of the screen, which leads to consistent screening quality of the entire screen area.

As the housing has only a static function, no dynamic loads are created and transmitted to the building. Due to the low vibrations the directly excited screens do not require a heavy steel structure even when located at the top of the building. Connections to on- and off-going chute work are designed dust-tight without flexible sealing to minimise down time for maintenance. Reducing energy consumption, increasing availability, saving steel structure and avoiding unnecessary maintenance have been successfully incorporated into the urea screening plant for increasing the efficiency of the whole urea granulation plant.

Step 4: Quality control

To optimise the urea plant design screening trials are carried out. Test trials offer the possibility to compare laboratory results with the respective product data. These results have a significant role in the design process of the respective machine guaranteeing later success in production.

In order to check if the guaranteed product qualities can be reached, trials were conducted in the RHEWUM laboratory. Based on former experience, the trials were made using a WAU screen type. Furthermore, the screen products were analysed on a laboratory screen tower and the optical measurement system "SizeChecker". The results of both measurements are presented in Fig. 4.

The diagram shows that all measurements of the SizeChecker match the corresponding analyses performed on a laboratory screen tower. The same samples were used for both the screening analysis and the SizeChecker analyses.

The SizeChecker is a compact particle size measurement device allowing simultaneous measurement of particle sizes and particle shapes continuously. By means of digital image processing pourable particles of 0.2-20 mm can be optically measured. Since all particles of the product sample are completely scanned, the RHEWUM SizeChecker offers a cost effective alternative to common analysis screens. The SizeChecker can be used in production with an automatic sampler device to avoid time consuming sample taking and manual analyses. The measured results are automatically recorded and alarms can be set in case of variation in the particle size distribution.

The sample is conveyed via a hopper and a distribution feeder along the light source to the material outlet. During this time the contact-free measuring is carried out. The digital pictures produced by the camera are free from distortion and are electronically processed.

The SizeChecker can be integrated into a process for production monitoring and quality control.

Outlook

After the convincing performance at the RHEWUM test facilities the screening machine type WAU will prove its high-grade applicability for screening urea at the Persian Gulf for the next decades. The tests conducted by RHEWUM in Remscheid determined that PPC's demands on purity and yield have been reached and exceeded at site. The next reasonable step for the producer will be to set up a fourth urea granulation plant in the future.

Conclusion

Together with PPC, RHEWUM has designed, supplied and commissioned a highly efficient screen for urea at high capacities. Aspects like availability, energy consumption, saving natural resources and optimising the maintenance schedules have been successfully incorporated into the operation. ■

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A silver bullet to higher margins

C. Schröder of thyssenkrupp Fertilizer Technology (tkFT) discusses the benefits of product diversification to match changing market requirements. Sulphur-enhanced urea fertilizers and non-fertilizer uses of urea are highlighted as potential attractive solutions for a wider product portfolio for urea producers based on the use of existing equipment.

The opportunity to gain higher margins on product sales is always welcome. Product diversification provides such an opportunity. It mitigates risks of fluctuations in the market by providing customers with a greater variety of product options and services. It can distinguish a company from its competitors and can therefore give a tremendous boost to the company's profitability and reputation.

The easiest and fastest approach for a successful product portfolio diversification is to identify market trends and to serve those needs with the equipment already available or with cost efficient additional investment. thyssenkrupp Fertilizer Technology (tkFT), the leading licensor for urea granulation technology with references for more than 70 plants operating in all climatic conditions, is continuously developing easy ways to diversify the portfolio around urea granules in order to match market requirements. Examples include tkFT's solution for reducing the worldwide sulphur deficit in soils and the utilisation of urea granules for non-fertilizer applications.

Sulphur deficit in soils

Over the past decades, the composition of fertilizers has shifted away from lower analysis, sulphur- containing fertilizers like SSP and ammonium sulphate, towards higher analysis fertilizers like MAP (monoammonium phosphate), DAP (diammonium phosphate) and urea. During the same period increasingly stringent sulphur limits on fossil fuels and reduced power plant emissions, have resulted in significantly lower sulphur depositions from the atmosphere. The growing world population requires the use of higher yielding crop varieties, which have significantly higher nutrient requirements. These factors have resulted in a growing global sulphur deficiency of soils.

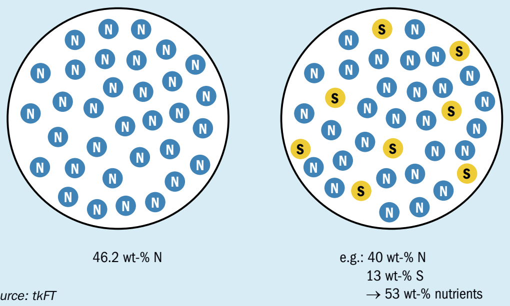
While various sulphur containing fertilizers have been introduced by the fertilizer industries over the years these innovations and capacities have not been enough to eliminate the sulphur deficit. The Sulphur Institute estimated in 2017, that the sulphur deficit in soils has risen to about 10-12 million tonnes of sulphur each year. CRU Insight published an article in October 2016 in which they forecast fundamental crop requirements for sulphur to exceed 24 million tonnes by 2020 with current fertilizer application at only half of this requirement. This means that more sulphur is being removed from soils than is replaced which has already led to lower agricultural outputs in some regions.

Urea, as the most widely used fertilizer globally, is an ideal sulphur delivery vehicle to alleviate the global sulphur deficiency of soils. A sulphur-enhanced urea such as Urea-ES can replace more expensive UAS and ASN fertilizers and also has higher nutrient content than urea alone or the sulphate-based nitrogen fertilizers (Fig. 1). Urea-ES therefore provides the opportunity to create added value for the fertilizer producer by delivering a higher nutrient density fertilizer. Replacing split application of urea and expensive ammonium sulphate lowers application costs by reducing spreading operations at the farm. Further benefits to the farmer include higher crop yields and crop quality improvements.

