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Number 376

March | April 2022

nitrogen+syngas

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Europe's fertilizer industry

Nitrogen project showcases

Reformer services

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Published by:
BCInsight

War returns to Europe

Late February saw the diplomatic crisis between Russia and Ukraine abruptly devolve into all-out war, on a scale not seen in Europe since the collapse of Yugoslavia in the early 1990s – some would argue not since the end of the Second World War. At time of writing, the conflict is still barely two weeks old, but has already produced an unfolding humanitarian catastrophe, and a refugee crisis of massive proportions. But over the medium and longer term, together with the international sanctions that have swiftly followed, it also has the power to deliver an economic shock to commodities markets in particular and the world economy in general that may be as bad if not worse than the crash of 2008-9.

> "Potentially most devastating for the world is the loss of the region's grain supplies..."

From the very parochial standpoint of the industries covered by this magazine, the impact is likely to be massive. Though Russia only produces 3% of the world's methanol, Russia and Ukraine collectively represent 12% of global ammonia and 7% of global urea production, and more importantly 24% of globally traded ammonia and 18% of traded urea. Russia also represents 21% of world AN/CAN production and 27% of globally traded ammonium nitrate. Although the EU and US had imposed tariffs on AN from Russia, and Russia had itself already banned fertilizer exports until at least June to ensure that domestic consumers remained supplied at a time of unprecedented nitrogen prices, the prolonged absence of this supply could keep markets tight for years to come. As with Iran's sanctions regime, Russia may find buyers somewhere, but the financial restrictions that have been imposed will make payments difficult and uncertain.

Of equally significant impact could be the loss or at least disruption of Russian oil and gas supplies. European gas prices were only slowly coming down from record levels, and have rebounded back to stratospheric levels which, even at ammonia prices of $1,100/t, will effectively remove most European production from the market as well. Europe has in the past paid lip service to the idea of diversifying its gas supply, but now will be forced into additional investment in renewables and LNG.

But potentially most devastating for the world is the loss of the region's grain supplies. Russia and Ukraine represent between them 30% of globally traded wheat and 20% of corn. As IFA pointed out in its statement on March 4th: "the global food system is already fragile. The long-term consequences of this war on global food supply will impact both the rich and the poor parts of the world, with the poorest countries affected the most. While the consumption of most products and services can be delayed in times of crisis, food is an essential good, produced from land, with the help of plant nutrients, including mineral fertilizers." The combination of lack of grain and lack of fertilizer will hit world food prices hard. Rich countries will suffer but likely weather the storm, but the impact upon developing countries could be severe, even potentially catastrophic in places.

Other knock-on effects also seem certain to overturn previous market certainties. It is possible, even probable, that a sovereign default on Russian debt is coming, though the exposure of the world financial system is not believed to be huge. The list of companies who have decided to exit Russia also grows by the day, with BP and Shell among the more prominent. Clariant said on March 4th it would suspend business with Russia. But a tit for tat expropriation of holdings of western companies based in Russia is also starting to look increasingly likely. The worry, unless some form of face saving peace deal can be patched up in the short term, is that this could become a pivotal event, on a 9/11 scale, which may reconfigure the whole world. Three decades of Russia's re-entry into world markets after the end of the Cold War are being rolled back, and every planning assumption that the industry has made for the future has now been called into question. Unless wiser heads prevail we could be at the beginning of a very long and dark road. ■

Richard Hands, Editor

Price Trends

Market Insight courtesy of Argus Media

NITROGEN

The removal of 200,000 tonnes/month of ammonia from the Black Sea has exposed the market to even further volatility, and several key buy regions are likely to be left short of ammonia in April. Large buyers made moves at the beginning of March to secure March volumes but most market participants are locked in negotiations for any available spot cargoes.

Moroccan, Turkish, Tunisian and Indian buyers are some of the first at risk from shortages, with Pivdenny suppliers unable to cover shipments and ToAz declaring *force majeure* on contracts. Some are looking to Middle East producers to fill the gap, and fob prices are expected to spike higher in the region once negotiations have been finalized. Soaring gas prices are making it difficult for traders to firm up a position, with the European cost of production fluctuating from below $1,000/t at the end of February to over $1,700/t on 2nd March.

Early March market drivers include rising prices for Baltic contracts; Yara settled the Baltic contract price with Russian producers Eurochem and Uralchem at $1,155/t f.o.b., up $40/t for March shipments from Ventspils and Sillamae. Gas and bunker prices have also soared following the outbreak of the Russia-Ukraine conflict, settling at a new high of around $57/MMBtu on 2nd March. Bunker costs also spiked to over $900/t, putting further pressure on ammonia logistics costs. Tampa talks ended without a settlement – Yara and Mosaic failed to reach an agreement for contract shipments to Tampa in March, with both sides remaining too far apart on price. Mosaic bought a spot cargo from Trammo in line with last month's contract price.

In urea markets, sanctions by Western countries on Russia have severely curtailed the effective supply available to most buyers in early March and drove nitrogen prices rapidly higher. Importers in Europe, central and south America stepped into the market *en masse* at the beginning of March looking for urea, while traders competed for tonnage from producers, pushing f.o.b. and c.fr levels up in concert. Egypt, as ever, was a particular standout and granular urea prices added another $145/t in a flurry of trades through early March, finishing at $905/t f.o.b. Asian markets were quieter – Russian supply is less significant there – but still saw double-digit price increases for most locations.

Recent market drivers include Russia sanctions – freight for Russian cargoes is hard to find, and expensive. Many buyers in Europe and the Americas will not buy Russian fertilizer. Financing trade in Russian fertilizers is proving challenging. EU natural gas prices have soared to record highs, likely to drive nitrate prices up or EU producers to shut down. On freight rates, soaring crude oil prices and resurgent demand have pushed levels to fresh highs. ■

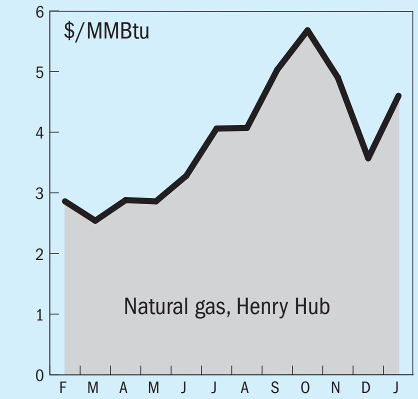
Table 1: **Price indications**

Cash equivalent	**mid-Feb**	**mid-Dec**	**mid-Oct**	**mid-Aug**
Ammonia ($/t)				
f.o.b. Black Sea	1,115-1,140	950-1,055	603-710	560-610
f.o.b. Caribbean	1,020-1,075	875-1,000	575-675	540-600
f.o.b. Arab Gulf	860-985	850-1,000	580-620	590-640
c.fr N.W. Europe	1,150-1,180	1,020-1,120	680-800	625-680
Urea ($/t)				
f.o.b. bulk Black Sea	518-620	800-905	685-765	390-435
f.o.b. bulk Arab Gulf*	750-825	810-910	730-845	439-470
f.o.b. NOLA barge (metric tonnes)	570-580	770-780	719-840	400-440
f.o.b. bagged China	560-700	830-920	520-630	415-450
DAP ($/t)				
f.o.b. bulk US Gulf	785-849	814-825	735-757	655-667
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	680-740	680-740	n.m.	157

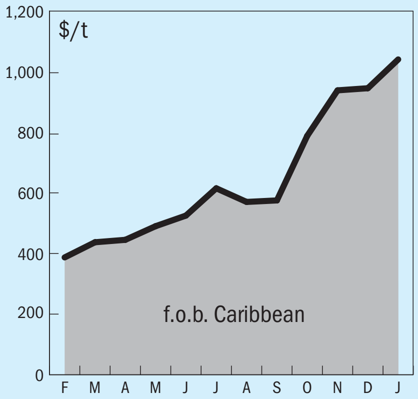
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

END OF MONTH SPOT PRICES

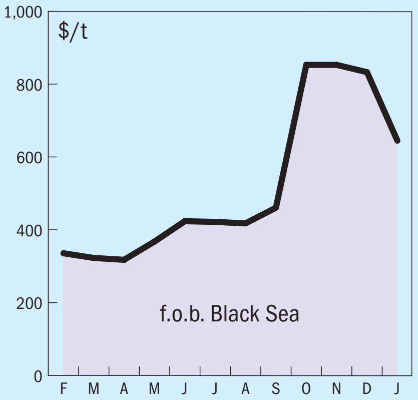
natural gas



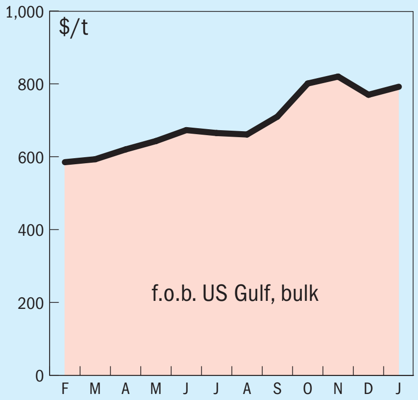
ammonia



urea



diammonium phosphate



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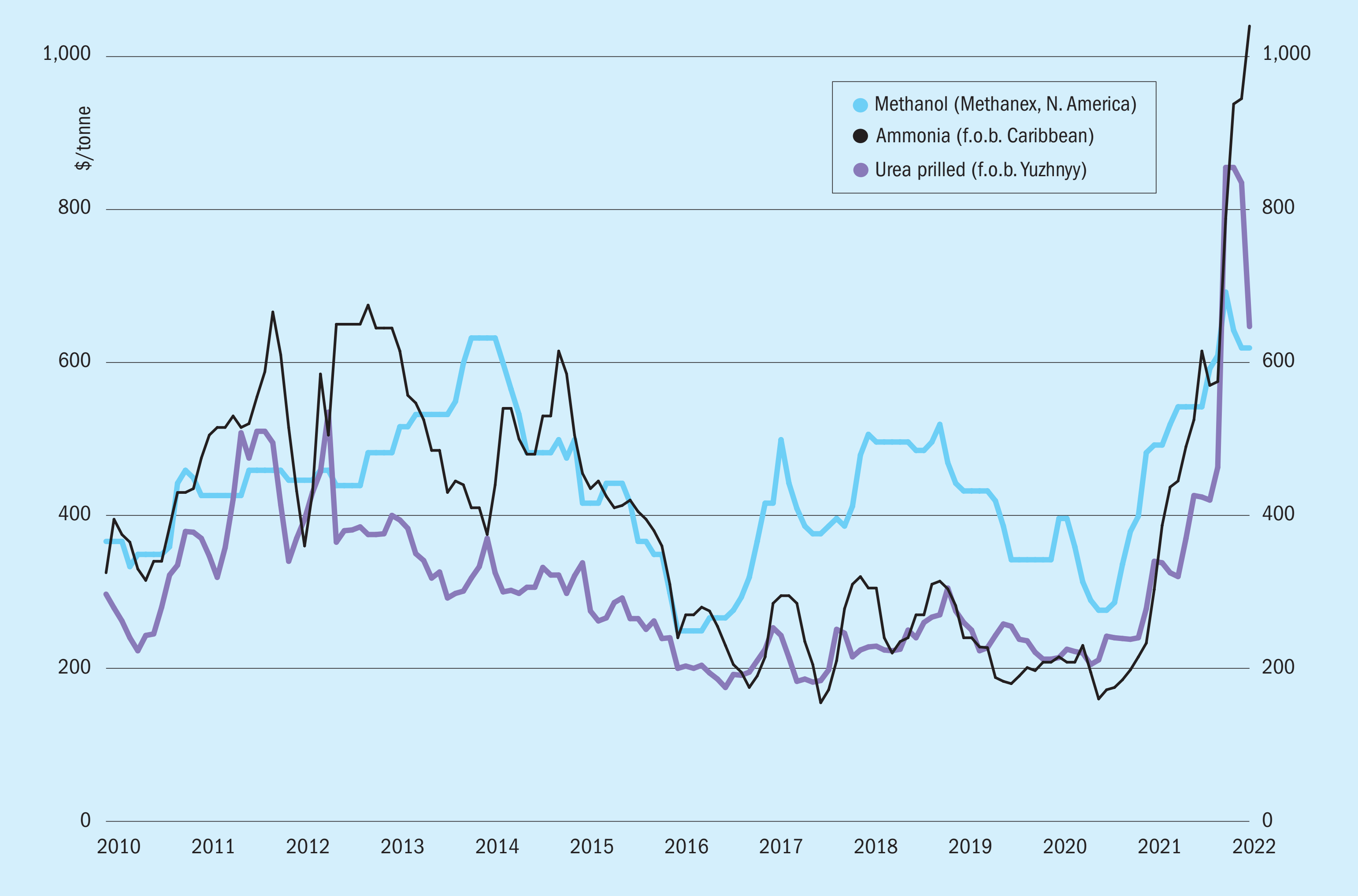
Market Outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- The ammonia market, already seeing record pricing in the wake of the winter's gas price squeeze, is braced for even higher pricing in the wake of the Russian invasion of Ukraine. The impact upon gas prices has been most marked, with rates of over $65/MMBtu seen in European forward pricing as the threat of a cessation of Russian gas exports loomed. This will undoubtedly lead to widespread idling of ammonia capacity in Europe.
- Likewise the loss of ammonia from the Black Sea is likely to be for the foreseeable future, removing millions of tonnes of traded ammonia from the market. Russia represents more than 20% of global ammonia exports.
- Conversely, a reduction in demand from DAP producers who cannot afford to buy ammonia at over $1,000/tonne could bring some market relief. There is also some additional ammonia supply available east of Suez.

UREA

- The urea market outlook is highly volatile, as might be expected. Russia represents 14% of all globally traded urea exports. It is expected in the longer term that market participants will adjust to the new difficulties in trading Russian fertilizer under the financial sanctions regime, as they did to supply from Iran, for example.
- However, in the short term, supply is tight, and the soaring prices in Europe and lack of other options mean that price rises are being passed on worldwide. Egyptian urea prices rose $300/t in a week.
- Prior to the outbreak of conflict, India had as usual been setting the market tone, with IPL having secured 1.4 million tonnes at netbacks of around $520/t f.o.b. Baltic Sea.

METHANOL

- Reference methanol prices have been falling, and generally rolled over from February to March at unchanged values. Methanex's non-discounted reference price for North America remained constant at $619/t and its Asian contract price (ACP) for March was also unchanged at $480/t.
- Argus launched a monthly European contract price. European contract prices are normally assessed quarterly, but buyers and sellers are discussing a move to monthly pricing as occurs in North America and Asia. The first Argus European monthly methanol contract price (CP) was assessed at €495/t 25 February for March supply.
- While contract prices have remained unruffled, spot prices in all regions have been climbing following the outbreak of conflict between Russia and Ukraine. Russia is one of the largest exporters of methanol to Europe. Indian prices followed European prices upwards in early March. As yet however there are no signs of disruption to the supply of methanol, with availability generally good.
- The jump in gas prices, especially in Europe, is sure to lead to shutdowns among producers however. ■

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Nitrogen Industry News

AUSTRIA

EuroChem makes offer for Borealis' nitrogen business

Borealis' Linz site, Austria.

Switzerland-based EuroChem Group AG says it has entered into exclusive negotiations to acquire the nitrogen business of the Borealis group, after having submitted a binding offer. One of Europe's leading fertilizer producers, Borealis operates fertilizer plants in Germany, Austria and France, as well as more than 50 distribution points across Europe. It supplies 3.9 million tonnes of fertilizer products per year, including 800,000 t/a of technical nitrogen solutions and 150,000 t/a of melamine via the Borealis LAT distribution network. It is a market leader in melamine, with its operations in Austria and Germany supplying primarily the woodworking industry. EuroChem says that melamine and technical nitrogen solutions represent important new business lines for the company to expand its nitrogen-based product portfolio in Europe.

"EuroChem is a global leader in the mineral fertilizer industry, with a significant presence in all major markets," said EuroChem Group CEO Vladimir Rashevskiy. "The addition of the Borealis nitrogen business to our portfolio, once approved, will strengthen our foothold considerably in such a key market as Europe. We are delighted with the results of our negotiations, and look forward to creating opportunities for further growth in the European market together with Borealis' impressive management team."

SWITZERLAND

EuroChem posts record profits for 2021

EuroChem Group says that it achieved full-year 2021 sales of $10.2 billion and sales volumes of 27 million metric tonnes, generating a company-record EBITDA of $3.9 billion. The figure is more than double that for 2020, mainly, the company says, due to a more favourable pricing environment, a 6% increase in total sales volumes, and higher operating efficiencies.

"These encouraging results will allow EuroChem to build upon its position as a leading global fertilizer player," said CEO Vladimir Rashevskiy. "The supportive environment enables us to set even higher goals for ourselves and invest in ambitious new projects to stay on our growth trajectory."

Capital expenditure rose 6% year on year to $1.24 billion, with construction continuing on the 1.4 million t/a Northwest 2 ammonia/urea plant, and a new 8 million t/a capacity transshipment terminal at Ust-Luga on the Baltic Sea, among other projects.

Nitrogen sales volumes continued to be driven by urea, sales of which rose 18% to 3.4 million t/a amid tight markets in Europe due to high energy costs and limited availability from China. Ammonia sales rose 33% to 700,000 t/a in a market also impacted by elevated feedstock costs that kept prices high and supply short, with some European capacity idled. EuroChem became self-sufficient in ammonia after the 2019 launch of its 1.0 million t/a Northwest 1 facility at Kingisepp in Russia, which in 2021 produced 991,000 t/a. UAN sales volumes dropped by 10% to 1.4 million t/a year on year, although US sales remained roughly flat despite the imposition of preliminary anti-dumping duties on imports from Russia and Trinidad and Tobago.

RUSSIA

Topsoe signs MoU with Acron

On February 2nd, Haldor Topsoe signed a memorandum of understanding with Russia's Acron Group for the purpose of jointly working within green technologies area. The MoU includes initiatives within joint development of technologies aimed to reduce greenhouse gas emissions (CO_2 and N_2O) at Acron's existing production sites of and the development of promising projects for new products with minimum environmental impact.

Speaking prior to the events at the end of February that saw major sanctions imposed on Russian financial institutions, Aleksandr Popov, chairman of the board of directors of Acron PJSC, said: "Acron Group continues to introduce the ESG principles to the production operations of its facilities. We are happy to partner with Topsoe, the recognized technology leader in the industry. We expect our cooperation to result in break-through solutions in green technology use, which will reduce the environmental load and improve the overall eco-efficiency of the Group's facilities."