Developing solutions

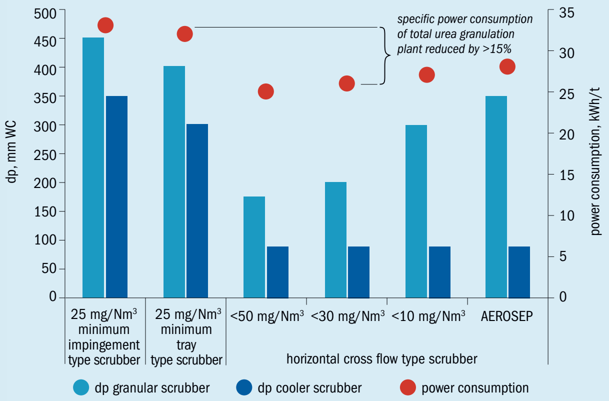
To meet the demand for sulphur fertilizers, tkFT joined forces with Shell to integrate Shell's Thiogro micronisation technology into tkFT's urea granulation technology. This resulted in the development of a new sulphur-enhanced urea fertilizer – Urea-ES – which incorporates elemental sulphur into the urea fertilizer granule.

Fig. 1: **Comparison of nutrition content between urea and Urea-ES**



Source: tkFT

Fig. 2: **Example of reduced pressure drop of tkFT's horizontal cross flow scrubber**



Source: tkFT

Elemental sulphur is the most concentrated form of sulphur. It is readily available and a cost effective raw material. However, to produce homogenous granules and therefore a good quality product, it is necessary to create a stable emulsion of molten sulphur and liquid urea. Due to the significant differences in density and surface tension, simply mixing the two components results in visible segregation of sulphur and urea upon solidification. Shell's Thiogro technology utilises a high speed shear mill (ThioMill) and a proprietary additive (ThioAdd®) to efficiently disperse liquid sulphur in the urea melt, to stabilise the emulsion and to bind the sulphur and urea during the solidification process.

Shell and tkFT carried out an extensive programme of trials in tkFT's batch operated pilot plant to optimise the process conditions and product characteristics of Urea-ES.

At the beginning of the process, liquid sulphur is mixed with concentrated urea solution, ThioAdd® and any other optional additive for trace elements or anti caking. This mixture is then homogenised in the high speed shear mill to form the emulsion. An industrial scale sulphur dispersion unit requires about the same space as the well-known urea solution feed pump system.

From the ThioMill, the sulphur/ urea emulsion is pumped to the granulator spray nozzles. tkFT's spray nozzles used in all UFT fluid bed granulation plants are able to handle the emulsion without any modification to produce a high quality Urea-ES granule.

A significant side effect of the sulphur addition, due to the much lower heat of crystallisation of sulphur, is a lower heat input into the granulator, resulting in a reduction in the amount of cooling air required for Urea-ES production. As a result, the specific investment cost per tonne of product for a new plant can be reduced, because of the reduced size of the granulator, dust scrubber and fluidisation air system, which, in turn, leads to a reduced building height and small plot size.

As a revamp option for existing plants, a higher production capacity is possible by utilising the design margins of the installed equipment. In case a higher production rate is not feasible, the production cost of the product can be lowered by utilising the low cost sulphur while at the same time the specific consumption of ammonia, carbon dioxide, power and natural gas is reduced.

A 2,000 t/d granulation plant would require about 110 t/d less ammonia, when producing Urea-ES containing 10% sulphur. The excess ammonia can be sold to the market or used for other high value products like technical grade urea, UAN or deNOx solutions.

The dust, arising during the fluidised bed granulation process, contains water-insoluble sulphur. Therefore, the bleed from the dust scrubbers cannot be recycled to the evaporation unit of the urea synthesis plant (HP synthesis and recirculation). In order to avoid this contamination a small additional evaporation unit is required for the granulation plant. Such recycle evaporation units are already used in tkFT's proprietary ACT (Ammonia Convert Technology) ammonia emission reduction systems. In the evaporation unit all liquid recycle streams from the granulation plant are processed and its condensate is solely used as make-up water for the dust scrubbers and is not returned to the synthesis plant or water treatment.

tkFT's horizontal crossflow scrubbers, already applied in new UFT fluid bed granulation plants, are already fully suitable for this service, simultaneously decreasing pressure drop (see Fig. 2). For other dust scrubbing systems it needs to be investigated whether they can be operated with a urea solution/sulphur suspension resulting from the insoluble sulphur in the water.

The additional evaporation unit reduces the load of the existing evaporation unit in the urea synthesis plant. However, the overall steam consumption is not increased and the reduced load to the existing evaporation unit allows for a higher urea feed solution flow, if this unit is the limiting factor.

The separate recycle evaporation unit gives the granulation plant and the synthesis plant the potential to implement an acidic scrubbing system in order to reduce the ammonia emissions from the site. The recycle evaporation unit can process the ammonium salt solution from the acidic scrubbing and return it to the granulation process. This allows producers to meet increasingly stringent ammonia emission limits.

Urea-ES in UFT fluid bed granulation

The classic UFT fluid bed granulation process is shown in Fig. 3, which also shows typical emission values. The next step was to implement Urea-ES into the well-known and established tkFT process, as shown in Fig. 4.

Fig. 4 shows the impact on the flexibility, product portfolio diversification and emission values that can be achieved by adding the three small process steps:

- an emulsion unit;
- recycle evaporation;
- NH_3 scrubbing.

That means, if a producer is already under pressure due to more stringent emission limitations, producing Urea-ES can be used to diversify the product portfolio and reduce

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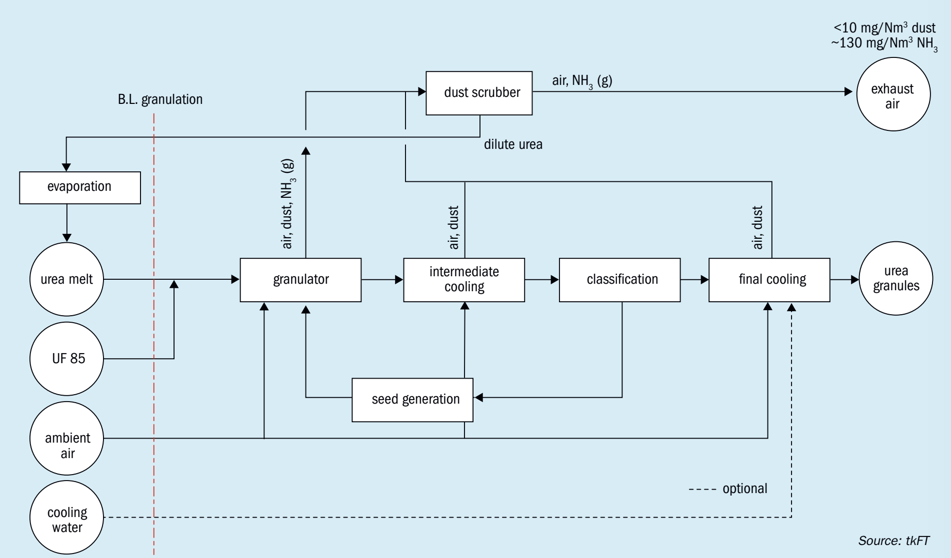
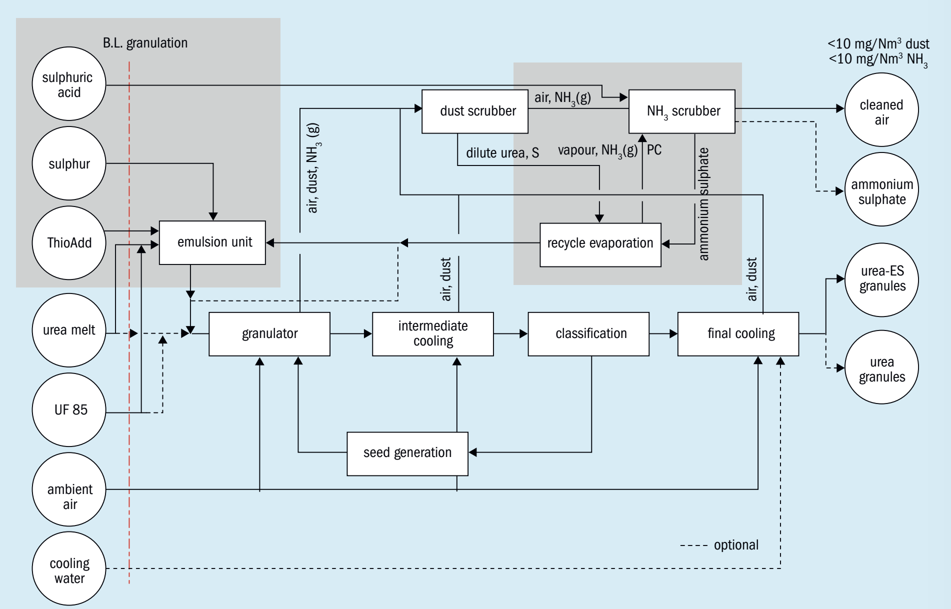
Fig. 3: **Classic UFT fluid bed granulation process without acidic scrubbing**



Source: tkFT

Fig. 4: **Product diversification with urea-ES production**



Source: tkFT

Table 1: **Categorisation of formaldehyde**

IARC	GHS	NTP	ACGIH	EU (CLP)
Group 1	Category 1a	Known	A1	Category 1a
	Category 1b			Category 1b
Group 2a	Category 2	Reasonably suspected	A2	Category 2
Group 2b			A3	
Group 3			A4	
Group 4			A5	

IARC: International Agency for Research on Cancer; GHS: Globally Harmonized System of Classification and Labelling of Chemicals; NTP: National Toxicology Program; ACGIH: American Conference of Governmental Industrial Hygienists; EU (CLP): European Union regulation for Classification, Labelling and Packing

Source: tkFT

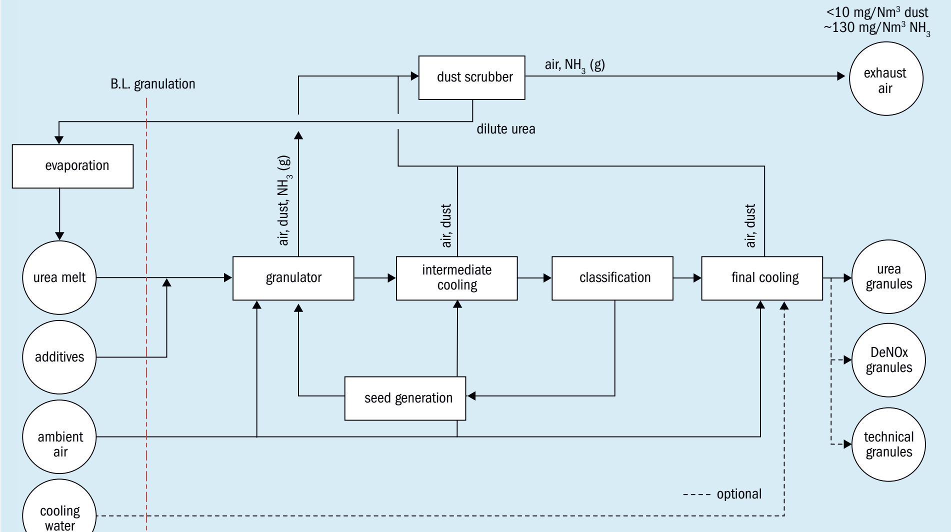
emissions in one step. Urea-ES is therefore also an excellent revamp option for existing urea granulation plants.