"We are excited by Acron's commitment to join pioneers in practical discovering of green technologies capabilities. I believe, together we will find the most efficient and advanced solutions that could be implemented on Acron's facilities to minimize greenhouse gas emission and to contribute into sustainable development of industry in Russia," said Roeland Baan, CEO, Haldor Topsoe.

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Domestic demand for fertilizer increased 20% in 2021

The Russian Fertilizer Producers Association (RFPA) reports that domestic sales of mineral fertilizers increased by nearly 20% to 4.7 million t/a (tonnes nutrient) in 2021.This figure is expected to rise to 8 million t/a by 2025. However, domestic sales continued to be dwarfed by production by RFPA members, which increased 5% to 54.7 million t/a (tonnes product).

Andrey Guryev, president of the RFPA and CEO of PhosAgro, said: "Last year, RFPA members met and even exceeded the goals of providing mineral fertilizers to our priority domestic market. While many countries are already facing shortages, and a spike in prices for agrochemicals has become a real test for farmers elsewhere, there are no shortages in Russia, and the price controls that companies voluntarily introduced as a preventive measure in the middle of last year will remain in effect until the end of May 2022. Producers are now working to build up stockpiles of product in Russia's regions and are planning their subsequent delivery to farmers before spring sowing. As in previous years, Russian producers will meet in full the demand from domestic agribusiness for 2022 in the amount of nearly 5 million tonnes of active ingredient."

Russia currently has imposed a temporary export quota for the six months from December 2021 to June 2022 to alleviate the concerns of farmers regarding the availability of fertilizers for spring sowing. It has also banned the export of ammonium nitrate fertilizer until April. However, the impact of EU and US financial sanctions on Russia following the invasion of Ukraine remains unknown at present. Russia was the largest exporter of ammonia and urea, UAN and ammonium nitrate in 2021, with major markets including Brazil, the EU and US.

Russia has been building a large amount of export-oriented nitrogen capacity lately, including a new nitrogen solutions plant for EuroChem at Novomoskovsk and a project to build an ammonia-urea plant in the Leningrad region. In 2021, Acron Group completed an upgrade of its urea plant No. 6 at Veliky Novgorod, and the company has started construction of a calcium nitrate production facility and began upgrading its number 2 and 3 ammonia units and urea units 1-4. Kemerovo Azot plans to build 3,500 t/d of ammonia and 4,200 t/d of urea capacity, together with a 1,500 t/d industrial grade AN unit. KuibyshevAzot has started up a new ammonium sulphate nitrate plant and is completing construction of a urea facility with a capacity of 525,000 t/a. Shchekinoazot launched a new methanol unit and is preparing to launch a facility for the production of nitric acid and ammonium nitrate.

UNITED STATES

Clariant to sell Scientific Design stake to SABIC

Clariant has signed definitive agreements to divest its 50 % stake in the Scientific Design Company to its long-term joint venture partner, SABIC. SABIC is executing a call option raised in 2015 to acquire this stake, originally purchased by Süd-Chemie AG in 2003 and acquired by Clariant in 2011. Clariant reported a book value for the 50% stake of CHF 108 million as of 31 December 2020. The Scientific Design Company, headquartered in Little Ferry, New Jersey, is involved in the development, licensing and catalyst supply of proprietary processes for the production of ethylene oxide (EO), ethylene glycol (EO/EG), bio-ethylene, bio-EO, bio-EG, EO derivatives, polyols and maleic anhydride. In addition to these technologies, Scientific Design Company Inc. produces proprietary catalysts and equipment for use in their own and other industrial processes.

Feasibility study on green hydrogen plant

Canadian-based AmmPower says that it has signed a letter of intent to develop a green hydrogen and ammonia plant at the Port of South Louisiana. It is conducting an initial feasibility study for a facility that could produce up to 4,000 t/d of green ammonia, potentially fuelling 4,500 vessels which pass through the busy port, which stretches for 50 miles along the Mississippi River. The provisional price tag is put at $1 billion, with a three year construction timescale.

"This initiative allows the Port of South Louisiana, being the largest energy transfer port in the United States, to move towards green hydrogen and ammonia in a robust manner," said Gary Benninger, CEO of AmmPower. "Port of South Louisiana is not only one of the largest ports in the world, but will now have the infrastructure to support ocean going vessels that require green ammonia for fuel."

Fire at AN facility

On January 31st a fire broke out at the Winston Weaver Company fertilizer blending facility at Winston-Salem, North Carolina. It was reported that there was 600 tonnes of raw AN on-site as well as 5,000 tonnes of finished fertilizer. The AN stockpile burned for four days, but fortunately there was no explosion as has been a risk at other major AN fires, such as West, Texas. Up to 6,500 local residents were evacuated as a precaution. Local media reported that the owners of the plant failed to submit a required chemical inventory to the NC Department of Public Safety in 2020 or 2021.

OMAN

Clariant to supply catalyst for green ammonia project

Clariant says it has been selected to supply, via licensor KBR, its next generation *AmoMax 10 Plus* catalyst for Oman's new $3.5 billion green hydrogen and ammonia at the Duqm Special Economic Zone, Oman. Once completed, the plant will be a fully integrated, carbon-neutral facility, using solar and wind energy to produce 300 t/d of ammonia.

Stefan Heuser, senior vice president and general manager of Business Unit Catalysts at Clariant, commented, "We are convinced that green ammonia will play a crucial role in the global energy transition and with our novel ammonia synthesis catalyst *AmoMax 10 Plus*, we provide a state-of-the-art product to facilitate this change towards a more sustainable future. Together with our partner KBR we look forward to setting a new standard in a more sustainable and profitable green ammonia production."

NORWAY

Linde to build electrolyser for ammonia plant

Yara International says it has contracted Linde Engineering to build a 24-MW green hydrogen demonstration facility at Yara's ammonia plant at Porsgrunn, Norway. The project, which has been awarded a $31.6 million equivalent grant by government funding agency Enova, will use proton exchange membrane (PEM) technology by UK company ITM Power. Casale says that it will design the ammonia converter using its

own technology. The plant is intended to demonstrate that ammonia produced with renewable energy can reduce carbon dioxide emissions in fertilizer production.

The electrolysis system will produce around 10 t/d of green hydrogen, which will replace some of the hydrocarbon-based hydrogen production in Yara's plant, avoiding 41,000 t.a of CO_2 emissions.

"The project aims to supply the first green ammonia products to the market as early as mid-2023, both as fossil-free fertilisers, as well as emissions-free shipping fuel," said Magnus Ankarstrand, president Yara Clean Ammonia.

JAPAN

Ammonia fuel to be trialled in naphtha cracker

A Japanese consortium is planning to use ammonia as fuel to operate a naphtha cracker, as part of efforts to decarbonise the petrochemical sector. Mitsui Chemicals, Maruzen Petrochemical, Toyo Engineering and Sojitz will develop and demonstrate the technology, which will be partially funded by $200 million of subsidies from state research and development institute Nedo. The ammonia will be used at Mitsui's Osaka ethylene plant, and Maruzen's Chiba plant. Toyo Engineering will build and test the demonstration cracker and associated facilities, and Sojitz will develop and build an ammonia burner. The project will run to 2031, with the aim of building a commercial ammonia-fired cracker by the end.

SAUDI ARABIA

Ma'aden completes third ammonia plant

The Saudi Arabian Mining Company (Ma'aden) says that it has completed construction and pre-commissioning at its the third ammonia plant at Ras al Khair Industrial City, part of the Phosphate 3 Project. Trial production has now begun at the 1.1 million t/a plant, which has been built by Daelim at a cost of $893 million.

SOUTH AFRICA

Plans for large scale green ammonia plant

A joint venture between Linde, solar energy supplier Hive Hydrogen and South African investment company Built Africa have unveiled plans to build a huge $4 billion green ammonia plant at Nelson Mandela Bay in South Africa. The 800,000 t/a ammonia plant would be – once completed – the largest green ammonia unit in the world, although at present it exists only at a feasibility study stage. It is anticipated that it will take power from a neighbouring solar power project being developed by Hive Energy, as well as having access to a 1.4 GW wind energy facility for when solar power is limited. Construction is due to be completed by the end of 2025, with operations beginning in 2026.

Sasolburg to trial green hydrogen

Sasol has said that it will spend 350 million rand ($22.7 million) to repurpose an operational electrolyser at the company's Sasolburg site to produce green hydrogen. The 'proof of concept' project is aimed to be operational within two years, producing 5 t/d of green hydrogen and feeding into ammonia production at Sasolburg. Sasol is also moving to procure 60 MW of additional renewable energy from independent power producers in addition to the 620MW it is already buying from Air Liquide and other suppliers to provide electricity for the plant. The company expects to be procuring a total of 1.2 GW of renewable energy by 2030 as part of its commitment to lower its greenhouse gas emissions by 30% by that date.

MALAYSIA

Casale wins melamine contract

Southeast Asia's first grassroots melamine plant will be build using Casale technology, according to the company. The 60,000 single train plant is being constructed by Technip and Dialog Group Bhd for Petronas Fertilizer Kedah. Casale says it will supply the technology license, know-how, process design package, engineering assistance and proprietary items for the melamine plant. Additionally, because of its position as a leading urea licensor, it will also be responsible for ensuring smooth integration with the existing ammonia-stripping urea plant, which will receive the off gases of the melamine plant.

The plant will be based on Casale's *LEM*™ melamine process, which the company says offers the lowest energy consumption for both the melamine and associated urea plants; the highest urea to melamine conversion; high product quality; a low carbon footprint; and smooth integration with the existing urea plant due to the urea-based melamine off-gas scrubbing unit.

Federico Zardi, CEO and owner of Casale said: "We are very happy by this new success, especially for the detailed technical and economical selection process Casale and Technip have gone through during the dual-FEED stage of this project. Being the third melamine award in a row in the last 12 months, it clearly underlines the significant preference of the market for the cutting-edge LEM process."

BRAZIL

Hitches ahead for sale of urea plant to Acron

Brazil's state energy company Petrobras reportedly faces numerous legal hurdles in trying to conclude the sale of its Unidade de Fertilizantes Nitrogenados (UFN) 3 urea plant at Tres Lagoas in Mato Grosso do Sul state, in addition to the new issues with finance that global sanctions will create. The plant, which has a capacity of 800,000 t/a of ammonia and 1.3 million t/a of urea, was around 80% complete in 2014 when construction was abandoned. Petrobras terminated the EPC contract with Brazil's Galvao Engenharia and China's Sinopec at that time, for alleged non-compliance. However, both companies are suing Petrobras for breaching the contract, and local media reports that there are also "hundreds" of civil and labour lawsuits under way related to the sudden end of construction. Galvao was also ensnared in the subsequent Petrobras corruption scandal and filed for bankruptcy protection in 2015. Acron tried to purchase the plant in 2018-19 but negotiations came to nothing, but recent cooperation between presidents Putin and Bolsonaro seem to have put the deal back onto the front burner again.

BRUNEI

First cargoes sold from BFI

State-owned urea producer Brunei Fertilizer Industries (BFI) says that it sold its first cargoes of granular urea in early February, with two urea cargoes each of 6-7,000 tonnes being sold for delivery to Thailand and South Korea respectively. BFI has been ramping up production at the new 1.3 million t/a plant, which began produced its first commercial urea on January 23rd. ■

Syngas News

UNITED KINGDOM

INEOS to build blue hydrogen plant

INEOS says that it is aiming to forward its plans for a 'net zero' future for its Grangemouth site in Scotland by inviting major engineering design contractors to tender for the next stage of the design of a world scale carbon capture enabled hydrogen plant and associated infrastructure.

Stuart Collings, CEO INEOS O&P UK, said, "We are progressing at pace with our commitment to deliver our Net Zero plans. This will see the displacement of hydrocarbon fuels used at Grangemouth, like natural gas, with clean, low carbon hydrogen to power our processes and manufacture vital materials used across a wide range of sectors. To achieve this, we are inviting bids from the best engineering companies to design both a state of the art carbon capture enabled hydrogen production plant and… related infrastructure projects. The carbon dioxide from this project will be routed to the Scottish Cluster's Acorn CO_2 transport and storage project, resulting in reductions of more than one million tonnes of carbon dioxide emissions each year."

INEOS has already committed over £500 million ($670 million) on projects across the site including a New Energy Plant which is due to commission in late 2023. This plant will employ highly efficient technology to supply energy to all site operations and drive down emissions by at least 150,000 t/a of CO_2. It will subsequently be converted to run on hydrogen to further reduce emissions.

Access to locally produced hydrogen will have benefits for other assets at the Grangemouth Site, fuelling the existing Combined Heat and Power Plant, the KG Ethylene Plant and assets in the Petroineos Refinery. This will require a new hydrogen distribution network throughout the site and modifications to the existing fuel gas network. The project will tie into the Scottish Cluster carbon capture and storage (CCS) infrastructure. In excess of 1 million t/a of CO_2 from the hydrogen plant will be sent through existing gas pipelines to depleted offshore reservoirs under the North Sea. ■

UK government to boost production of hydrogen from biomass

The UK government has launched a new £5 million ($6.7 million) programme to help develop innovative technologies that produce hydrogen via bio-energy with carbon capture and storage (BECCS). This will involve gasification and partial oxidation of a biomass feed and subsequent carbon capture and storage, resulting in carbon negative hydrogen for use as a clean fuel. The programme forms part of the Department for Business, Energy and Industrial Strategy's (BEIS) £1 billion Net Zero Innovation Portfolio, which aims to accelerate the commercialisation of innovative clean energy technologies and processes through the 2020s and 2030s.

BEIS intends to use the Hydrogen BECCS Innovation Programme to support the development of low cost, energy and material efficient technologies which will optimise biomass and waste feedstocks for use in advanced gasification, as well as the development of advanced gasification technology components that can be used to convert biomass or waste into aviation fuel, diesel, hydrogen, methane and other hydrocarbons. It also hopes to support the development of novel biohydrogen technologies, such as dark fermentation, anaerobic digestion and wastewater treatment, which can be combined with carbon capture.

UNITED STATES

Topsoe to supply technology for renewable aviation fuel plants

Haldor Topsoe says that it has agreed to provide technologies for two renewable fuel production plants in the US. Indaba Renewable Fuels is a US-based waste-to-renewable fuels company aiming to convert a mix of plant and animal oils, fats, and grease-based feedstock into 'sustainable aviation fuel'. Indaba will construct two 6,500 bbl/d greenfield plants in California and Missouri based on Topsoe's *HydroFlex*™ technology, with production due to begin in 2024. Topsoe will also provide its *H2bridge*™ hydrogen technology to both facilities, based on a modular, efficient convection reformer technology, which further replaces fossil fuels with renewable liquids like LPG or naphtha to lower the carbon intensity of the products.

"We are excited to provide Indaba with refining technology and catalysts as they initiate production of renewable fuels in the United States. Our *HydroFlex*™ solution is designed to produce sustainable aviation fuel (SAF) based on renewable feedstock, with a minimal Carbon Intensity (CI score) compared to traditional petroleum aviation fuel," says Henrik Rasmussen, managing director, The Americas for Haldor Topsoe.

IRAN

Methanol plant shut down by gas supply issues

Iran's Kaveh methanol plant has reportedly halted production due to problems with natural gas supply. The plant, based in the southern province of Bushehr, was forced to idle after the state-run National Gas Company ordered a 50% reduction in supply of natural gas to the company and the price of gas being supplied rose to a reported $8.80/MMBtu. Kaveh Methanol said in a letter to petrochemical producers that this price was uncompetitive compared with rates in Europe and in the US, and that it would raise the price of each tonne of methanol produced to at least $430/t. Gas has been in short supply in Iran because of increased demand due to freezing cold winter temperatures.

BELGIUM

Topsoe joins Hydrogen Council

Haldor Topsoe has become a member of Hydrogen Council. Topsoe says that it hopes to promote green hydrogen solutions and accelerate Power-to-X solutions for hard to abate sectors including steel, cement, mining, and heavy transportation. It is the first Danish company to join the Council.

"We are excited to join the Hydrogen Council as it resonates very well with Topsoe's mission to help our customers reduce their carbon footprint radically every year," said Roeland Baan, CEO of Topsoe. "We look forward to cooperation with the Council's members to accelerate the deployment of green hydrogen solutions in the hard-to-abate sectors – and pass on a better world to our children."

TRINIDAD & TOBAGO

Proman agrees partnership with NGC

Proman, operator of the Methanol Holdings Trinidad Ltd (MHTL) methanol plants on Trinidad, says that it has entered into a new partnership with gas supplier National Gas Company of Trinidad and Tobago (NGC). The arrangement, effective from January 2022, provides NGC with access to methanol produced at MHTL's plants in the Point Lisas Industrial Estate which will be used to bolster the NGC's commodity and trading portfolio as well as expand its reach into international methanol markets. The first cargoes will be traded in March 2022 according to Proman. Proman will take delivery of four of its six methanol-fuelled new build vessels this year, and Proman and NGC say that they are exploring the possibility of using these low emission ships to transport the methanol cargoes.

NGC's President Mark Loquan said: "This new business collaboration between NGC and MHTL serves to strengthen the relationship between both parties by maximising the value to be derived from Trinidad and Tobago's petrochemical capacity. It also demonstrates NGC's commitment to look beyond our current business model and apply innovative thinking to create new opportunities for growing and diversifying our income streams. NGC will continue to evaluate similar value-adding activities in sustainable energy-related business, as we build our global brand of an integrated energy player, with a focus on marrying both our current business and future green business."

INDIA

Four coal to chemicals plants on the agenda

India's 2022-23 budget will include a provision for the development of four coal gasification and coal-to-chemicals pilot plants to assess the technical and financial viability of such projects, according to Finance Minister Nirmala Sitharaman. The plants will have an eventual cost of $4 billion. The announcement forms part of India's plan to emulate China's success in producing methanol and ammonia from coal. The country has set itself a target of 100 million t/a of coal gasification capacity by 2030, at the same time that it cuts coal use in power production by half.

Reliance restructuring its gasification business

Reliance Industries Ltd says that it is spinning off its gasification assets into a subsidiary. The company says that this "will provide flexibility to induct suitable strategic partners and distinct sets of investors". The $4 billion of assets are mainly based around the company's petroleum coke gasification plant at Jamnagar. Reliance says that it plans to produce blue hydrogen at a "competitive cost" of about $1.20-$1.50/kg until the cost of green hydrogen comes down, at which time the syngas from the plant will be converted to chemicals.