Formaldehyde-free urea granules

For the production of prilled and granulated urea an additive is needed in order to ensure that certain process parameters, such as a controlled granule growth rate, reduced dust formation during the production process and good product quality, remain stable over a long period of time. Urea produced by this route is used as fertilizer and annual production exceeds 180 million t/a. At present, formaldehyde is applied as an additive to prilled and granulated urea in the form of precondensate, in which the formaldehyde has already partly reacted with urea to methylol urea, but still contains a substantial amount of free formaldehyde. Formaldehyde is highly toxic to humans and all animals and was suspected as a substance that can cause cancer for nearly 40 years. Recent research confirms what has been suspected for so many years and formaldehyde was classified as a Group 1 substance "carcinogenic to humans" (see Table 1) by the IARC (International Agency for Research on Cancer). If this was not already enough motivation for tkFT to focus its research and development resources to find an alternative, formaldehyde-free granulation aide, additional pressure is being placed on the producers of prilled and granulated urea: The European Union has placed formaldehyde on the "substitute it now" list (www.sinlist.org) and even categorised it as "substance of high concern".

For the development of an alternative additive to formaldehyde tkFT started by screening different substances that were not harmful to health or the environment. During laboratory scale testing of components on their suitability as additive for urea fluid bed granulation, potential substances were identified and tested for their specific effects on the desired product quality such as caking tendency or crushing strength. The second step was to test the different components and mixtures at tkFT's batch-operated pilot plant to generate a data base to carry out product design for the alternative additives in terms of the desired product quality. As a result, an alternative additive has been found that is at least as effective as urea formaldehyde and it was found that less than half the

Fig. 5: **Product diversification with formaldehyde-free additives without acidic scrubbing**



Source: tkFT

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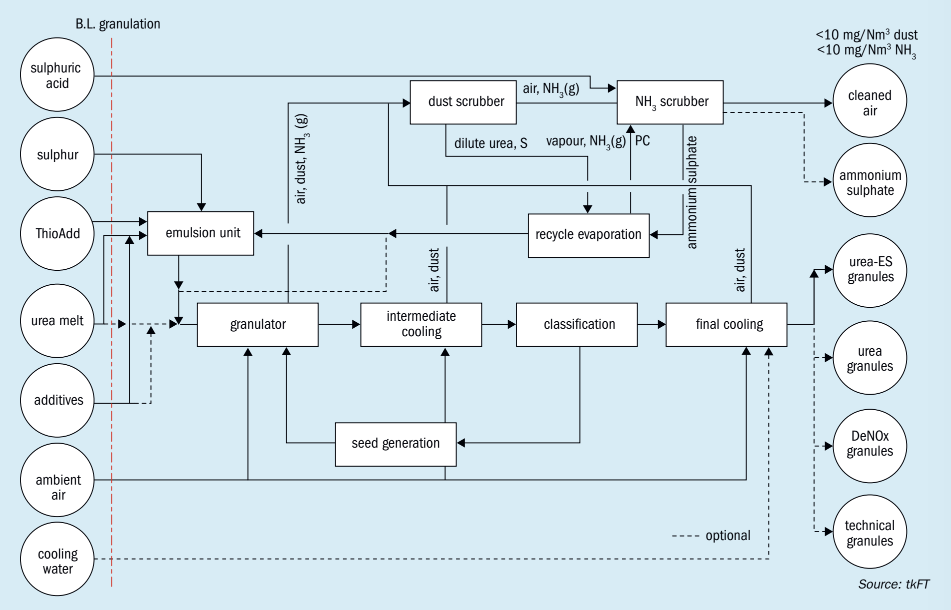
Fig. 6: **Fully extended UFT fluid bed granulation process**



Source: tkFT

dosage of formaldehyde is required to achieve at least the same product quality.

The developed additive consists of functional polymers in combination with carboxylic acid and all of its components are non-hazardous and even have several FDA (Food and Drug Administration) approvals for direct and or indirect food contact. This opens up additional fields of application for the so produced urea and it is no longer limited to fertilizer use. This allows the producer to benefit, not only from a continuously growing fertilizer demand, but also from the even faster increasing demand for non-fertilizer grade urea like UF resins, cattle feed or even deNOx applications just by product diversification with existing equipment, or at least with negligible modifications compared to the benefit.

Implementation is extremely convenient, UF-85 is simply replaced with the formaldehyde free additive with no further modifications in the plant required (Fig. 5).

One plant – multiple products

From the point of having two possibilities to extend the product portfolio of the manufacturer, the final step was self-explanatory – to combine the extension varieties in one single process which has been successfully engineered in tkFT's fully extended UFT fluid bed granulation process (Fig. 6).

This allows the producer to kill two birds with one stone. If the producer is already under pressure to comply with increasingly stringent emission limits, the fully extended UFT fluid bed granulation process offers the chance to diversify the product portfolio, to provide its customers a variety of products and services.

Even without any external pressures, tkFT's latest developments on product diversification gives producers the opportunity to stand out from their competitors in a labour and environmentally friendly way by replacing harmful substances and making the plant a much healthier working place for its operators.