MALAYSIA

Memorandum of understanding on blue and green hydrogen project

Samsung Engineering, Posco, Lotte Chemical and the Sarawak Economic Development Corporation have signed a memorandum of understanding for the development of a green hydrogen and ammonia project at Bintulu. The H2biscus Project is looking to convert hydro-electric power and natural gas to green hydrogen/methanol and blue hydrogen, and for the conversion of hydrogen to ammonia, aiming to supply hydrogen and ammonia to Korea and Sarawak. The project is expected to produce 7000 t/a of green hydrogen for Sarawak's domestic market, 600,000 t/a of blue ammonia, 630,000 t/a of green ammonia and 460,000 t/a of green methanol. The feasibility study is nearing completion, after which the project is expected to move to front end engineering and design. The Bintulu site is already home to chemical process plants including the

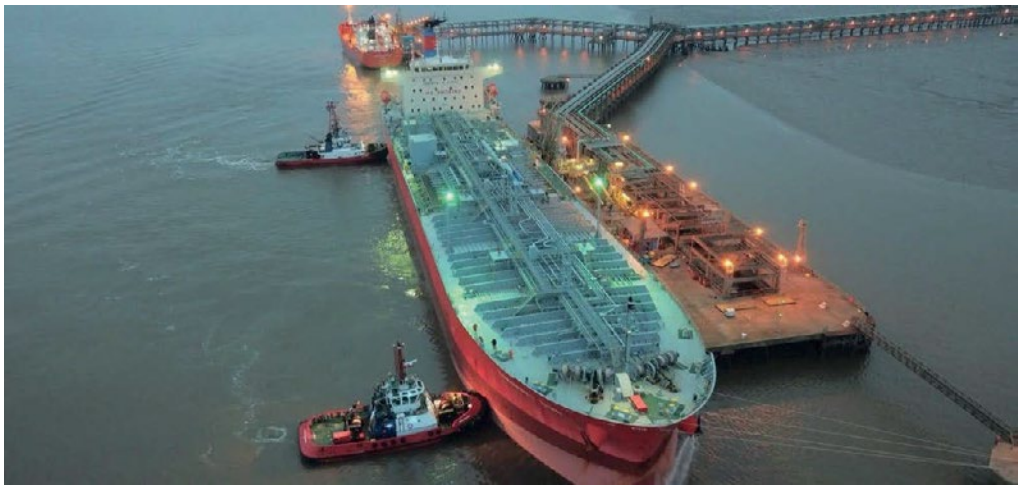
PHOTO: WATERFRONT SHIPPING

The Taranaki Sun, one of Waterfront Shipping's methanol tankers.

Petronas LNG Complex and Shell's gas-to-liquids facility.

CANADA

Methanex sells minority stake in Waterfront Shipping

Methanex says that it has completed the sale of a 40% share in its Waterfront Shipping subsidiary to Mitsui OSK Lines Ltd, at a cost of $145 million. Methanex will retain the remaining 60% majority interest in Waterfront and says it will continue to operate the company "as a key element of its global supply chain capabilities".

NETHERLANDS

Joint venture to produce syngas from biomass

Dutch energy infrastructure firm Gasunie has formed a 50/50 joint venture with Perpetual Next to produce syngas from organic waste. Perpetual Next is a developer of torrefaction technology, which converts biomass at high temperatures into a more dense 'biochar', sometimes called 'biocoal', which can then be gasified to generate syngas. The two companies will develop and build the Torrgas Delfzijl project which will accept organic waste streams, green waste and scrap wood by barge for conversion into 'green gas'. The plant will be sited in the Delfzijl chemical cluster, part of Chemport Europe. Perpetual Next will manage and operate the plant and Gasunie will distribute the gas which will be delivered underground to the built environment and industry via the national network. The project is expected to be operational by 2024 and start with green gas production of 12 million m^3 per year.

"The collaborations with Gasunie and the location of Chemport Europe are strategically important to us," said Martijn van Rheenen, co-founder of Perpetual Next. "It's great to see that, in this way, the region will once again be supplying gas, but a future-proof alternative. The availability of raw materials, the space to build production facilities with new clean technologies, and the knowledge and expertise available make this the perfect environment."

Ulco Vermeulen, member of Gasunie's executive board, commented: "The goal in the Climate Agreement is to produce 2 billion m^3 of green gas by 2030. With other parties, we are working to make green gas affordable and bring it to the market on a large scale. This project is in line with that ambition, and we are very confident that together we will achieve a sustainable, successful, and technologically advanced project."

SOUTH AFRICA

Plastics to syngas power plant project

Irish based Kibo Energy has signed a 10 year power purchase contract with Sustinieri Energy for the power to be generated from a 2.7 MW plastics to syngas plant at an industrial park in Gauteng province, which encompasses Johannesburg and Pretoria. Sustinieri Energy is a 65-35 joint venture between Kibo and Industrial Green Energy Solutions (IGES). The facility will take non-recyclable plastics, which can no longer be deposited to landfill according to changes to South African law. The plastic waste will be pyrolised at 400°C to produce syngas, which is then burned to power a gas turbine. Sustineri Energy has awarded the engineering, procurement and construction (EPC) contract for the plant to Lesedi Nuclear Services. The capital cost of the project is expected to be $12 million, with financial close planned for 3Q 2022. Thereafter, the construction phase will take about 11 to 14 months to complete.

SAUDI ARABIA

Chemanol to expand methanol production

Saudi Arabian chemical producer Chemanol says that it is to proceed with plans to increase production at its methanol plant at Al Jubail by 100,000 t/a to 330,000 t/a, and that it has signed an agreement for the plant's basic engineering design, though the contractor was not specified. Chemanol, formerly the Saudi Formaldehyde Chemical Company, is one of the world's largest producers of formaldehyde, with a capacity of 1.0 million t/a. Additional methanol will be used as feedstock for new side streams, including dimethyl disulphide plant and methyl diethanolamine, according to the company.

INDONESIA

Work begins on coal gasification plant

Construction has begun on a new coal gasification based dimethyl ether (DME) plant at Murara Enim on South Sumatra. The plant will consume 6 million t/a of coal supplied by state coal miner Bukit Asam to produce 1.4 million t/a of DME. The aim is to use the DME as a blendstock for LPG in order to reduce Indonesia's exports of LPG, which stood at 6.4 million t/a in 2021. The plant is being built by Bukit Asam, operating in partnership with Air Products and Chemicals, Inc. Construction is slated to take 30 months and state energy company Pertamina is expected to take the DME produced from the plant.

EGYPT

Approval for waste-to-hydrogen plant

Egypt's Suez Canal Economic Zone has given H2 Industries preliminary approval for a $3 billion waste-to-hydrogen plant at Port Said. The plant will gasify 4 million t/a of organic and non-recyclable waste to produce 300,000 t/a of hydrogen at a site at the northern Mediterranean entrance to the Suez Canal. Michael Stusch, executive chairman and chief executive of H2 Industries, told local media that the plant is so far at the feasibility study stage, and is still subject to final approval from the General Authority of the Suez Canal Economic Zone. Construction time is estimated to be five years. ■

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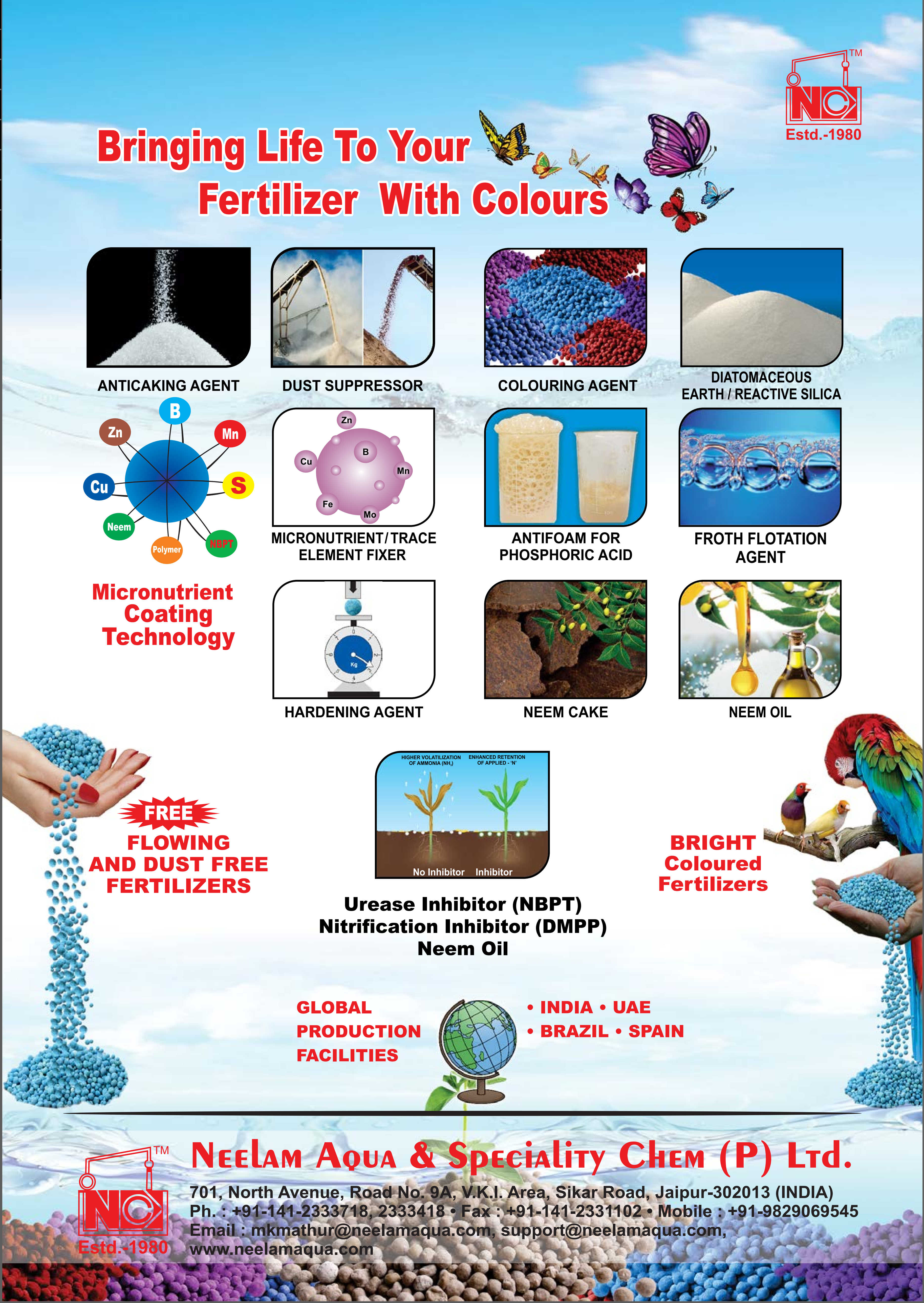
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Email : mkmathur@neelamaqua.com, support@neelamaqua.com,
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People

Haldor Topsoe has appointed **Elena Scaltritti** as the company's new chief commercial officer. She will take up her new position no later than July 1st, 2022. She has previously been executive vice president at Korea's SONGWON Industrial Group, where she was responsible for the group's commercial activities.

"I'm excited and very much looking forward to work with Elena. She has solid chemical industry experience and a strong commercial background. With Elena's hands on experience of driving growth, working with commercial excellence, key account management, and pricing, she can secure our leading position in existing markets and help us accelerate Topsoe's position in the green energy market," said Roeland Baan, CEO at Topsoe.

Ib Jensen has been appointed the new CFO at Perstorp Holding AB as of February 1st. Previously, Jensen was CFO at Arxada, a spin off from Lonza Specialty Ingredients. He has also held CFO and executive roles within finance and IT companies such as Lonza, Syngenta, Danisco and LEGO.

Perstorp President & CEO Jan Secher comments: "It is with great pleasure we welcome such a seasoned executive in to our team and the CFO role. In particular I value the highly relevant experience from our industry, however most importantly, Ib has a great personality and I am convinced he will fit in to our already diverse team and contribute to future value creation in a very successful way."

Ib Jensen takes over the CFO role from **Ulf Berghult**, who will leave Perstorp in April.

In the first quarter of 2021, Perstorp redefined its business strategy to become a leading sustainable solutions provider, focusing on the global Resins & Coatings, Engineered Fluids and Animal Nutrition markets. This strategic direction will see Perstorp focus its specialty chemicals growth initiatives primarily on selected customer segments where innovation and services are prioritised, and with a focus on Asia as the main driver for future growth. Perstorp's strategy also reconfirms the company's aspiration to be among the front-runners in sustainability.

BASF Corp., the North American affiliate of Germany-based chemical company BASF SE, has named a new chairman and CEO. **Michael Heinz** takes over the leadership role for the New Jersey-based company, succeeding **Wayne T. Smith**, who led the business for six years. Heinz has been with BASF for almost four decades, including more than a decade in US leadership roles.

"I am eager to take over responsibility for one of BASF's major markets and to further develop our strong presence in the North American region," Heinz said. "Given my experience with BASF in the United States, I am honoured by this appointment, as it allows me to lead an outstanding team and, at the same time, return to a country that feels like a second home to me."

Heinz will remain a member of BASF SE's board of executive directors, a role he has held since 2011. He is also responsible for the global Chemicals and Materials business segments as well as the South America region.

Elena Scaltritti.

! The following events may be subject to postponement or cancellation due to the global coronavirus pandemic. Please check the status of individual events with organisers.

Calendar 2022

MARCH

28-30

Nitrogen+Syngas Conference 2022,
BERLIN, Germany
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

31 MARCH – 2 APRIL

IFA Annual Conference,
NEW DELHI, India
Contact: IFA Conference Service,
49 Avenue d'Iena,
Paris, F75116, France
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

APRIL

25-27

Syngas 2022,
BATON ROUGE, Louisiana, USA
Contact: Betty Helm, Syngas Association
Email: betty@syngasassociation.com
Web: www.syngasassociation.com

MAY

2-4

Nitrogen+Syngas USA Conference 2022,
TULSA, Oklahoma, USA
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Fax: +44 (0) 20 7903 2172
Email: conferences@crugroup.com

31 MAY – 2 JUNE

China International Fertilizer Show 2022,
SHANGHAI, China
Contact: CCPIT Sub-Council of Chemical Industry, Beijing
Tel: +86 10 84 255 960
Email: zhengyingying@ccpitchem.org.cn

JUNE

2-3

NH3 Event Europe 2022,
ROTTERDAM, Netherlands
Contact: Stichting NH3 event Europe,
Karel Doormanweg 5,
3115 JD Schiedam, The Netherlands
Tel: +31 10 4267275
Email: info@nh3event.com

9-10

32nd IMPCA Methanol Mini-Conference,
PORTO, Portugal
Contact: IMPCA, Avenue de Tervueren
270 Tervurenlaan, 1150 Brussels, Belgium
Tel: +32 2 741 86 64
E-mail: info@impca.be

12-15

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

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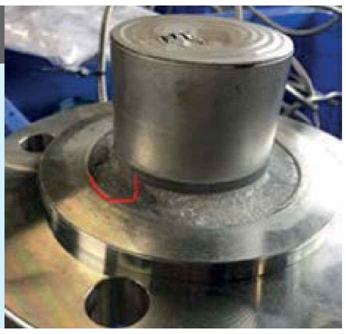
Plant Manager+

Incident No. 6 Corrosion in gasket area

This case study refers to the carbamate condensers and separators in the urea recirculation and hydrolyser desorber section of a urea plant, operating under normal operation at 0.3 MPa and 75°C. After 48,000 hours of operation, during the turnaround of the urea plant, the diaphragm type instruments were sent to the original equipment manufacturer for inspection and refurbishment. In addition to damage of the diaphragm, crevice corrosion was found in the gasket area (see picture) posing a health and safety risk.



Warning signs and immediate response

Finding corrosion upon inspection during a turnaround prompted immediate replacement of the transmitter.

Causes

A chromium oxide layer should protect the material from high corrosion rates. A continuous supply of fresh oxygen should be secured at any wetted surface to assure this chromium oxide layer. Here one sees severe corrosion phenomena in the gasket area, which means that ammonium carbamate could enter between the gasket and the flange face. The oxygen in the trapped ammonium carbamate liquid will be consumed and at a certain moment instead of passive corrosion, active corrosion starts with a corrosion rate which is much higher. The chromium content of Hastelloy C276 is too low to assure a passive chromium oxide layer under these circumstances. In case a weld is applied in these areas, the heat affected zones are typically even more sensitive to corrosion.

Consequences

Potentially a leak can occur resulting in loss of containment.
A subsequent unplanned shutdown could cost >$1 million.

Prevention safeguards

1. Perform corrosion inspections during the turnaround.
2. Apply better materials like 25-22-2 (or zirconium) in these critical areas.
3. Proper gasket design, conditions, installation, and torquing are critical factors to avoid these problems.

Mitigation safeguards

In case of a leak, confirm and locate the leak, shut down the plant and drain the synthesis section as soon as possible.

Comments

Hastelloy C276 is not a suitable material for this application, typically 316L or 25 -2 2-2 is applied in these sections. When applying 316L stainless steels the gas phase should be properly traced and insulated to avoid condensation corrosion and crystallisation of carbamate. The tracing should be such that the temperature of the diaphragm is higher than the condensation temperature of carbamate at the operating pressure.

A brownish colour is normal, there could be oil or some chromium/iron oxide products from the unavoidable passive corrosion of stainless steels in carbamate solutions. In the gas phase one typically sees some blueish colour.

The damage to the diaphragm itself shown in the picture appears to be mechanical damage (external impact) or may have happened during removal of the transmitter from the process. Proper care when removing and installing these instruments is advisable.

This case study report is taken from UreaKnowHow.com's Fertilizer Industry Operational Risks Database, FIORDA.

The future of Europe's nitrogen industry

PHOTO: YARA INTERNATIONAL

High feedstock prices and regulatory burdens continue to put pressure on European nitrogen producers to innovate.

Above: Yara's Sluiskil plant, Netherlands.

If any continent can be said to have invented the modern nitrogen industry, then it is Europe. It was there in 1909 that Fritz Haber invented the process for ammonia production that bears his name, and where Carl Bosch subsequently commercialised it for BASF. It was where in 1902 Wilhelm Ostwald invented the ammonia route to nitric acid manufacture that has become the basis of all commercial nitrate production. Using synthesis gas from partial combustion of coal, the ammonia industry first took off in Europe between the First and Second World Wars, and by 1960 the continent still represented two thirds of all global ammonia production. It remains the home to many of the companies that pioneered ammonia and urea production, such as Casale, Yara (formerly Norsk Hydro) and BASF.

In spite of the massive growth in nitrogen production and use that has occurred around the world in the intervening six decades, particularly in China, the European Union is still responsible for around 9% of global nitrogen production and 11% of consumption, according to 2020 figures; much larger than the continent's share of other fertilizer nutrients such as phosphorus or potash. However, while it still represents €10 billion in annual turnover and employs 74,000 people, according to industry body Fertilizers Europe, the European nitrogen industry continues to have to contend with high feedstock prices and the regulatory ambitions of the EU at the same time that it faces stiff competition from imports from Russia, Trinidad and the Middle East. Even so, it has managed to carve out a niche for itself and continues to pioneer developments in production efficiency as well as some of the 'green' technologies that will shape the industry over the next 60 years.

Nitrogen demand

European nitrogen fertilizer demand was 11.2 million tonnes N in 2020. Some 60% of this was accounted for by nitrates, mainly straight ammonium nitrate, but also calcium ammonium nitrate and urea ammonium nitrate. Urea use represented another 20% of fertilizer demand, with various NPKs and speciality fertilizers making up the rest. On top of this, another 2.8 million t/a of ammonia and derivatives goes to a variety of industrial processes, including urea solutions for exhaust cleaning ('AdBlue'), fibre production – especially nylon, polyurethanes, nitrobenzene and so on.

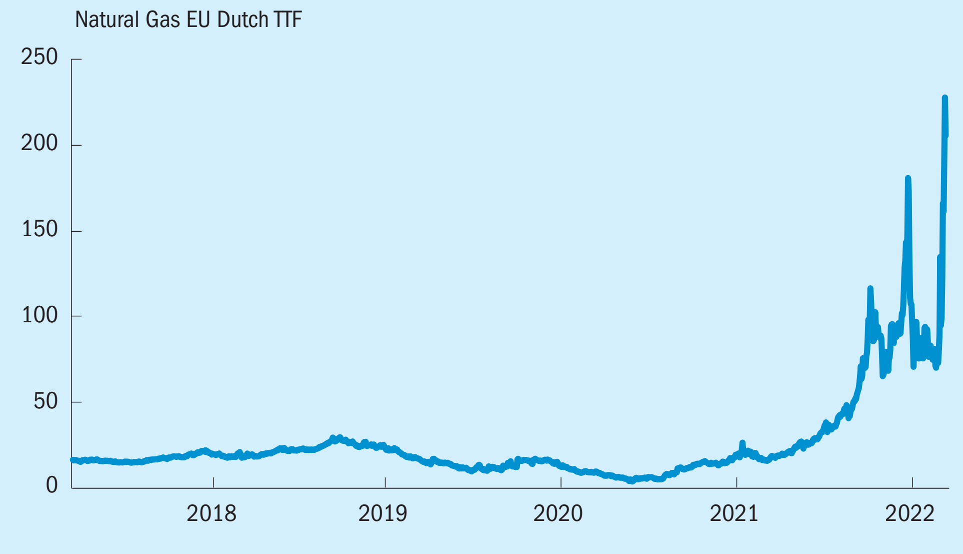
Around 60% of EU fertilizer demand is accounted for by wheat, coarse grains (barley, rye, oats, maize etc) and oilseed rape. European agriculture is mature, and demand for nitrogen fertilizer has remained essentially unchanged since the 1990s, at around 11 million tonnes N. However, projections for the period 2021-2031 by Fertilizers Europe show a decline in nitrogen consumption of 6% due to tightening environmental regulation.

'Farm to Fork'

The European Commission's view of future nitrogen consumption in the EU is set out in its 'Farm to Fork' and 'Biodiversity' strategies published in May 2020, as part of its 'Fit for 55' initiative to reduce greenhouse gas emissions by 55% by 2030. Of particular concern is nitrous oxide, N_2O, which is released from the breakdown of nitrogen fertilizers and manures in fields, and which is responsible for 2.4% of all global greenhouse gas emissions (6% in countries such as the US and an estimated 10% in the EU). Therefore, in relation to plant nutrients, the EC's ambition is to reduce nutrient losses to the environment from both organic and mineral fertilizers by at least 50%, while ensuring no deterioration in soil fertility. This is expected to result in a 20% reduction in fertilizer use. It hopes to achieve this via a focus on nutrient use efficiency (NUE). The EU is already fairly efficient in terms of NUE; NUE for nitrogen – defined as the amount of nitrogen taken up by plants compared to the amount applied to the soil – rose from 50% in 1990 to 59% in 2004 according to OECD figures. The EU hopes to improve this to 80% by 2030, although this is starting to approach the theoretical maximum; the EU Nitrogen Expert Panel has established a maximum theoretical threshold of 90% NUE to account for natural nitrogen losses while avoiding the deterioration of the soil's fertility – above 90% efficiency the soil becomes degraded. Fertilizers Europe has argued that the 90% target is too stringent, points to studies conducted by the US Department of Agriculture, the Joint Research Centre of the EU (JRC), and Kiel and Wageningen universities which have all concluded that the impact of a 40-60% reduction in greenhouse gas emissions from European agriculture stemming from the implementation of Farm to Fork targets will lead to outsourcing European agricultural production, leading to the kind of 'carbon leakage' that has been seen with the ammonia industry, as well as reducing EU food production by 10-20%, leading to imports and possibly food insecurity. FE argues that more reasonable NUE target would be 70%, mid-way between the 90% maximum and the figure of 50% below which there are significant losses to the environment.

Either way, there is going to be pressure on European farmers to improve nutrient uptake via techniques such as precision agriculture, nutrient management plans, balanced and timely nutrient application, and enhanced efficiency and controlled release fertilizers. As stated, the EU envisages a fall in fertilizer use by up to 20% by 2030, while Fertilizers Europe puts the figure at around 6%, but it could be reasonable if we were to assume a 10% drop in EU agricultural nitrogen consumption by the end of the decade, or around 1 million tonnes N.

Fig. 1: **Dutch TTF natural gas prices, €/MWh, 2017-present**



Source: Trading Economics

Nitrogen production

Europe has 18.5 million t/a (15.2 million tonnes N) of ammonia capacity remaining, at 36 sites (see Table 1). About 40% of this is concentrated in Germany, Poland and the Netherlands. In terms of company ownership, Yara has the largest capacity, at 4.5 million t/a, spread widely across the continent. Grupa Azoty in Poland has another 2.0 million t/a, from the merger and takeover of most of the old Polish plant operating companies. Austrian-based Borealis, with facilities in France and Linz has another 1.5 million t/a, although the company has been trying to exit the nitrogen business for some years. It sold its Harfleur plant to Yara in 2014 and announced in February this year that it had reached a deal for its entire remaining nitrogen business in Europe with EuroChem, for a reported value of €455 million. However, EuroChem, though headquartered in Switzerland, is primarily a Russian fertilizer producer, and the impact of the current sanctions regime against Russia remains to be seen.

Downstream capacity is mainly based around ammonium nitrate and derivatives. There is 7.5 million tonnes N of AN melt capacity (22 million tonnes product), divided between ammonium nitrate fertilizer (73%), industrial grade AN (3%), and calcium ammonium nitrate (22%), the remainder going to NPK production. There is also 5.2 million tonnes N of urea capacity (11.3 million tonnes product).

European nitrogen capacity has been gradually closing over the years. The past decade has seen plants in Portugal and at Hull in the UK close, and two Romanian plants fall into bankruptcy and become idled before being bought up, refurbished and re-started. The Pancevo plant near Novi Sad in Serbia likewise has been shut down due to bankruptcy but new owner Promist says that it intends to return it to working order. On the other hand, expansions and debottlenecks at other sites have kept actual operating capacity in Europe fairly constant.

Feedstock price

The major issue for European producers has been the price of natural gas feedstock. European gas prices have traditionally been higher than those elsewhere in the world, particularly places with cheaper gas where export-oriented capacity grew up during the 1980s and 90s, such as the Middle East, Trinidad and Russia and the CIS states. More recent additions to that list have included Nigeria. European producers have the advantage of nearby markets and developed distribution chains, as well as production integrated into other sites, especially on the industrial side. However, at times of expensive gas and cheap freight rates this has not been

Table 1: **European ammonia capacity, t/a**

Country	Company	Site	Capacity
Austria	Borealis	Linz	500,000 t/a
Belgium	BASF	Antwerp	590,000 t/a
	Yara	Tertre	400,000 t/a
Bulgaria	Neochim	Dmitrovgrad	450,000 t/a
Croatia	Petrokemija	Kutina	450,000 t/a
Czechia	Chempetrol	Litvinov	350,000 t/a
Estonia	Nitrofert	Kothla-Jarve	165,000 t/a
France	Borealis	Grand Quevelly	380,000 t/a
	Borealis	Grandpuits	380,000 t/a
	Borealis	Ottmarsheim	215,000 t/a
	Yara	Harfleur	400,000 t/a
Germany	BASF	Ludwigshafen	800,000 t/a
	Ineos	Cologne	300,000 t/a
	SKW Piesteritz	Piesteritz	1,100,000 t/a
	Yara	Brunsbuttel	750,000 t/a
Greece	Kavala Ferts	Nea Karvali	165,000 t/a
Hungary	Nitrogenmuvek	Petfurdo	545,000 t/a
Italy	Yara	Ferrara	760,000 t/a
Lithuania	Achema	Jonavos	990,000 t/a
Netherlands	OCI	Geleen	1,100,000 t/a
	Yara	Sluiskil	1,900,000 t/a
Norway	Yara	Porsgrunn	500,000 t/a
Poland	Anwil	Wloclawek	500,000 t/a
	Grupa Azoty	Police	1,200,000 t/a
	Grupa Azoty	Kedzierzyn	180,000 t/a
	Grupa Azoty	Pulawy	280,000 t/a
	Grupa Azoty	Tarnow	380,000 t/a
Romania	Chemgas	Slobozia	330,000 t/a
	Azomures	Targu Mures	470,000 t/a
	InterAgro	Donau	330,000 t/a
Serbia	Promist	Pancevo	(300,000 t/a)
Slovakia	Duslo	Sala Nad	430,000 t/a
Spain	Fertiberia	Palos	370,000 t/a
	Fertiberia	Puertellano	200,000 t/a
UK	CF Fertilizers	Billingham	500,000 t/a
	CF Fertilizers	Ince	350,000 t/a

Source: BCInsight

enough to allow European plants to keep operating.

The problem with European gas prices was that Europe has become an increasing importer of natural gas, particularly from Russia, though also increasingly as LNG. In both cases contracts were often priced via oil related benchmarks, rather than via gas on gas competition. In both cases the past decade or so has seen oil indexed pricing retreat from Russian gas and LNG, and European gas prices had been falling, especially once the covid pandemic began. Several closed ammonia plants in eastern Europe were restarted during this time. But the past year has seen gas prices soar for a variety of reasons, as we detailed in the article in our previous issue (Jan/Feb 2022, pp16-18). The outbreak of war in Ukraine has merely compounded these worries, and as Figure 1 shows, the Dutch TTF benchmark gas price had at time of writing reached unprecedented levels of over €200/MWh, at times touching €345/MWh on spot markets, equivalent to $110/MMBtu! €200/MWh is approximately equivalent to $65/MMBtu; equivalent to more than $2,000 per tonne of ammonia.

While it can only be hoped that this is a temporary situation, it highlights the risk posed to European fertilizer producers by the continent's dependence on Russian natural gas. It could be that the current oil and gas price shock behaves much like the one of 1973 in changing attitudes to fuel economy, decarbonisation etc. The International Energy Agency recently promulgated a ten-point plan for Europe to wean itself off this dependence. This includes:

- Ending new contracts with Russian gas producers.
- Maximising use of alternate sources (LNG, Norway, Algeria etc).
- Introducing minimum gas storage requirements to enhance market resilience.
- Accelerate the deployment of renewable energy projects.
- More production from low carbon sources such as nuclear and bioenergy.
- Short term measures to protect vulnerable consumers from high prices.
- Increased replacement of gas boilers with heat pumps.
- Accelerate energy efficiency measures.
- Encourage temporary thermostat adjustment by consumers.
- Flexibility measures to reduce industrial electricity and gas demand in peak hours.

Green production

One of the ways that European nitrogen producers are being encouraged to move is towards greater use of renewable energy to generate hydrogen feeds, or carbon and capture and storage for existing facilities; 'green' and 'blue' production respectively. While these have traditionally been thought of as expensive production routes, the natural gas prices of the past year make that assumption far less tenable. The additional effects of carbon pricing, as discussed elsewhere in this issue, also offer low carbon production routes a financial boost.

The past two years have seen a flurry of project announcements for green or blue ammonia production, with locations clustered in Australia, the Middle East and Europe. In Europe, Yara has announced the ambition of eventually fully converting its Porsgrunn ammonia plant to electrolysis, though in the initial phase this will be about 20,000 t/a of green production by 2023. Hy2Gen recently announced a 200,000 t/a green ammonia project for Sauda in southwest Norway. There is also a larger, 1.0 million t/a 'Barents Blue' project in Norway which would use carbon capture and storage, with start-up around 2026, and Norwegian based Equinor is also discussing a 300MW electrolysis to ammonia plant for the UK's Humber estuary. A smaller green ammonia plant is proposed for the Orkney Islands. Denmark also has two low carbon ammonia projects planned, one project at Ejsberg to produce 300,000 t/a of green ammonia form 2026, and another smaller 10,000 t/a project to start up in 2023. Fertiberia is working with Swedish partners on a 500,000 t/a green ammonia plant in Norbotten. Borealis has signed a deal to partially convert its hydrogen feed at Ottmarsheim to electrolysis by 2025, producing 24,000 t/a of green ammonia. No doubt not all of these projects will proceed to fruition, but equally without doubt there will be further project announcements.

It is easy to overstate the impact of green production. Probably only 10% of ammonia production will be using electrolysis by 2030, but it offers an opportunity for European producers to take advantage of lower cost renewable energy and carbon credits.

Imports

Imported nitrogen represents about 30% of European consumption, with Russia, Belarus, Egypt and Algeria some of the major suppliers. In 2020, Europe imported 2.9 million tonnes N of ammonia (3.5 million tonnes product), 1.3 million tonnes N (45%) of that from Russia, and 2.2 million tonnes N (4.8 million tonnes product) of urea, 0.65 million tonnes N from Russia. There was also some ammonium nitrate and CAN, though relatively small volumes. The EU and UK have imposed anti-dumping duties on Russian AN which has diverted exports elsewhere. However, the current war in Ukraine seems sure to affect ammonia and urea exports; some 2.4 million tonnes of ammonia passed through the port of Odessa in 2021.

The future

European fertilizer producers continue to face pressures from EU environmental measures and high feedstock prices. This has forced them to pursue more efficient operations – Europe is the world's most efficient region for ammonia production in terms of energy use. Automation and smart working are also assisting with boosting operating efficiency. Many manufacturers have also looked to monetise expertise in fertilizer marketing and distribution and farm advisory services. There is a focus on higher value, speciality products and tie ins with other industrial side streams such as melamine production.

While the burden of EU regulation has driven some manufacturers out of the region or out of business altogether, there are signs that the EU is adopting a more pragmatic may of working via its Carbon Border Adjustment Mechanism which may actually benefit those producers who invest in low carbon technologies. However, the best answer to continuing competitiveness will be a solution to Europe's ongoing natural gas supply problem. ■

China turns green: a 100 MW floating solar photovoltaic project in Anhui Province.

PHOTO: SUNGROW

Emissions trading after COP-26

The COP-26 summit in Glasgow last year signed into force new rules on carbon emissions trading which may gradually start to see carbon pricing spread worldwide, with knock-on effects on emissions intensive industries like ammonia and methanol.

Controlling emissions of carbon dioxide and equivalent gases in order to mitigate the worst effects of man-made climate change has become one of the defining issues of the first half of the 21st century. However, actually achieving change on the scale required is a long and difficult process. There is general agreement that change on a planet-wide scale will require the cooperation of governments around the world, but how to produce and more importantly enforce that cooperation is a vexed issue.

The first major step in organising international cooperation was the United Nations Framework Convention on Climate Change (UNFCCC), which was signed in 1994 by 154 countries – this has now expanded to 165, as well as 32 other 'parties', mainly groupings of other countries such as OPEC and the European Union. The UNFCCC established a series of principles for tackling climate change, as well as mandating a series of regular summits, called the Conference of the Parties (COP) to discuss and ratify agreements.

The first significant fruit of this was the 1997 Kyoto Protocol, which finally achieved the number of signatories for ratification in 2005. This set binding targets on emissions reduction, mainly for developed countries, and created a set of new legal instruments for emissions reductions and removals to be tracked and traded via so-called 'flexibility mechanisms'. The guiding principle was to set a price for carbon emissions which could then be traded via international emissions trading (IET), as well as encouraging projects which could be 'offset' against carbon emissions. These had two forms; Joint Implementation (JI), projects which operated between developed ('Annex 1') countries, and Clean Development Mechanism (CDM), projects which were based in developing countries, but which could be used to meet developed country climate targets. The nitric acid industry in particular has been the beneficiary of a number of JI and CDM projects, as relatively inexpensive modifications can significantly reduce the emission of nitrous oxide (N_2O), which has a global warming potential 300 times that of the equivalent weight of CO_2.

However, outside of this area, there were concerns with the mechanisms for ensuring that projects were actually achieving any meaningful reductions in greenhouse gas emissions, leading to accusations of 'greenwashing'. A 2017 EU Commission study found that 85% of projects funded by the CDM had not in fact reduced carbon equivalent emissions.

Emissions trading

The flexibility mechanisms led to the emergence of emissions trading schemes such as the European Union Emission Trading System (ETS), and similar systems for California, China and the UK, as well as voluntary markets such as the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). In theory, by controlling the number of credits and progressively reducing them, it would give a monetary value to industries which emit large amounts of CO_2 or equivalent and give a financial incentive to developing and deploying abatement technologies.

In practice, however, the EU ETS suffered initially from over-caution on the part of European governments as to the impact on industry, and too many credits being made available. This meant that up until the mid-2010s the price of a European carbon credit was only €3-5/tonne CO_2e, offering little incentive to reduce emissions. Because the scheme only applied within the EU, it also encouraged more polluting industries to move to jurisdictions with less stringent regulation; so-called 'carbon leakage'.

Attempts to fix issues with emissions trading systems were incorporated into the 21st meeting of the Conference of Parties (COP-21) in Paris in 2015, via Article 6.

However, binding rules to actually put these into operation were not agreed at COP-21, and indeed languished for several more years of argument before a breakthrough was finally achieved towards the end of the most recent Conference of the Parties, COP-26 in Glasgow in November 2021. COP-26 has therefore set a new framework for carbon trading which is likely to significantly impact industries such as fertilizer production over the coming years.