Summary

To extend product portfolios, tkFT has engineered an easy solution for product portfolio diversification by implementing Urea-ES in the well-known and established UFT fluid bed granulation process and by combining it with newly developed, formaldehyde-free additives to create a highly flexible and environmentally friendly process. The process shown in Fig. 6 can either be easily implemented in existing production facilities with no or very cost effective investments, or be designed for new production facilities with negligible higher investment cost compared to the traditional process concept. The manufacturer simultaneously benefits from the opportunity to gain higher margins on product sales and a raise its reputation by replacing hazardous substances to make the urea plant a safer place to work. ■

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New steam superheater for ammonia production

A new steam superheater design has been developed to meet the needs of next generation ammonia plants. The improved design fulfils the critical criteria: life time, reliability, and availability, to provide the licensor and the customer with a more reliable solution for improved overall process efficiency. **Dr Jörg Weidenfeller** of Schmidtsche Schack / Arvos GmbH discusses the development, key features and benefits of the new design.

PHOTO: SCHMIDTSCHE SCHACK

High performance steam superheater ready for shipment.

The steam system in ammonia plants is often referred to as the heart of the production plant, since steam at different pressure levels is used for the process itself, as well as for the driving power for the process compressors. The steam is produced by waste heat recovery from the process and additional natural gas fired auxiliary boilers. Depending on the plant situation, modern steam systems are designed either for zero steam export or for steam export to produce electricity or, in case of an ammonia/urea complex, to supply steam and electricity to the urea plant since this plant is a consumer for both. To improve the overall process efficiency it is obvious that the steam system is a great lever.

In ammonia plants, most of the steam generation by waste heat recovery takes place downstream of the secondary reformer. The waste heat boiler package often consists of a horizontal process gas cooler (PGC) with a steam drum on top followed by a steam superheater (SSH) to improve the overall process efficiency. The waste heat boiler package generally operates with natural circulation of water/steam. A typical arrangement for two parallel lines is shown in Fig. 1.

The process gas enters the waste heat boiler package typically at 900°C to 1,000°C and is cooled down to 350°C depending on further downstream process requirements like high temperature shift. By recovering the heat from the process gas, high pressure steam is generated and superheated.

Schmidtsche Schack / Arvos is a solution provider for this kind of waste heat boiler package design and manufactures the complete package as well as individual components. Based on completed and requested projects for all major chemical process licensors the steam pressure and superheated temperature are in the range of 100 bar to 130 bar and 330°C to 470°C, while most of these constructions have high pressure steam at 125 bar and 400°C, respectively.

Motivation for change

An increase in superheated steam temperature has a beneficial impact on the overall process efficiency and cost effectiveness of the plant. Because Schmidtsche Schack / Arvos is not in a role of a process designer, the further assessment focusses only on the system of the waste heat boiler package by

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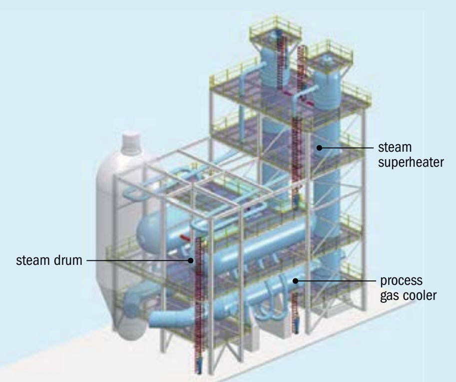
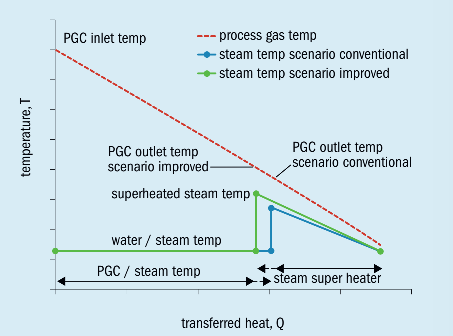
Fig. 1: **Typical waste heat boiler package**



Source: Schmidtsche Schack

Fig. 2: **Q-T diagram for waste heat boiler package, conventional and improved scenario**



Source: Schmidtsche Schack

keeping the process conditions of the system constant. This is shown in Fig. 2 for both the baseline scenario and the conventional scenario, as well as for the improved scenario in the heat-temperature (Q-T) diagram. It can clearly be seen that the process gas inlet and outlet temperatures (as well as pressure and gas mass flow) are not changed for both scenarios, while the superheated steam temperature is increased for the improved scenario. Since the total available heat of the process gas remains constant and the heat required for the steam superheating increases, the heat available for steam generation in the PGC decreases. As a result, the improved scenario produces less steam, but at a higher superheated temperature.

To quantify this effect, a baseline of a superheated steam temperature of 400°C at 125 bar is chosen. An increase of the steam temperature by 15% means an increase of the specific steam energy by 21%, and consequently, as described above, a reduction of the steam mass flow by 12% occurs. Overall, however, the increase of SSH duty is 38% compared to the baseline scenario. By increasing the superheated steam temperature by 30% the overall SSH duty increases by 58%. Consequently, this additional duty can be used for further electricity production or to reduce the duty of natural gas fired auxiliary boilers.

A rough financial assessment for both improved scenarios is shown in Table 1, and clearly indicates the financial benefit of increasing the superheated steam temperature, either in terms of natural gas savings or additional electricity generation revenues.

However, an essential prerequisite for these scenarios is mechanically robust and reliable steam superheaters with high availability and long service life.