The new rules – ITMOs

Article 6.2 covers voluntary cooperation and allows a country that achieves better than its climate target to transfer carbon credits as Internationally Transferred Migrations Outcomes (ITMOs) to another country to assist in meeting the other country's targets. The new rules clarify that countries can make their own bilateral and multilateral arrangements to trade carbon credits, but it also tightens up the wording to avoid the kind of double counting that had become a problem with the old JI/CDM system. It also obliges countries to denominate ITMOs in either tonnes CO_2e, or another non-greenhouse gas metric (such as renewable energy targets). Through this accounting framework, ITMOs might function as a kind of standard international carbon credit, representing either one tonne of CO_2e, or another appropriate metric.

The new rules will also require a "transaction fee" whenever carbon credits are purchased, meaning that buyers will have to pay a fee, as well as giving 5% of credits purchased to a fund that helps poor countries adapt to climate change.

The sustainable development mechanism

Article 6.4 covers the so-called sustainable development mechanism (SDM). This is a centralised mechanism, governed by the United Nations and overseen by a new Supervisory Body which replaces the old JI/CDM offset mechanisms, and allows private companies or countries to trade emissions reductions, generating credits from emissions avoidance or removal activities in the host country such as renewable energy installations, tree planting etc. Private companies can be project financiers, developers, and operators of SDM activities. But the rules clarify that SDM activities can only generate credits for "real, measurable and long-term" emissions reductions, as measured against a hypothetical "business as usual" baseline scenario. This covers one of the complaints about previous JI/CDM projects; that many of them would have occurred anyway without the added incentive of carbon credits, and hence had not been as a result of carbon credits.

SDM projects must apply best available technologies which are economically feasible and environmentally appropriate for each activity or achieve the average emissions level of the best-performing comparable activities. All must be formally registered with the new SDM Supervisory Body, composed of UNFCCC member state representatives.

Although JI and CDM mechanisms no longer work, the SDM does allow the carryover of carbon credits from CDM projects registered since 2013. This caused much discussion and debate, with the German delegation objecting to the carryover of credits which could be for 'low quality' projects that brought few tangible emissions control benefits. However, the end result is a compromise aimed at balancing concerns about flooding carbon markets with economic interests and the interests of project developers holding large volumes of legacy carbon credits.

Non-market approaches

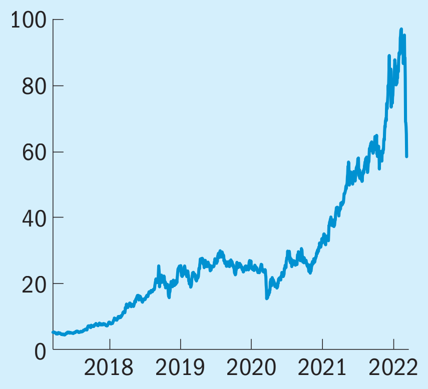
Article 6.8 sets out a third type of voluntary cooperation; "non-market approaches" to reduce emissions. While the term is purposely left undefined, it tends cover climate commitments, initiatives, pledge programmes, roadmaps, or statements made by stakeholders, such as the Global Methane Pledge, in which 100 countries signed up to reducing methane emissions by at least 30% compared to 2020 levels by 2030. It also includes the Glasgow Financial Alliance for Net Zero; a coalition of 450 asset owners, banks, and insurers holding around $130 trillion in assets who pledged to cut emissions from their investing and lending activities to net zero by 2050.

Carbon pricing

The aim for carbon pricing mechanisms is to generate a sufficient cost or incentive via carbon credits/penalties to drive investment in less polluting technologies. As noted earlier, the EU's ETS generated carbon prices of only around €5/tonne by 2017, although its subsequent round of credit issuance had fewer available credits, leading to prices rising to around €25/tonne from 2018-2020, and €50/tonne in 2021. Since the end of COP-26, this has continued to rise (see Figure 1), peaking in early February at just under €100/tonne. The outbreak of war in Ukraine has led to a slump back towards €65/tonne CO_2e, though the long-term impact is nevertheless expected to be bullish as natural gas supplies are restricted. High gas prices make it more economical for some generators to burn coal, which produces around double the amount of carbon dioxide emissions as gas plants and requires more permits.

Carbon pricing can have an effect. The UK government doubled carbon prices in 2013 compared to the EU ETS price, which helped pushed down coal's share of power generation in the UK from around 30% to close to zero by 2020. However, in order to work as intended, the carbon price has to reach a sufficient level. The UN estimates that the carbon price required to cut emissions by 30% by 2030 would be around $40/tonne, and it is estimated that for carbon capture and storage (CCS) to be commercial it requires a carbon price of $60-100/tonne, while existing direct air capture (DAC) processes require up to $200/tonne to break even. Nevertheless, as companies set about meeting net zero targets, it is expected that there will be an upsurge in demand for carbon credits, and companies involved in the field expect that the price of carbon offsets is likely to rise to around $50/tonne over the next few years. This could produce a market worth close to $200 billion per year by 2050.

Fig. 1: **EU ETS carbon prices, 2018-present**



Source: Trading Economics

A recent Reuters survey of several ETS market analysts indicated that EU carbon allowances (EUAs) are expected to average €84/tonne in 2022 and €92/tonne in 2023, potentially rising to €94/tonne CO_2e in 2024.

Impact on nitrogen producers

The EU has led the way on ETS schemes. Within the EU, all eyes have been on proposals from the European Commission for its Carbon Border Adjustment Mechanism (CBAM). The EU has set itself the goal of achieving carbon neutrality by 2050 via the so-called European Green Deal. The CBAM is a way of regulating carbon intensive industries such as ammonia and cement manufacture via a tariff on products from outside the EU which are not regulated by current emissions trading schemes, to create a level playing field for EU producers, while still encouraging lower emission technologies.

At present under the EU ETS, ammonia producers are allocated a free allowance of carbon credits based on the benchmark calculated by reference to the lowest 10% emitting ammonia producers in the EU. The idea is to encourage producers to use the best available techniques to lower emissions to the current benchmark, and enable those deploying green technologies which lower emissions below the benchmark to monetise their allowance. The CBAM extends this system, continuing with the 'free' benchmark allowances of carbon credits, while attempting to impose the same costs on imports of ammonia by requiring importers to acquire and surrender CBAM certificates for carbon emissions to the extent that they are in excess of the benchmarks. By setting the benchmarks against conventional gas-based ('grey') ammonia production, it also continues to incentivise 'blue' and 'green' ammonia production. The CBAM is due to start recording carbon reporting statistics in 2023, with the scheme proper beginning in 2026 and running in its present form at least until 2030.

Fertilizers Europe, covering fertilizer producers across the continent, has broadly welcomed the CBAM, as it in theory at least ceases to uniquely penalise EU industry compared to producers elsewhere in the world, and so avoid the issue of carbon leakage, provided that the benchmarked free allowances system continues. The devil, of course, is likely to be in the detail.

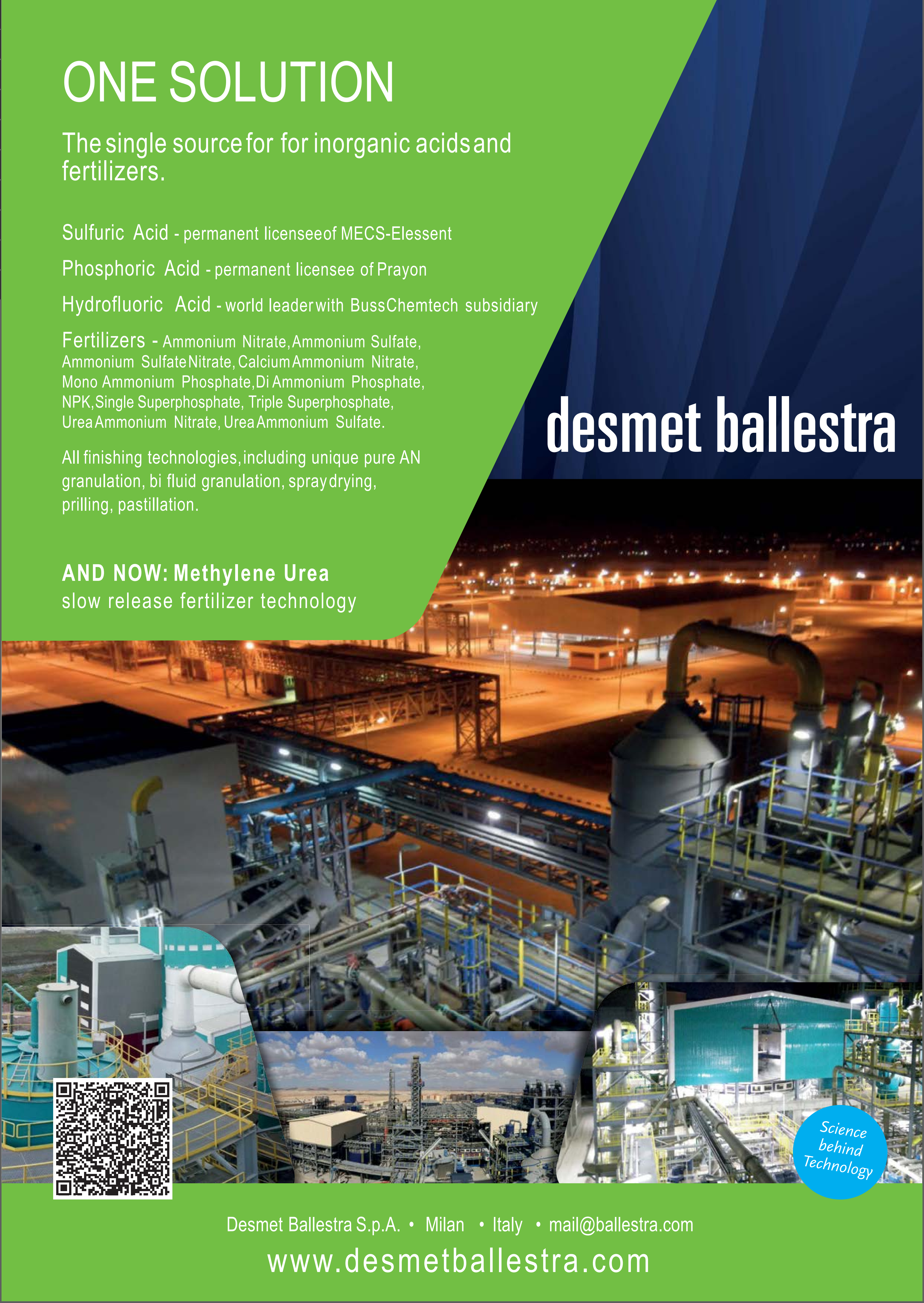
Worldwide

Elsewhere, China began a national ETS in 2021, though it is currently solely focused on the power sector. It also allocates sectoral credits via a benchmarking system. Though it only covers 40% of China's emissions, that is still 12% of the global total, and already makes the Chinese ETS larger than the EU one in terms of volume. As yet the scheme does not cover chemical industries such as ammonia and methanol, of which China represents 26% and 60% of global production respectively, but the Chinese government is reportedly concerned about the potential impact of the EU CBAM on e.g. urea markets, and may start to move to a similar system to the EU ETS, covering all major polluting industries, over the next couple of years. However, Chinese carbon prices have languished below $10/tonne since the system came into operation.

Though now outside the EU, the UK government has maintained a system which mirrors the EU ETS, and the UK government says that it aims to "be at least as ambitious as the current EU ETS". New Zealand also operates an ETS, and Canada is moving to incorporate various provincial ETS schemes in a new federal ETS. South Korea operates an ETS schemes covering 74% of emission, Japan has two regional ETS schemes, and Mexico is piloting a scheme which is due to become operational next year.

The United States as yet has no federal ETS, but California maintains its own ETS, and there is now a 'creeping' ETS – the Regional Greenhouse Gas Initiative – across some of the eastern states of the US. The RGGI currently covers Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, Vermont, and Virginia. Like the Chinese ETS, it also currently only covers large power producers. Given the fractious and fragmented nature of US politics, it seems unlikely that something like the EU ETS could appear in the medium term future.

In general, carbon pricing so far has been mainly a concern for European producers. The introduction of the CBAM however may start to have a knock-on effect on producers who export to Europe. This remains an area where considerable change could happen over the coming decade.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Hydrofluoric Acid - world leader with Buss Chemtech subsidiary
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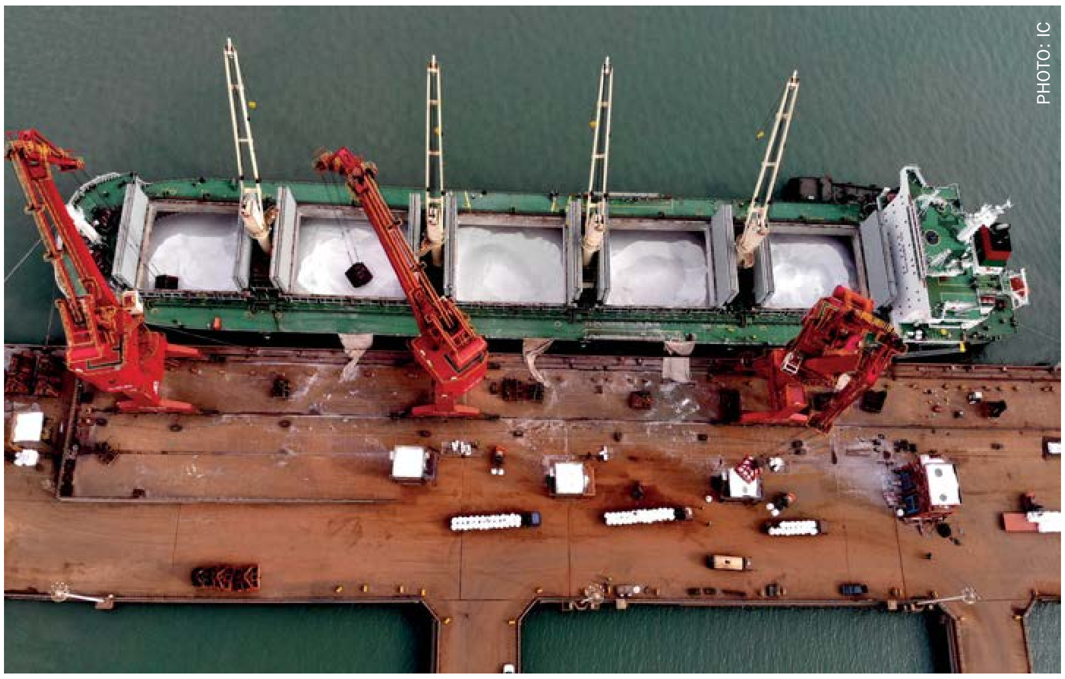
Ukraine and fertilizer supply, an Indian perspective



Dr M.P. Sukumaran Nair, formerly Secretary to Chief Minister, Kerala and Chairman, Public Sector Restructuring & Audit Board, Government of Kerala looks at the impact of the conflict in Ukraine on supply of fertilizer to India and the world.

Left: A ship unloads potassium chloride fertilizer.

The direct economic impact of Russia's conflict in Ukraine is that prices of food, energy and fertilizers in India and the world will tend to rise unless the conflict ends soon. Ukraine is a major food grain, wheat and corn producer, Russia, a major supplier of natural gas to Europe, and the Black Sea region a major hub of fertilizer production and trade.

A variety of sanctions have also been imposed on Russia by the US, European Union, UK, Japan, Germany, Canada, and Australia. This includes the freezing of assets, banning trade, investments, the purchase of sovereign debts, access to fintech solutions, bans on the use of airspace, stock exchanges, and the blacklisting of politicians and officials etc. Modern governments find it difficult to sustain operations and people are put to numerous difficulties in everyday life without the support of these transactions.

Ever since the outbreak of the conflict, global IT, finance, technology, and manufacturing powers have shown that any nation, however powerful and capable they are, can be subjected to restrictions and denial of access to important services, systems, and linkages. Banks and such technology-oriented institutions, who are dependent on foreign networks and cloud storage need to be supported by local servers to ensure services can continue. Academic, research and development, skill and manpower training needs, including higher education, will need a thorough review in this context, and it has shown us that we may all have to develop our own institutions and strengthen existing ones using indigenous resources and capabilities. Even military requirements need to be strengthened with indigenous manufacturing and service support capabilities. All the above highlights the need for national level self-reliance at least in critical areas like IT/ ITES capabilities, banking, technology development and the rapidly emerging frontier technologies and advancing developments in current science. Professionals and organisations, including quality and standards regulators need to re-look, re-engineer and dedicate themselves to ensure national capabilities and shun self-imposed walls in the name of independent working for their own name or economy of scale and adopt a cooperative and collaborative approach.

The conflict has already taken a toll on energy markets all over Europe. Russia supplies about one-third of Europe's natural gas supply, the main feedstock to major power and chemical producers who will be forced to shut down the units if gas prices continue to rise. Heating and power prices are already rising, media reports say and by the end of the month, the intensity is going to be severe for the households, businesses, and heavy industries which need the energy at a fair price to operate comfortably.

India

In India, the aggression is going to impact our fertilizer supplies in a major way with regard to price and availability. Around 2.4 million tonnes of ammonia was shipped from Pivdenny port (Odessa) in 2021, of which only 150,000 tonnes came from Ukraine and the rest from Russia, supplied through the Togliatti Azot and Rossosh pipelines. Russia is the second-largest producer of ammonia, urea and potash in the world, and the fifth-largest producer of complex phosphates. The country accounts for 23% of the global ammonia export market, 14% of urea, 21% for potash and 10% of the complex phosphates. The war has already started disrupting the global fertilizer market, as Russia is a leading supplier of fertilizer and related raw materials. It is also the largest exporter of urea, NPKs, ammonia, UAN and ammonium nitrate, and the third-largest potash exporter. In the phosphate sector, traditionally dominated by China and Morocco, Russia is a major exporter, with 4 million tonnes per year of DAP/MAP shipments last year. The Black seaports of Yuzhnyy and Odessa are major fertilizer handling ports with pipeline transport facilities for ammonia from Russia.

Like other countries, India too depends heavily on imports for meeting its fertilizer raw materials (natural gas, sulphur and rock phosphates), intermediates (ammonia and sulphuric and phosphoric acids), and finished products (diammonium phosphate, potash and complex fertilizers) requirements. The self-sufficiency in urea production achieved by 2000 was lost due to policies which discouraged further investments in the sector for two decades and also due to the privatisation move and closure of a number of plants on account of low energy efficiency which paved way for large scale exports.

India, the world's largest urea importer, is also significantly imports phosphatic and potassic fertilizers. Urea imports amount to 8-9 million tonnes per annum, mostly from China, Oman, Ukraine, and Egypt. China has restricted urea imports since October 2021. As gas prices go up, imported ammonia price has also followed suit. A significant part of the supply shortage could be met by maximising production in the newly commissioned fertiliser plants at Gorakhpur, Barauni and Sindri. On an average, 5 million tonnes of phosphatic fertilizers are imported to India, mostly from China, Morocco, Saudi Arabia Russia and Jordan. Potash supplies (around 4 million tonnes per year) are fully imported from Canada, Russia, Belarus Jordan, Lithuania, Israel, and Germany. Current imports, of course, are going to be at much higher rates due to the emergent situation in these countries. Earlier, our major suppliers of DAP were Saudi Arabia, Morocco and China. China has already restricted exports of DAP last year, so India is already constrained to tap Morocco and Saudi Arabia and Jordan. Expectations of fertilizer subsidy allocation of Rs 1.05 lakh crores ($14 billion) for 2023 in the recent budget are likely to be a major underestimate on account of the war.

Here again, disruption in production in Russia and Ukraine and closure of plants in Europe will result in an increase in fertilizer commodity prices all over the world. A shift in product movement from traditional markets will lead to price volatility in the global fertilizer market significantly impacting availability. Had India continued the fertilizer expansion policy of the 1980s and 1990s, where government-owned fertilizer companies contributed significantly to meet the demand for mineral-based plant nutrients, it would not have been in such a precarious situation as we are now. Today, farmers are hard-pressed for the easy availability of fertilizer products whose prices have also skyrocketed. Only urea which still remains under administrative price control is cheap and affordable to farmers. The need of the hour is that the governments rush to tie up alternate supplies and ensure adequate availability of mineral nutrients to their farmers. Any laxity in doing so will adversely impact the food security of the nation in a couple of years. ■

Nitrogen + Syngas 2022 Conference & Exhibition

Berlin cathedral.

PHOTO: BERLINPICTURES/SHUTTERSTOCK.COM

The CRU Nitrogen + Syngas Conference returns to Berlin for a live event from 28-30 March 2022. The conference will be run as a hybrid event giving participants the option to attend live in-person or online via the virtual platform.

As the world learns to live with Covid, industry professionals will once again have the opportunity to meet face-to-face, to network and to discover the latest technical developments driving sustainability, efficiency and operational improvements across the nitrogen and syngas industries.

With over 50 technical papers and a large exhibition, the conference offers an unparalleled opportunity for professional development and networking.

This year, CRU is making it even easier for delegates to make targeted connections with its new professional matchmaking and networking system: Grip.

Grip is a web- and app-based event platform that uses AI-powered technology to make personalised recommendations and to connect users with peers and experts with shared interests or required skills and solutions. The platform can be fully customised allowing delegates to chat with one another, view exhibitor profiles, schedule meetings and build a personalised agenda of conference sessions and meetings. The platform can also be used to access live streamed and on-demand content whether attending in person or virtually.

The 2022 conference agenda starts with technical showcase presentations – a series of shorter technical presentations on a variety of subjects. Key market updates are next on the agenda with CRU's global outlook for nitrogen and gas, presented by Shruti Kashyap, and an update from the Ammonia Energy Association, presented by Kevin Rouwenhorst. The main technical programme follows with parallel sessions on days 2 and 3 of the conference. ■

2022 Nitrogen + Syngas Technical Programme

Latest developments in green ammonia production

- Production and conversion of green ammonia for current and future applications (Yawar Abbas Naqvi, Topsoe A/S)
- Casale flexible green ammonia plant, the economically viable green production (Giovanni Genova, CASALE SA)
- Green ammonia technology: Case studies and global developments (Akhil Nahar, KBR)
- Stami green ammonia to play a key role in decarbonising the fertilizer industry (Deepak Shetty, Stamicarbon)

Decarbonisation options for existing assets

- Decarbonising ammonia production (Klemens Wawrzinek, Linde GmbH)
- Green ammonia by Haldor Topsoe hybrid revamp of existing ammonia plants (Ameet Kakoti, Topsoe A/S)
- Decarbonisation options for syngas plants using green and blue hydrogen through benchmarking (Dan Barnett, BD Energy Systems)
- Economics of decarbonisation options in ammonia plants (Vinod Arora, Kinetics Process Improvements)

Low carbon and blue ammonia

- Making and breaking ammonia: Ammonia and its place in the low carbon economy (Julie Ashcroft, Johnson Matthey)
- Shaping the future of ammonia (Massimiliano Sala, Saipem)

Advances in the sustainable and efficient production of methanol

- IMC's energy efficiency enhancement project exceeding the target (Muhammad Adnan Tariq, Sahara International Petrochemicals)
- Advanced Methanol Amsterdam (AMA): robust technologies which become a successful path to a green methanol plant (Dennis Chafiâ, G.I. Dynamics and Isabella Muscionico, Casale)
- How nanoscale discoveries can result in mega scale benefits for methanol producers (Jens Sehested, Topsøe AS)

Energy efficiency enhancements for ammonia plants

- Transition technology toward carbon footprint reduction and energy intensification of steam methane reformer in ammonia production (Olivier Brasseur, BD Energy Systems, LLC and Nenad Zecevic, PETROKEMIJA)
- Replacing vertical ammonia converters with optimised energy efficiency, increased capacity, safe and reliable ones (Mahesh Gandhi, KBR)

Improving the sustainability and efficiency of urea production

- Casale LEM™ improved process: Know-how and technology, the best mix to maximise environmental sustainability (Simone Gamba; Gabriele Di Carlo, CASALE SA)
- Toyo's latest innovations in urea synthesis technologies and sustainable urea production (Takahiro Yanagawa, Toyo Engineering Corporation)
- The efficiency of methylene urea (Massimo Gori; Svetoslav Valkov, Desmet Ballestra)

Optimising urea operations: Enhancing reliability

- Composite control valve (Paul Jorissen, Stamicarbon)
- Importance of high-quality service and how can this minimise the down time and increase the reliability of fertilizer plant (Filippo Colucci; Richard Jandl, Christof Group SBN)
- New superduplex material for application in high pressure synthesis of urea plant (Alberto Serrafero, Saipem)
- Engro's 50+ years experience of effectively managing plant turnarounds (Narmeen Habib and Asad Khan, Engro Fertilizers Limited)

Urea plant monitoring solutions

- Leak detection system commissioning (Mohamed Kamal Mohamed Ibrahim and Fawzy Tayel, Abu Qir Fertilizers Company)
- Reliable, accurate continuous dust emission monitoring from urea and ammonium nitrate prilling towers and granulation plants (David Inward, SICK spol. s.r.o.)

Syngas generation/gasification from waste sources

- Production of sustainable aviation fuel (SAF) from woody biomass by Gasification-FT Synthesis Technology – Successful demonstration to fly a commercial flight (Yasuhiko Kojima, Toyo Engineering Corporation)
- Green hydrogen and renewable natural gas from waste in a circular economy: Producing low-cost hydrogen and RNG with a negative CO_2 footprint from minimally prepared waste or biomass (Marc Bacon, OMNI Conversion Technologies)

Catalyst developments

- AmoMax® 10 Plus: From fundamental understanding to industrial application (Rene Eckert, Clariant)
- Getting the most $ value from your nickel – Improved profitability and reduced emissions from sustainable reforming catalysts (Thomas Ithell, Johnson Matthey)

Digitalisation

- Clariant Service Portal – Next-generation digitalised catalyst support to enhance plant operation (Vaclav Jurcik; Maximilian Aigner, Clariant)
- Choosing and deploying a digital Energy Management Solution (Matthieu Poulain, METRON)
- Intelligent plant monitoring: Avoiding the costs of unplanned shutdowns (Flavio Fabbri and Lisa Krumpholz, Navigance GmbH)

Corrosion resistant materials

- Case study: Using field-sprayed metal alloys to prevent corrosion in syngas production (Vitaly Geraskin, Integrated Global Services)
- VDM® Alloy 699 XA: results after two years field application at metal dusting conditions (Tatiana Hentrich, VDM Metals International GmbH)
- Sandvik's innovative material developments avoid corrosion in nitric acid producing plants (Angela Philipp, Sandvik)

Ammonia operations: Reliability and performance improvements

- Engineering, modelling and layout considerations to obtain best combustion performance when revamping downfired reformers (Rene Becker and Ali Gueniche, Koch Engineered Solutions)
- Design vs maintenance of ammonia converter syngas boilers (Stefano Villa, Alfa Laval Olmi SpA)
- A novel idea to sustain plant operation (Qazi Wasif Ud Din, Engro Fertilizers Limited)
- Ammonia plant reliability assurance by improving process safety and engineering controls (Ali Haider, Fatima Fertilizer Company Limited)
- Exclusive experience of ammonia convertor operation with leaked methanator feed/effluent exchanger (Muhammad umar Riaz and Muhammad Hashim, Fatima Fertilizer Company limited)

Emissions reduction from nitric acid plants

- Nitrous oxide emissions reduction from nitric acid manufacturing plants (Iain Hepplewhite, Johnson Matthey)
- Sustainable N_2O abatement technology for nitric acid plants (Partha Pratim Chowdhury, Rit Desai, KBR)
- Krastsvetmet solutions for emission reduction in nitric acid plants at capacity increase (Alexander Dyukov, JSC Krastsvetmet)

Optimising the performance of nitric acid & nitrate fertilizer plants

- Nitric acid plant: revamp case studies for process optimisation, capacity augmentation, and concentration enhancement (Piyush Agnihotri; Rit Desai, KBR)
- Sharing experience on implementing EPC contract for revamp of existing AK-72 nitric acid units: switching to low-temperature selective catalytic exhaust system along with capacity increase (Alexander Vasiliev, GIAP Group)
- Enhanced efficiency in nitrate fertilizer production by AI based soft sensors for real-time quality prediction (Kathrin Rodermund, thyssenkrupp Industrial Solutions
- Project Green Salpeter: Towards a better understanding of Pt-catalyzed ammonia combustion (Artur Wiser, Umicore AG & Co. and Johannes Dammeier, thyssenkrupp Industrial Solutions AG)
- Make high use of low caloric heat of a nitric acid plant (Johannes Dammeier, thyssenkrupp Industrial Solutions AG)

Leak detection and monitoring

- From early warning to long term monitoring – A solution for detecting dangerous gas emissions of ammonia processing facilities (René Braun, Grandperspective GmbH)
- Return of experience on the efficacy and reliability of fiber optic ammonia leakage detection systems (Roberto Walder, Smartec SA)

Waste gas cleaning

- Challenges in waste gas cleaning of a fertilizer production (Martin Joksch, P&P Industries AG) ■

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State-of-the-art plant technology

Saipem, Stamicarbon, Toyo Engineering Corporation and KBR showcase recent projects and latest technology for urea and nitric acid plants.

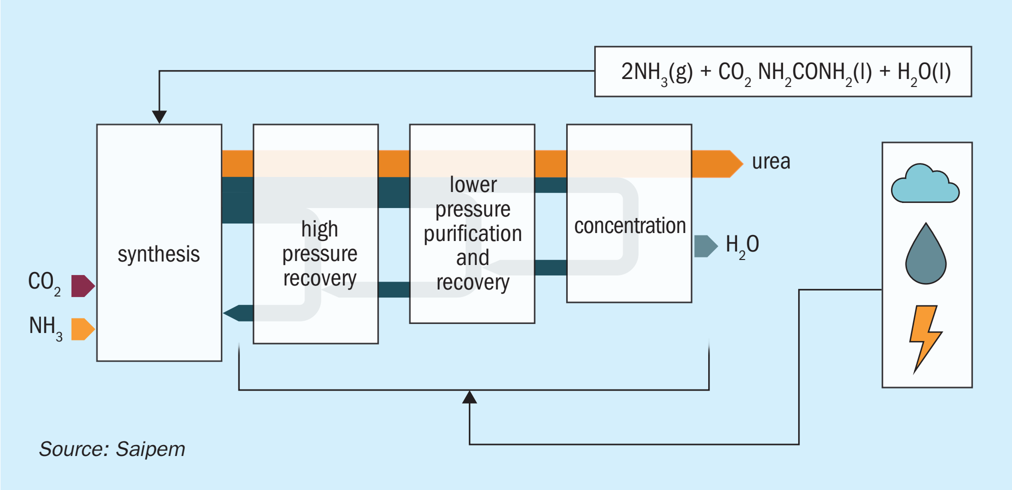
SAIPEM

Increasing the sustainability of urea plants with SuperCups

SuperCups was developed by Saipem, owner and licensor of the Snamprogetti™ Urea Technology, to boost the performances of urea reactors. This article analyses the technology from a theoretical viewpoint and discusses practical experiences based on the results of plants operating with SuperCups.

Urea formation is ruled by an equilibrium reaction and a limited yield of urea formation, with the consequence that some reagents will remain unconverted at the outlet of the synthesis section. These unreacted reagents require a continuous consumption of utilities (such as steam, cooling water and electric power) in the downstream sections to recover and recycle these unreacted reagents (dark-blue coloured streams in Fig. 1) back to the synthesis section.

Fig. 1: **Conceptual scheme of a urea production plant**



Source: Saipem

The quantity of utilities required for such recovery is directly dependent on the composition of the stream at the outlet of the reactor. It is therefore important to maximise the conversion in the reactor in order to decrease the energy consumption of the whole plant.

SuperCups have demonstrated their effectiveness for this purpose, proving to be, thanks to their triple fluid-dynamic effect, active reaction stages, rather than simple internals.

The first fluid-dynamic effect is the formation of a gas cushion below each tray; thanks to this cushion the gas (CO_2) is evenly distributed along the reactor section providing a uniform feed to each cup. Second, the gas entering the cups is subject to intensive mixing with the liquid phase thus maximising the contact between the gas and the liquid phases. Third, is the improvement of the residence time distribution inside the reactor which allows the SuperCups design to be tailored to meet the specific demands of each plant.

SuperCups are applicable to both new reactors and to the retrofit of existing reactors.

By applying SuperCups to new reactors the investment costs (capex) associated with the reactors and the plot plan will be reduced, while installing the SuperCups in existing reactors will maximise their performance with consequent benefits to the operation costs (opex).

Fig. 2 plots the performance vs. plant load curves for a reactor with installed sieve trays and the same reactor after a retrofit with SuperCups. As can be seen, the SuperCups have better performance, achieving a higher efficiency at higher plant loads.

As shown in Figs 3 and 4 the installation of SuperCups can lead to two different operating approaches:

- operate at higher loads maintaining the same performances of the original reactor design;
- operate at same load increasing the performances of the reactor.

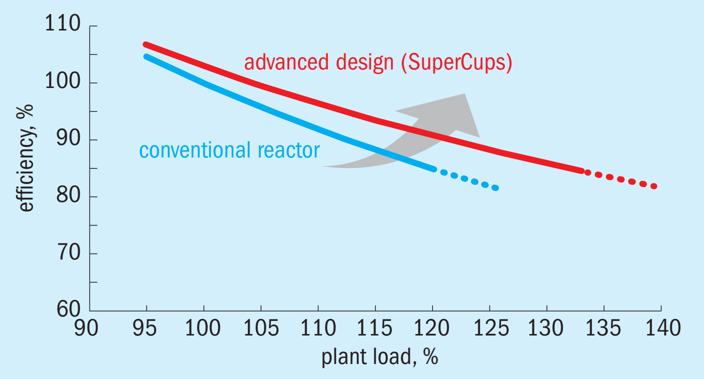
As can be easily inferred, these two approaches are not exclusive and can be combined to operate at any intermediate point in between the two (Fig. 5).

The number of SuperCups references to date since the first installation in 2014 is 25, each tailored to the targets of the plant.

The first applications of SuperCups were mainly installed to replace a limited number of trays (compared to the whole set inside a urea reactor).

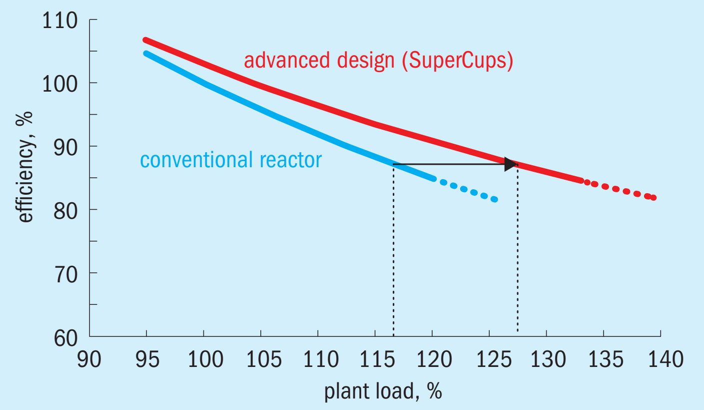
For example, in one case a plant installed a total of seven SuperCups in the bottom of the reactor. Even with this "limited" intervention it resulted in a saving of 45 kg MP steam/t of urea together with

Fig. 2: Reactor performance curves for a reactor with sieve trays vs SuperCups



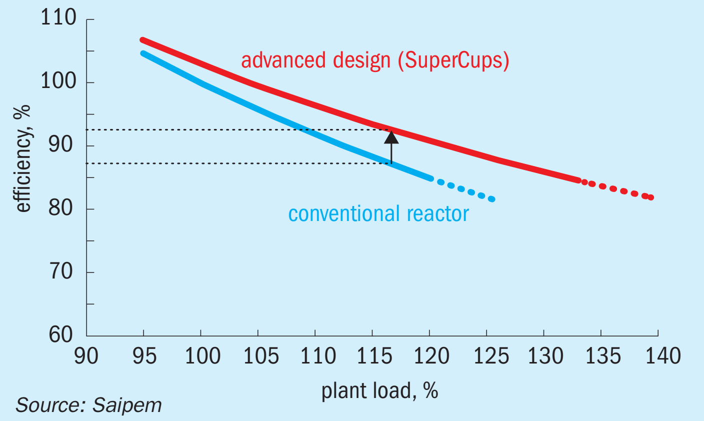
Source: Saipem

Fig. 3: Operation at higher load and fixed performance



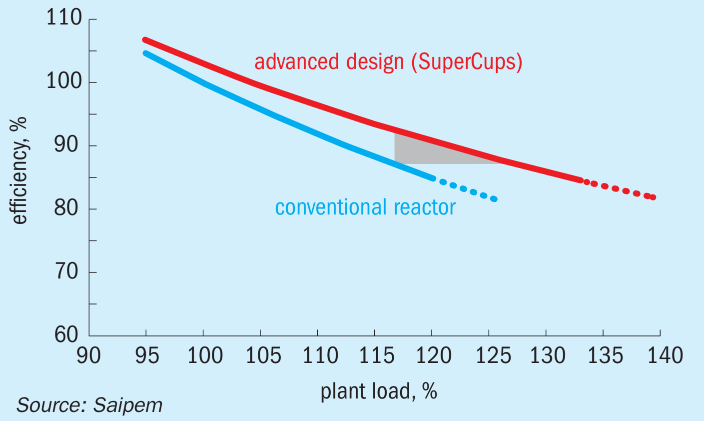
Source: Saipem

Fig. 4: Operation at fixed load and higher performance



Source: Saipem

Fig. 5: Operating possibilities with SuperCups



Source: Saipem

a general increase of operability. These exceptional results have convinced the client to replace all of the remaining trays with new SuperCups trays. As of today (February 2022), the performance results are not yet available as the SuperCups are still in the manufacturing phase, but a further increase in operability is expected with total steam savings in the range of 70-90 kg/t of urea.