Table 1: **Representative financial assessment of increasing superheated steam temperatures by SSHs**

Ammonia process, 2,200 t/d plant assessment for one year operation

Superheated steam temperature (°C)	Duty increase (MW)	Natural gas savings (million $)	Revenue for electricity production (million $)
400	baseline	0	0
470	7	0.530	0.590
520	11	0.900	0.810

Assumptions:
- *Natural gas price 10.2 €/MWh (3.2 $/million Btu)*
- *Reimbursement for electricity 0.05 €/kWh*
- *Steam turbine expansion to 70°C*
- *Plant operation: 7800 h/y*
- *Efficiency steam to electricity 40%*

Source: Schmidtsche Schack

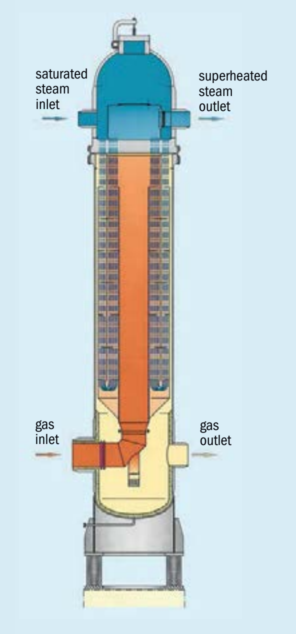
Steam superheater conventional design

The steam superheater is the critical component of the waste heat boiler package, requiring a robust and reliable design. As a result, Schmidtsche Schack / Arvos developed and installed the Schmidtsche® U-type steam superheater for ammonia plants approximately 15 years ago and later also applied a similar design for methanol plants.

Fig. 3 shows the design principle of the Schmidtsche® U-type SSH. The process gas enters the gas inlet channel at the bottom and is guided upwards in a central tube. At the central tube outlet near the tube sheet the gas turns, enters the inner hot pass and flows downwards alongside the heating surface. At the bottom, the gas turns again, enters the second cold pass of the U-type heating surface and flows to the top where it leaves the heating surface. Thereafter the cooled gas flows down between the inner liner of the second pass and the outer pressure shell into the gas exit chamber. This means that the hot process gas is at no time in direct contact with the pressure vessel wall, which is advantageous for the mechanical design of the outer shell.

The internal bypass valve governs the process gas outlet temperature. Cooled gas through the heat exchanger meets with hot gas which bypassed the heating surfaces in the gas exit chamber, where it mixes to achieve the required constant gas outlet temperature.

Fig. 3: **U-type steam superheater**



Source: Schmidtsche Schack

The superheater operates in counter-current flow, which means that the saturated steam flows into the U-tube from the second to the first pass. The upper head is designed as a combined steam inlet and outlet chamber, where the superheated steam is collected in an internal steam chamber.

Refractory is always a risk as cracks and material losses can occur. Such damage requires immediate repair action requiring unexpected shut down. That is why the Schmidtsche Schack / Arvos design is focused on a minimum use of refractory material, applied only to the exit chamber, increasing the availability of the steam superheater and the ammonia production line, respectively.

The effectiveness of the heat transfer design is based on the counter current flow of the media. This has a beneficial impact on the required size of the heating surface and thus on the size, weight and cost of the steam superheater.

Looking in more detail, the consequence of the counter current flow design is that both hot streams of the process media meet at one point, close to the tube sheet at the first hot pass shown in Fig. 3. On the one hand, the hot process gas in the shell side and the superheated steam on the tube side lead to high material temperatures for the U-tube, on the other hand, the high temperature in the tube side is transferred to the tube sheet because of the hot U-tube leg. Few possibilities are available to reduce this temperature impact e.g. by inserting ferrules, but this would also increase the pressure drop on the steam side. Finally, the high temperature transfer to the tube sheet cannot be avoided.

This means that the temperature gradient caused by the media on the shell and tube side is not only across the tube sheet, but a temperature gradient in the radial direction along the tube sheet is superimposed because of the U-tube principle with a cold and a hot leg.

The tube sheet, which is the heart of the steam superheater, is loaded by the pressure of the steam and gas side as well as by the temperature gradients already described. A thick tube sheet is required to resist the primary stresses caused by the high steam pressure. But a thick tube sheet is also critical for thermal gradients, all the more for the thermal superposition mentioned above, which results in unfavourable secondary stresses.

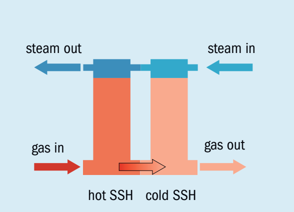
For current ammonia applications and the latest process temperatures the conventional Schmidtsche Schack / Arvos U-tube design is still feasible and reliable based on the long term experience for the thermal and mechanical design. But in case of improving the process efficiency by increasing the superheated steam temperature beyond 470°C, the conventional U-type design is no longer robust. The non-uniform temperature distribution mentioned gets worse and consequently the tube sheet expands thermally in a non-uniform way with additional thermal, secondary stresses. This drives crack propagation at the tube sheet, tube to tube sheet welds and connecting welds. The situation will be worse for cyclic operation, which is characterised by high temperature and load gradients.

High performance steam superheater

In general, for temperatures over 470°C, there are two steam superheater design options, as a U-type design would no longer be reliable:

- Option 1: Split the total steam superheater duty into two exchangers, one hot and one cold apparatus as shown in Fig. 4;
- Option 2: Apply and combine proven design features to achieve a reliable solution, which fulfils reliability and life time criteria.

Fig. 4: **Hot and cold stage, option 1**



Source: Schmidtsche Schack

Option 1 has the disadvantage that an additional heat exchanger is required for the process and therefore there is an additional risk of failure that reduces the overall availability of the production line. In addition, the hot stage of a SSH is critical because

- of high temperatures at the tube sheet. This has an impact on the mechanical integrity and life time.
- the shell is completely refractory lined. This reduces availability because damaged refractory has to be repaired immediately due to metal dusting atmosphere.