Such significant results appear to be reasonable when analysing the results obtained at another plant where a full set was installed; in this case the obtained steam saving, as demonstrated during the performance test, was more than 80 kg/t.

A similar case where SuperCups were installed in two phases is the Profertil plant in Argentina, where to begin with only four trays were installed in 2018 in the middle part of the reactor.

In this specific case, the number of SuperCups supplied in the first phase was determined by the need to replace some of the original sieve trays (significantly aged during the operation) and to adopt a fast track approach for the procurement (thus having to depend on the material available at the manufacturer's workshop) to meet the turnaround schedule.

The analysis of plant data performed after the installation of the four SuperCups showed a steam saving of 15-20 kg/t of urea. In addition, this result was achieved with no variations to the pressure profile of the reactor which had the benefit of not causing any limitation nor increasing the power demand of the CO_2 compressor.

The abovementioned results demonstrate that the capability of SuperCups to boost reactor performance is not limited to a specific portion of the reactor and does not require a minimum intervention making SuperCups suitable for all applications.

Enthusiastic about the obtained results, Profertil decided to complete the set of trays which was manufactured, delivered, and installed in 2021.

Plant data has demonstrated that the plant can be operated steadily at more than 120% and maximum achievable plant capacity has been increased by about 2-4%. The reduction in the consumption of MS steam to the urea stripper has been calculated to be about 90-95 kg/t of urea.

The benefits of SuperCups in terms of energy savings, operational flexibility as well as the possibility to optimise the size and layout of new urea units explains the fast growth of its applications worldwide in a very short time.

In terms of making urea production more sustainable, the reduction of medium-pressure steam consumption achieved in Profertil implies a net reduction of CO_2 emissions to the atmosphere both associated to direct sources (e.g. due to combustion, flaring and venting) and indirect sources (e.g. associated to power generation, heating, cooling). The contribution in terms of carbon footprint reduction of urea production is estimated to be equivalent to the yearly greenhouse emissions of about 3,500 cars.

In total, as of February 2022 the sum of all SuperCups references is equivalent to almost 20,000 cars kept off the road for one year. ■

STAMICARBON

First operational experiences with Stamicarbon's Ultra-Low Energy plant

Mieke Beaujean

The LAUNCH MELT™ Ultra-Low Energy design is Stamicarbon's latest process technology, launched in 2012 and today contracted for six grass-roots plants. The first two plants to apply this technology were the Jinjiang Xinlianxin and Hubei Sanning plants in China with a capacity of 2,334 t/d each. They successfully went into operation in 2021. The Gemlik plant in Turkey and the Henan Xinlianxin plant in China are under construction, while two other plants for China are in the design phase.

Stamicarbon, the innovation and licensing company of Maire Tecnimont Group, considers this technology to be the next generation of its Pool Condenser and Pool Reactor designs, as it utilises major proven proprietary technological developments and benefits from considerably lower steam consumption.

N=3 heat integration

The traditional urea processes are based on a so-called N=2 heat integration concept, in which the heat supplied to the urea plant in the form of extraction steam from the steam turbine is used twice. Stamicarbon's Ultra-Low Energy design is a breakthrough process technology that allows for heat supplied in the form of high pressure (typically 20 to 25 bar) steam to be used three times instead of two (Fig. 1). As a result, the steam consumption can be reduced by up to 40% and cooling water consumption by about 16%, compared to traditional CO_2 stripping processes.

The first time this steam is used as a heating agent to obtain high stripping efficiencies in the high-pressure stripper. Subsequently, the heat is recovered by condensing the strip gas in the high-pressure carbamate condenser, pool condenser or pool reactor in the synthesis section to produce low-pressure steam that is used in the sections downstream of the synthesis section.

Process description

The Ultra-Low Energy technology retains all the features of the Pool Condenser and Pool Reactor designs, such as reliability, operability, and use of proprietary Safurex® stainless steels. At the same time, it uses less energy for urea production, lowering operating expenses (opex) substantially by significantly reducing steam consumption.

It differs from the other designs in the centrepiece of this technology, the Ultra-Low Energy pool reactor. This reactor has two U-tube bundles with two separate sections and handles two different fluid mediums. One bundle ('steam bundle') is for generating low-pressure steam and the second bundle ('carbamate bundle') is used for heat integration with the medium-pressure recirculation section.

On the shell side of the carbamate bundle, condensation of strip gas releases heat (at about 144 bara and 175°C), which is used to decompose carbamate into ammonia and carbon dioxide on the tube side. Consequently, the tube side of this tube bundle in the pool reactor functions as a medium pressure rectifying heater. By integration of these two functions, without any intermediate heat transfer medium, the available temperature difference between both process sides allows the bundle to be relatively small.

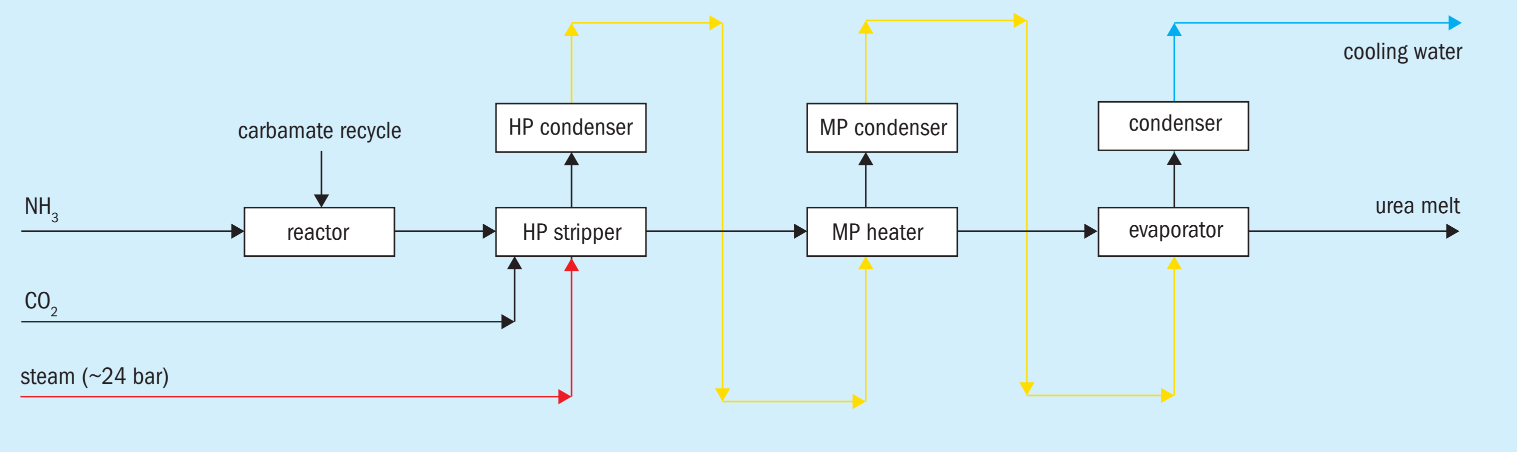
As illustrated in Fig. 2, the synthesis of the technology includes only two high-pressure pieces of equipment: a high-pressure stripper and a high-pressure pool reactor. The high-pressure scrubber is not required in the Ultra-Low Energy design thus optimising the capex of the plant.

In the Pool Reactor design, the total height of the high-pressure equipment structure is limited to about 20 m, where the heaviest piece of equipment, the pool reactor, is located. The stripper is located close to ground level. As the high-pressure scrubber is not part of the design, this results in the lower height of the structure. The vessel at the highest elevation in the plant is the first medium-pressure separator.

First start-up experience

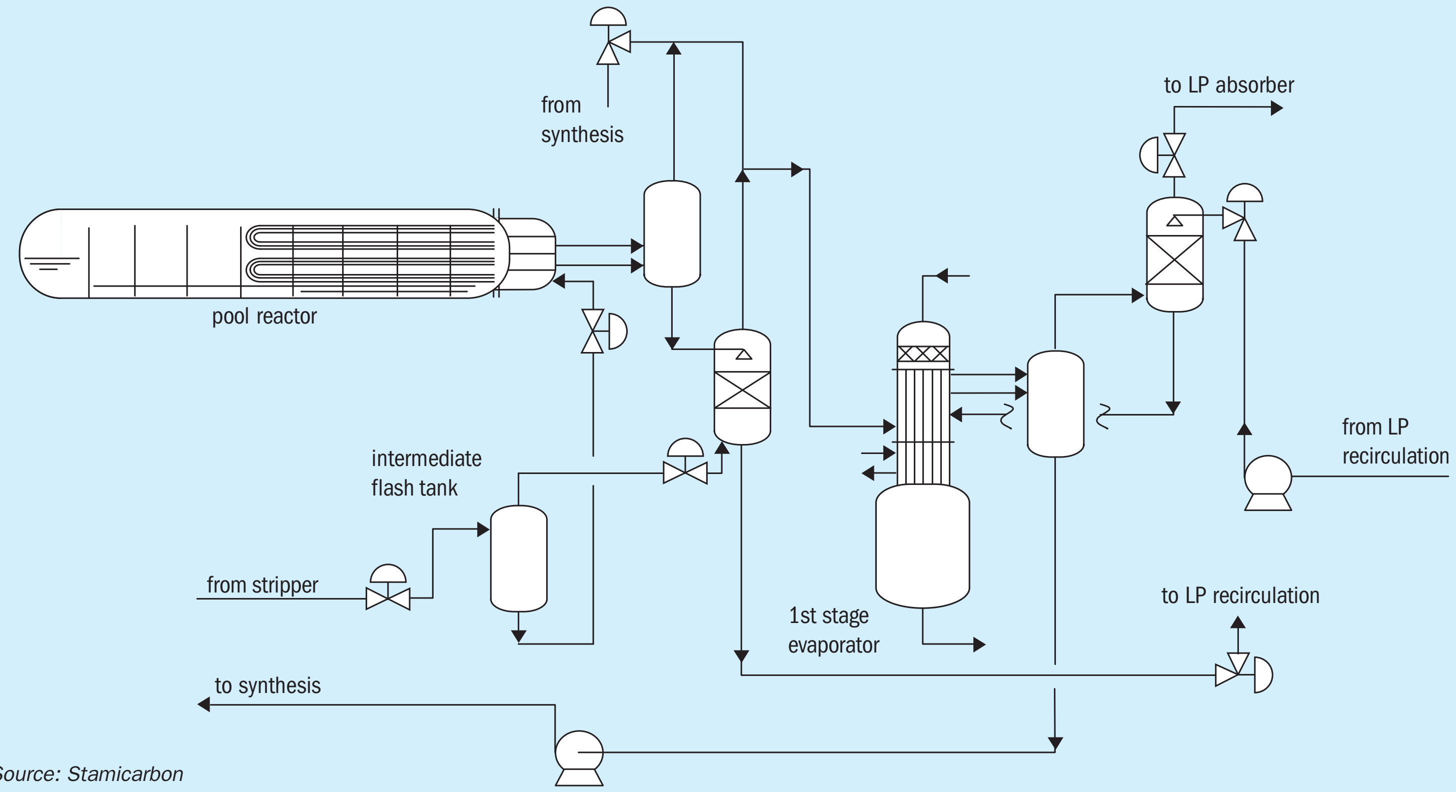
The Ultra-Low Energy plant with prilled product of Jinjiang Xinlianxin with a capacity of 2,334 t/d was the very first plant with this innovative technology. It was successfully started up in February 2021. Prior to start-up, the plant staff were thoroughly trained

Fig. 1: **N=3 Using high pressure steam three times**



Source: Stamicarbon

Fig. 2: **The Ultra-low Energy technology synthesis including the medium-pressure recirculation section**



Source: Stamicarbon

Table 1: **Consumption figures of the Ultra-Low Energy plant of Jinjiang Xinlianxin compared to a standard pool reactor plant**

Process concept	Steam consumption (23 bara, 330°C)	Cooling water consumption (ΔTCW as 10°C)
LAUNCH MELT™ Ultra-Low Energy plant China	567 kg steam t urea	61 t CW/t urea
LAUNCH MELT™ Pool Reactor designs	870 kg steam/t urea	73 t CW/t urea
Improvement	35%	16%

Source: Stamicarbon

by Stamicarbon on its Operator Training Simulator to get a good understanding of the expected reactor and plant behaviour. The start-up of the plant went very smoothly without any issues from the very first attempt. Initially, the plant was operated with turndown capacity operation. After the feedstocks were assured, the capacity of the plant was increased to above 100% within the first week of operation.

The energy consumption of the Ultra-Low Energy plant is considered to be a benchmark performance worldwide. The presence of the medium-pressure recirculation section with the carbamate bundle dampens disturbances that occur in traditional CO_2 stripping plants, originating from discharging liquid directly from the stripper operation to the low-pressure section.

The actual plant operation information from Jinjiang Xinlianxin is indicated in Table 1.

The performance parameters at an average plant operation capacity of 102% demonstrate that the Ultra-Low Energy concept is a major advancement in urea technology. The actual high-pressure steam (23 bara, 330°C) consumption is 567 kg/t urea, which is even lower than the initially expected value during design. This is expected to be further reduced by about 20 to 25 kg/ton urea, by optimisation of the process conditions of the ammonia feed temperature to the synthesis. The steam consumption is reduced by about 35% and cooling water consumption is reduced by about 16% compared to the traditional Pool Condenser and Pool Reactor Designs. The capex of the Ultra-Low Energy design is comparable.

The successful commissioning and stable operation of the plant also validated the mechanical design of the Ultra-Low Energy pool reactor. The design fully employs the superior resistant properties of Safurex® Infinity∞ steel against corrosion. The tube bundles and the internals of the distribution box are accessible through the manway by opening the internal covers and thus enabling non-destructive testing inspection without restrictions and without dismantling of heavy parts.

The ease of operation is considered to be another important benefit of the Ultra-Low Energy technology compared to a traditional plant. This convinced the same customer to contract a second Ultra-Low Energy plant, which is currently under construction.

The technology can be used in grassroots urea plants, but can also be applied for revamping plants, irrespective of the original technology or capacity. It can replace the existing aging reactor to increase plant capacity, while simultaneously reducing energy consumption. ■

TOYO ENGINEERING CORPORATION

Engineering for sustainable growth

Kenji Yoshimoto

Carbon neutral policies are being vigorously pursued around the world and present a big challenge for engineering companies, but can also create many business opportunities. In particular, Toyo Engineering Corporation (TOYO) is a technology leader in areas such as carbon-free ammonia fuel, and sustainable aviation fuel (SAF) using biomass and carbon dioxide as raw materials. In emerging countries, on the other hand, resolving food issues and economic disparities remain a common challenge according to the United Nations. Demand for chemical fertilizers, petrochemical products, and a stable electricity supply is expected to continue to grow along with population growth and economic development in the world. TOYO, whose mission is "Engineering for Sustainable Growth of the Global Community", recognises the importance of achieving a balance between harmony with the environment and economy and convenience. In this article, TOYO discusses three nitrogen and/or syngas projects corresponding to its mission.

Fig. 1: Indorama Train-2 urea plant.

Table 1: **Outline of Indorama Train-2 project**

Plant owner	**Indorama Eleme Fertilizer & Chemicals Limited (IEFCL)**
Plant capacity	Ammonia 2,300 t/d Urea 4,000 t/d (granular urea)
Location	Port Harcourt, Rivers State, Nigeria
Ammonia process	KBR Purifier™
Urea process	TOYO ACES21® and Spout Fluid Bed Granulation
Scope	Grant of license, development of basic design, detailed engineering, procurement, and dispatch of commissioning supervisors
Contract award	May 2018
Start-up	April 2021

Source: TOYO

Indorama Train-2 project, Nigeria

In 2018, in the wake of the successful completion of the Train-1 project, Indorama Eleme Fertilizer & Chemicals Limited (IEFCL) awarded a contract to TOYO to build one of the world's largest ammonia-urea complexes (Fig. 1 photo). The Train-2 project, located at Port Harcourt in Nigeria, has a design capacity of 2,300 t/d for ammonia (KBR Purifier™ process) and 4,000 t/d for granulated urea (TOYO ACES21® and Spout Fluid Bed Granulation). All milestones, including construction and the commissioning activities, were successfully completed in 2021. Especially for the initial start-up, the following events are regarded as being particularly noteworthy:

- The KBR ammonia plant achieved the fastest record of 11 days from natural gas feed in to producing the first drop of ammonia.
- The TOYO urea plant produced the first urea granules on the same day as the initial feed in of raw material from the ammonia plant.

Subsequently, the provisional acceptance of Train-2 was attained within two months of natural gas feed in and now the plant is being managed steadily by the owner at full load. The use of feedback from past projects, including Train-1, and the effective implementation of a start-up plan worked out with IEFCL helped the plant to start smoothly.

NTPC CO_2-to-methanol demonstration project, India

After competitive bidding, Toyo Engineering India Private Limited (TOYO-India), one of TOYO's affiliates, located in Mumbai, India, has been awarded a contract by NTPC Limited for a 10 t/d methanol synthesis demonstration plant. This demonstration plant will be built at NTPC's Vindyachal Super Thermal Power Station located in the State of Madhya Pradesh, India.

In this project, CO_2 captured from flue gas and hydrogen generated by water electrolysis will be utilised to synthesise methanol. TOYO will provide its proprietary methanol synthesis technology (g-Methanol®) for this project as a technology owner (see Fig. 2).