Due to experience with comparable steam superheated temperature in other applications and robust design features of the existing U-type Schmidtsche Schack / Arvos decided to give preference to option 2. Applying proven design procedures and features ensures best apparatus performance and eliminates the risk of failures.

The design for the pressure vessel of the previously described U-type steam superheater was used, since this design uses internal cooling features and a minimum of refractory. For the heating surface, the so-called bayonet design was used instead of U-tubes. This design was successfully applied by Schmidtsche Schack / Arvos more than 20 years ago for steam superheating at comparable process temperatures as shown in Table 2.

It is worth mentioning that the bayonet tube applied in the process gas cooler for steam generation has several inherent reliability issues. For example, deposits in the boiler feed water can agglomerate in the

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Table 2: **Combination of proven design features for the high performance steam superheater**

Process (year)	Steam side (bar/°C)	Gas side (bar/°C)	Design
Ammonia (2000-2014)	125/293	40/560	U-type
Styrol (1994)	0.9/840	3.1/642	bayonet tube
	↓		
Methanation (1981)	123/550	80/550	bayonet tube
Methanation (2014)	130/520	30/620	combination of design features for next generation SSH

Source: Schmidtsche Schack

end cap of the bayonet tube and reduce or block the cooling capability. This was reported in various conference papers[1, 2]. However, the application of the bayonet tube to superheat steam does not have the risk of agglomeration of deposits because there are no deposits in the saturated and superheated steam.

The bayonet tube is a tube in tube concept and is therefore comparable with the Schmidtsche® double tube design, which has been used for over 50 years in the ethylene industry in more than 7000 transfer line exchangers. The bayonet tube was not originally invented by Schmidtsche Schack / Arvos, but special thermal and mechanical design expertise and manufacturing experience is required to achieve reliable solutions.

The design was performed using three-dimensional numerical flow and heat transfer simulations accompanied by mechanical structure analysis. In addition, experimental tests were carried out to verify the boundary conditions for the simulation. A principal sketch of the Schmidtsche® bayonet type steam superheater is shown in Fig. 5.

The Schmidtsche® steam superheater operates in counter current flow like the U-tube design. Saturated steam flows downwards in the annular gap between the outer and inner tube. At the bottom of the outer tube, the steam is already superheated and flows back up in the inner tube. The process gas enters the heating surface from the bottom and flows upwards turned by disc and doughnut baffles, which optimise the heat transfer but have less pressure drop compared to standard baffle elements. At the end of the pass, the cooled process gas flows downwards between the inner liner and the outer pressure shell, which is comparable to the U-type design. An internal by-pass is also applied to control the gas outlet and steam outlet temperature, respectively. This Schmidtsche Schack / Arvos patented design has several thermal and mechanical advantages, which are described in more detail below.

The outer tube of the bayonet is connected to the tube sheet, which separates the steam and process gas side. This means that the tube sheet at steam side is only in contact with saturated steam, which is a major difference compared to the U-tube design. The superheated steam flows in the inner tube of the bayonet, which is connected to the bottom of the steam outlet chamber. This design ensures that the outer tube as well as the inner tube can thermally expand independently without any constraint. Consequently no stresses due to thermal expansion occur at the outer and inner tube.

The major advantage of this design is demonstrated by the temperature distribution across the tube sheet in Fig. 6 (top).

It can clearly be seen that the tube sheet is cooled by saturated steam, whereas on the gas side the tube sheet is in contact with the already cooled gas. This leads to the very homogenous temperature distribution at low level. Consequently this enables a design with a small tube sheet thickness which has the positive effect of minimal thermal stresses in the tube sheet and the tube to tube sheet welds. In addition, the smooth temperature distribution at low level has a beneficial on the thermal stresses. For comparison only, the temperature distribution across the tube sheet of a U-tube design for the same process and steam temperatures is shown in Fig. 6 (bottom).

Both figures have the same temperature scale (blue to red corresponds to cold to hot). It should be emphasised, that this U-tube tube sheet design is not robust and reliable but is only shown for comparison.

In contrast to the top figure, this tube sheet is in contact with saturated as well as superheated steam due to the U-tube concept. This leads to a superimposed temperature gradient in the radial direction, which has negative impact on the thermal stresses in the tube sheet and tube to tube sheet welds.

Metal dusting

In general, the risk for metal dusting is driven by the process gas composition, gas pressure and surface temperature of the metal, which is exposed to the process atmosphere. As discussed above, a higher superheated steam temperature requires a higher gas inlet temperature, and consequently the surface temperature of the heating surface increases. This increases the potential risk for metal dusting and the corrosion rate.

Schmidtsche Schack / Arvos performed corrosion assessments for several material grades and temperatures for ammonia applications. An example is shown in Fig. 7 for three different steam superheating temperatures. The corrosion rates for the various materials are related to the corrosion rate of SA213-T22 for a metal temperature, which is obtained for a steam superheated temperature of 390°C.

With increased metal temperature and superheated steam temperature, respectively, the corrosion rate for T22 increases by a factor of 5 at 470°C and 16 at 520°C, which is unacceptable. Therefore a material change to at least stainless steel for the superheater tubes is required to get moderate corrosion rates. To achieve the same corrosion rate for applications at 470°C as achieved at 390°C, the use of nickel alloy is required. This is already state of the art but even if the superheated temperature is increased further to 520°C with a corresponding increase in material temperature, the corrosion rate remains nearly constant when nickel alloy is applied for the heating surface.

The shell and the tube sheet of the Bayonet type steam superheater is only in contact with cold process gas as described above. With this inherent cooling feature, no risk of metal dusting for shell and tube sheet exists.

Fig. 5: **Bayonet type steam superheater**

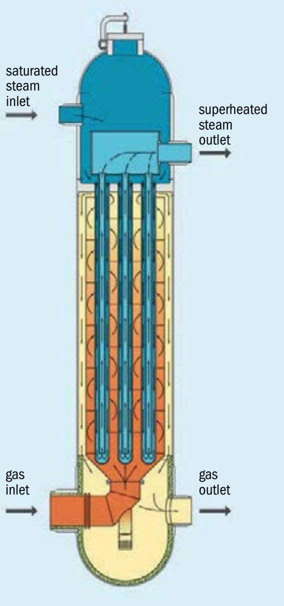

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Fig. 6: **Temperature distribution across the tube sheet of the bayonet tube steam superheater (top) and U-type (bottom)**

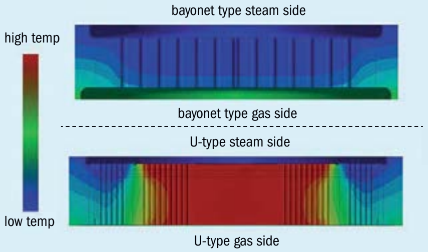

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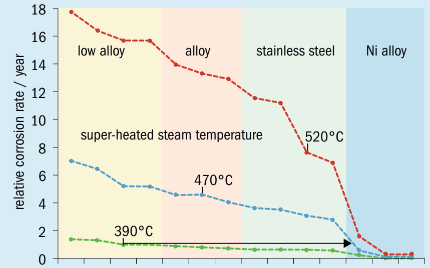
Fig. 7: **Corrosion assessment results for different material grades in ammonia applications**



Source: Schmidtsche Schack

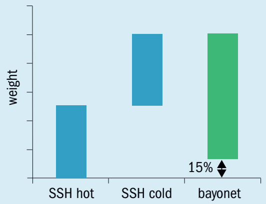
Design Comparison

As mentioned above, cascading the steam superheater by a hot and cold stage as shown in Fig. 4 might also be an option to realise high temperatures. Besides the fact that an additional heat exchanger bears the additional failure risk, which reduces the overall availability, the bayonet type has further advantages. For this comparison a hot and cold stage superheater as shown in Fig. 4 were designed which have the same overall process parameters as the bayonet design.

Both concepts are compared with respect to:

- Weight of the shell: The bayonet design has a shell diameter which is 80% of the staged design. Due to high pressure at gas and steam side, this impacts the wall thickness of the shell. In addition two gas inlet chambers and two steam chambers are required. Furthermore the shell of the bayonet design has 48% less weight than the SSH cascade.
- Weight of the refractory: the hot stage of the SSH cascade is completely refractory lined whereas for the cold stage only the gas inlet chamber is refractory lined. Consequently, the weight of the refractory for the bayonet has 55% less weight.
- Weight of the heating surface: the bayonet is a tube in tube design which leads to 40% higher weight of the heating surface compared to the SSH cascade.
- Overall weight (see Fig. 8): The overall weight of the bayonet design is 15% less than the cascade design. This effect is also noticeable in the cost of the heat exchanger.

Fig. 8: **Weight comparison between bayonet SSH**



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Conclusions

For current process gas and steam conditions in ammonia and methanol applications, the steam superheater with a U-tube design is still sufficiently robust and reliable. However, based on the process flow scheme, the U-type is close to its mechanical limits. For that reason, Schmidtsche Schack / Arvos has developed steam superheaters for the next generation of process temperatures, which are applied in methanation processes. The new apparatus design combines proven design features to ensure an evolutionary and reliable step in steam superheater development. Special care was taken in the process flow concept, the design of the heating surface and the tube sheet to achieve a mechanically robust design, which gives a long life time and reliability of the superheater. The application of internal cooling features significantly reduces the use of refractory, which positively supports high availability of the apparatus. ■

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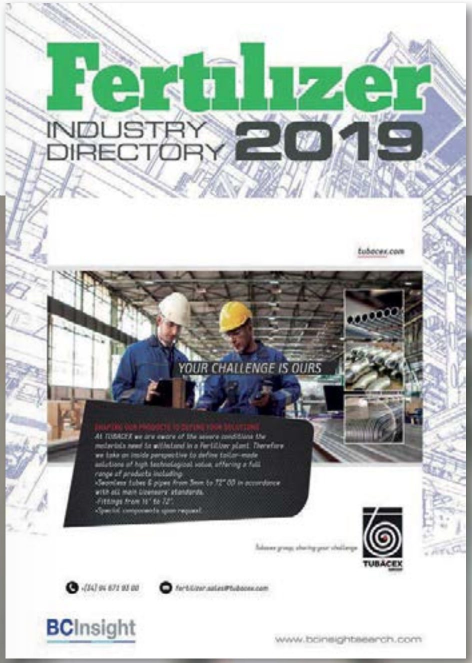

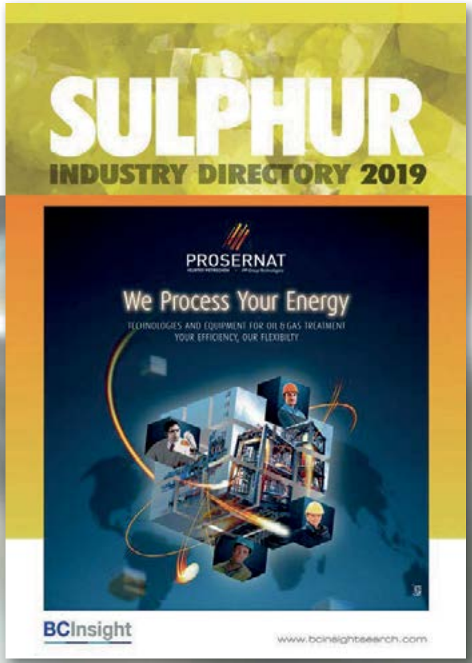

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