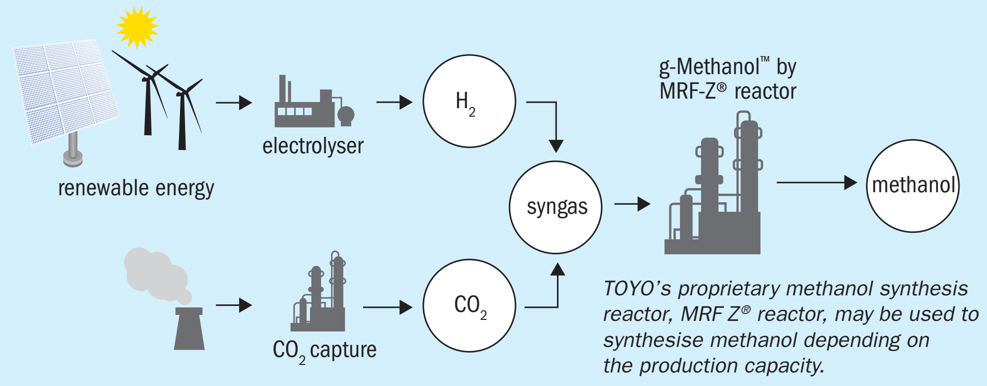
This project is part of NTPC's initiative in the field of clean energy and an important step towards India's commitment to addressing climate change. NTPC Ltd is a Maharatna company and India's largest energy conglomerate with roots planted way back in 1975 to accelerate power development in India. The

Table 2: NTPC green methanol demonstration project

Plant owner	**NTPC Limited**
Plant capacity	Methanol synthesis demonstration plant 10 t/d
Location	Vindyachal Super Thermal Power Station, the State of Madhya Pradesh, India
Methanol process	TOYO g-Methanol®
Scope as TOYO Group	Grant of license, development of process design, procurement (reactor), and dispatch of commissioning supervisors
Contract award	October 2021
Scheduled completion	February 2023

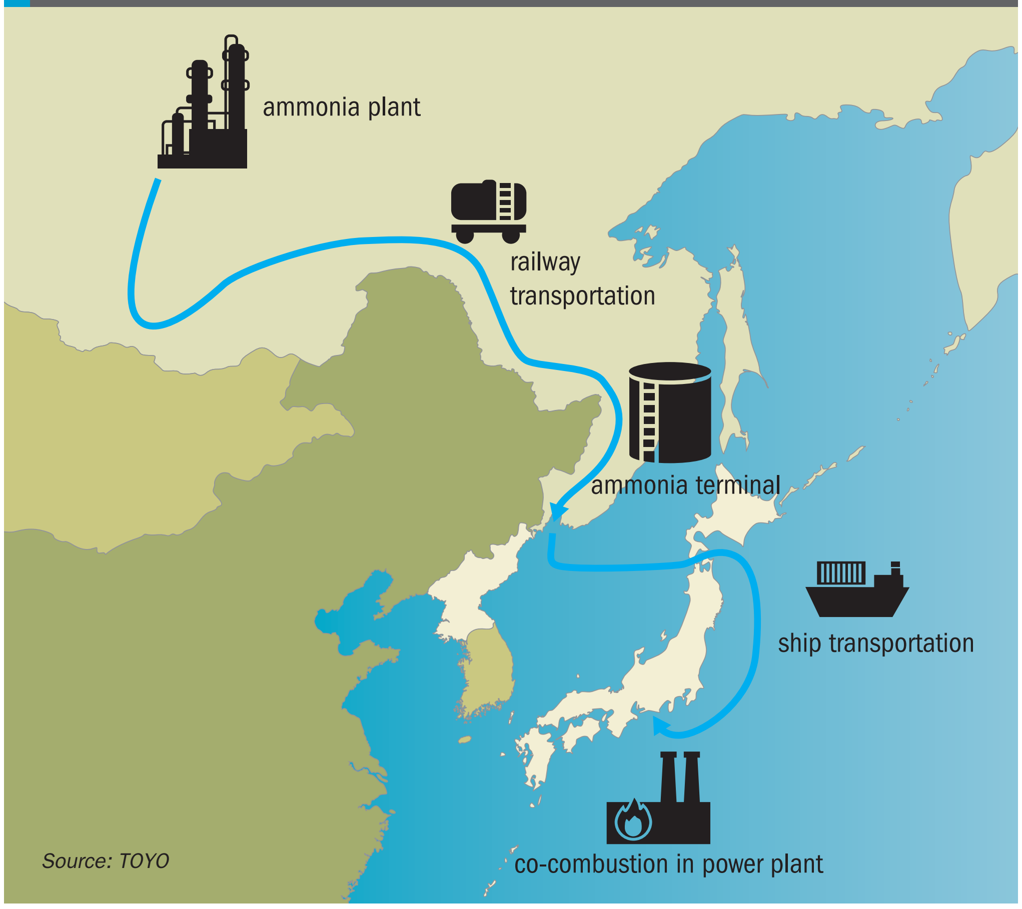
Source: TOYO

Fig. 2: Typical concept of g-Methanol®



Source: TOYO

Fig. 3: Blue ammonia value chain concept (as of January 2022)



Source: TOYO

total installed capacity of NTPC as of date is 67+ GW (including joint ventures).

With the award of this project, TOYO group is pleased to contribute to the national goal of carbon footprint reduction.

Blue ammonia feasibility study

(This article was prepared in the middle of February). Following the implementation of Phase 1 of a study in 2020 for the establishment of a blue ammonia value chain between Eastern Siberia and Japan, in July 2021, TOYO and Irkutsk Oil Company (IOC), Japan Oil, Gas and Metals National Corporation (JOGMEC), and ITOCHU Corporation (ITOCHU) agreed to implement a detailed study for commercialisation as Phase 2. As with Phase 1, TOYO and ITOCHU have implemented Phase 2 study entrusted by JOGMEC and established a master plan for the value chain that converts natural gas produced by the IOC in Eastern Siberia into ammonia and transports it to Japan.

In Phase 2, for the commercialisation of a large-scale blue ammonia value chain from Eastern Siberia to Japan, TOYO has executed a conceptual design to produce ammonia from natural gas produced in IOC's oil fields in Eastern Siberia. In this conceptual design, it is expected that CO_2 emitted during the production of ammonia is utilised for CO_2 EOR to increase oil production in the oil and gas fields in Eastern Siberia owned by IOC or other CCUS methods. For the inland transportation of ammonia, the utilisation of railway cargo or a pipeline is foreseen.

TOYO, IOC, JOGMEC and ITOCHU will establish a blue ammonia value chain between Eastern Siberia and Japan working in close collaboration to utilise the technologies and knowledge possessed by the parties (Fig. 3). The collaboration aims to contribute to the realisation of a sustainable society through efforts to reduce greenhouse gases by introducing blue ammonia in Japan and Asia as a fuel for thermal power plants, ships, and other uses, in line with its decarbonisation promise. The study is currently in an evaluation stage with all parties preparing further steps for moving ahead.

As demonstrated in these project examples, TOYO is striving to achieve both an environmentally-friendly society and to enrich people's lives by combining the strategies of sustainable technology and business development as well as advanced EPC operation, as part of its medium-term management plan for stepping towards the future.

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KBR

Nitric acid plant revamps

Piyush Agnihorti and Rit Desai

The owners of aging nitric acid plants face various challenges including reduced efficiency, reliability issues, high maintenance cost, and inability to meet local environmental standards. KBR's proprietary process simulation support offers competitive and innovative solutions based on vast theoretical process knowledge leveraged by experience of a licensed fleet of 76 plants globally.

Recently and in the past KBR has identified typical challenges and resolved them through revamping, ensuring improved plant reliability and annual production by eliminating constraints, related to compressors, heat train and process bottlenecks.

The technologies from KBR offer superior capex, opex, and better energy efficiency with very low technical risk. The technology revamp solutions offered by KBR are further enhanced by proprietary equipment supply by KBR which meet best design, fabrication, and industry quality control standards. Thus, KBR can support clients with a complete solution from design to delivery.

Why revamps are important

Usually for any plant like everything else there is an expected life, and if an old plant is approaching the end of its lifetime, a major overhaul may be the best path forward. Not only this, but if the operator needs to improve plant output, reliability, or to adopt to changing business or environmental needs, a revamp can provide the solution to these needs.

Once overhauled, a revamped plant could run successfully for another 15 years or more. The revamping or re-structuring of existing plants is a preferred economic solution for almost every branch of today's industries. It can become the perfect solution to re-establish competitiveness and comply with regulations and market demands.

Changes to the plant and its equipment are very likely to improve performance and reliability. Plant revamping to achieve capacity increase and modernisation to conform to ever changing regulations or product diversification can put an established production site back on top of the competition.

The following sections refer to KBR's latest experience from recent successfully completed nitric acid projects across the globe and discuss the following revamp goals:

- process optimisation and capacity enhancement solutions;
- increase heat recovery efficiency;
- improve product quality – acid concentration increase;
- reduce N_2O and NOx emissions through NSCR & SCR to meet environmental regulations.

Process optimisation and capacity enhancement solutions

Optimisation is defined as "making the best out of a situation" and process optimisation is no different, it is an exercise that aims to streamline operations within a process, maximising resource use and improving overall output.

KBR is currently involved in and has completed various projects where the client wanted a capacity increase of 15-25%. Based on the experience from these projects the major areas to investigate to provide a successful revamp are summarised below.

Pressure profile

Once the design basis is defined, the first and one of the most important steps is a realistic pressure profile of the existing plant and a best evaluated pressure profile for the revamp. A capacity enhancement revamp requires more flow passing through the plant which in turn will result in higher pressure losses. This eventually can turn into lower power extraction from the expander and many more complications. The pressure of the entire train, therefore, needs to be increased to minimise pressure losses, while at the same time accommodating increased mass flow of gases in the existing plant equipment and maintaining optimum volumetric flow rates.

KBR's inhouse software Poseidon is an important tool with high accuracy for estimating a very realistic pressure profile, which can be used to find a hydraulically and economically optimised solution.

Air compression

Air and ammonia are the two raw materials for producing nitric acid. The air availability from an existing air compressor often becomes a major bottleneck of the plant.

In case of revamping for capacity enhancement, the pressure of the plant has to be elevated as explained in the pressure profile section. KBR's inhouse software Heat Train Run is used to provide the best results for process optimisation for such a unit balancing the elevation in pressure, heat balance and the power extraction from the expander etc.

Heat train

The heat train includes several exchangers connected in series that helps in recovering the heat generated by the oxidation reactions of ammonia into NO and further the NO into NO_2.

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O + \text{heat}$$

$$2NO + O_2 \rightarrow 2NO_2 + \text{heat}$$

During capacity enhancement, the adequacy of these exchangers needs to be checked with the higher flows, heat flux, tube wall temperatures and differential pressures across the exchangers.

With capacity increase the temperature profile across the heat train can change significantly and may result in conditions that fall outside of the design conditions of the existing equipment. For these capacity increase cases KBR's inhouse simulation software Heat Train Run is used to do the analysis. Based on close inspection of the results, outcome recommendations are made for any modification to the equipment or for the addition of any exchanger to further improve heat recovery, keeping in mind the techno economic feasibility of that option.

Absorber

The absorber is the heart of the nitric acid process where both the NOx oxidation and reaction of NOx with water take place simultaneously to produce nitric acid. As explained above, during a revamp the pressure of the entire train is increased to minimise the pressure losses and to accommodate an increased volume flow of gases in the existing equipment.

This will result in the absorber being operated at a higher pressure than the existing operating pressure and it will partly help in reducing the NOx emissions from the absorber.

A higher pressure in the absorber increases the partial pressure of O_2, which promotes oxidation of NO to NO_2. This results in an increase in absorption efficiency in the absorber.

In cases where simulation indicates that the NOx emissions are still too high even at a higher operating pressure, the option of using chilled coils in the absorber can be explored. In two recent projects in India the option of chilled water coils in the absorber worked well.

The lower temperature of these chilled water coils makes the rising NOx vapours easier to condense and will greatly help in achieving controlled emissions from the absorber.

KBR has recently provided an absorber to a client in the US. The existing absorber has reached the end of its life and is a limiting factor for capacity increase. KBR has therefore designed an absorber that is sized for the future capacity expansion in consideration.

Excess tail gas

While increasing the capacity of the plant, the amount of tail gas coming from the absorber also increases as the total air flow increases. The expander intake volume becomes a bottleneck as it operates on a fixed volumetric flow basis.

Hence the excess tail gas needs to be bypassed around the expander. The option of heat recovery in this tail gas bypass can be explored.

Increase heat recovery efficiency

Efficient heat recovery is important in minimising the operational costs of plant like the energy required for driving the air compressor in this case.

The KBR proprietary design helps to efficiently recover the heat from the process gas as the reaction moves in the forward direction, either by generating steam or by heating the tail gas coming from the absorber. The energy is recovered and used to run the steam turbine or expander respectively.

While increasing the capacity of plant, the power required by the air compressor to deliver more air will increase and mostly, this power will be generated through the gas expander through which the heated tail gas is passed, and energy is recovered. Since the expander can only handle a fixed volumetric flow at a defined inlet pressure, the rest of the tail gas (approximately 25%) will bypass the expander and steam is generated through the tail gas bypass which can be exported or used in any of the steam heated exchangers based on the plant configuration.

Recently, in revamping a KBR designed plant in the US to enhance heat recovery, an oxidation spool piece and low-pressure waste heat boiler were added downstream of the tail gas heater which helped in increasing the oxidation volume, improving the conversion of NO to NO_2, while also increasing recovering heat and generating steam.

Improve product quality – acid concentration increase

Product quality is more critical for plant owners wishing to sell their product in the market. The quality of the product acid is measured by the dissolved NOx content in the product acid. Over time, as the plant reaches the end of its lifetime, the quality of the product may start to deteriorate. As a process licensor, KBR understands the importance of product quality and can offer a proprietary absorber and bleacher column designed by KBR to maintain or improve the quality of the product acid.

KBR solutions recommended to clients include the installation of a new bleacher column or the addition of a new bleacher column in series with the existing one to mitigate acid quality problems.

As part of a revamp, clients may also need to increase the concentration of the product acid according to market requirements and, in most cases, KBR has offered the solution by adjusting the absorber feed water requirement or by changing the product acid tray. In the past KBR has also used a pre-absorber to increase acid concentration.

Reduce N_2O and NOx emissions to meet environmental regulations

N_2O Abatement

Nitrous oxide (N_2O) is a powerful greenhouse gas with a global warming potential of 298 CO_2 equivalents. N_2O molecules remain in the atmosphere for an average of 114 years unless removed by a sink or destroyed through chemical reactions.

As of 2019, nitrous oxide accounted for nearly 7% of all greenhouse gas emissions resulting from activities like agriculture, fuel combustion, wastewater management, and industrial processes in the US.

In recent revamp projects KBR's tertiary N_2O abatement system has been helping nitric acid producers worldwide to meet governmental environment regulations and to keep the planet clean and green.

In the KBR tertiary control system, N_2O is catalytically decomposed into N_2 and O_2 as follows:

$$N_2O \rightarrow N_2 + \tfrac{1}{2}\,O_2$$

The process uses a proprietary Fe/Zeolite based catalyst. This catalyst can be bought in pellet form or as monolith bricks. The tertiary N_2O abatement can remove up to 98% of the N_2O content in the tail gas stream.

NOx abatement

The tail gas, which has been reduced in NOx content, leaves the absorber, and flows to the tail gas reheating system. New emission norms across the world have become stringent with respect to NOx emissions. As a solution KBR provides a NOx abatement system for all of its new plants.

Capacity increase/plant deterioration/availability of utilities can all increase the NOx content from the absorber. In recent projects to increase capacity KBR has made sure that the NOx content remains within the norms in the tail gas before being vented into the atmosphere.

NOx can be controlled to a limit by modification of the heat train and absorber. A NOx abatement system should be installed, or the capability of the existing NOx abatement system should be checked.

Tail gas exit from the hot gas expander is mixed with a small stream of ammonia vapour and is recycled in the ammonia/tail gas mixer before entering the NOx abator.

In the NOx abator, the tail gas NOx concentration is reduced to less than 25-50 ppm by volume. A start-up heater located upstream of the NOx abator is used to heat the tail gas before gauze light-off. The start-up heater utilises steam to heat the tail gas to approximately 205°C. This ensures that the NOx abator can operate during start-up and controlled shutdown to help achieve a near colourless tail gas stack.

In recent times KBR has offered the most advanced retrofit NOx and N_2O abatement systems for existing nitric acid units, upstream or downstream of expander gas heater (low temperature or high temperature applications based on client preference and the existing plant configuration). ■

Steam methane reformer assessment and optimisation

New innovations, services and latest technologies to improve the operation and reliability of steam methane reformers from AMETEK Land, Kontrolltechnik, BD Energy Systems, Koch Engineered Solutions, and Quest integrity.

AMETEK LAND

Optimising steam methane reformers to increase load, process efficiency and reduce downtime

Steam methane reformers (SMRs) are among the largest and most carbon-intensive fired heaters and are widely used in the hydrocarbon processing industries for the production of important gases – particularly hydrogen, methanol, and ammonia.

The steam reforming process requires a large primary reformer, heating many tubes containing a catalyst. When steam and natural gas are passed through the tubes and over the catalyst, synthetic gas (syngas) – a mix of hydrogen and carbon monoxide – is produced, and then used in the production of the desired product.

Maintaining temperatures below design limits avoids heat damage to the reformer tube, while ensuring good product yield. These temperature measurements are taken using infrared pyrometers. Infrared technology can be significantly affected by combustion products including steam, carbon dioxide (CO_2) and other hot gases, so wavelengths should be chosen according to the furnace atmosphere. Changing emissivity within the tube must also be considered.

Accurate temperature monitoring is essential to ensure maximum efficiency – reducing emissions of CO_2 – save energy costs, extend the lifespan of the reformer tube, and improve operator safety. However, any solution must overcome the challenging process conditions, while a non-contact measurement is needed to withstand the high temperatures involved.

Fig. 1 shows a thermal image of a side fired SMR.

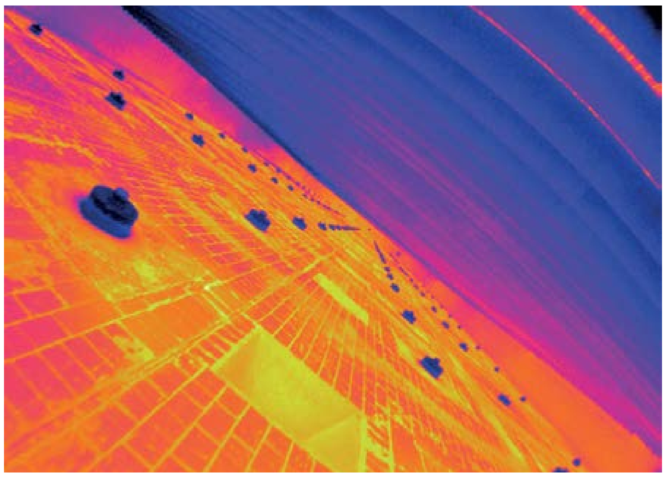


Fig. 1: Thermal image of a side-fired SMR.

Fig. 2: AMETEK Land Cyclops L pyrometer.

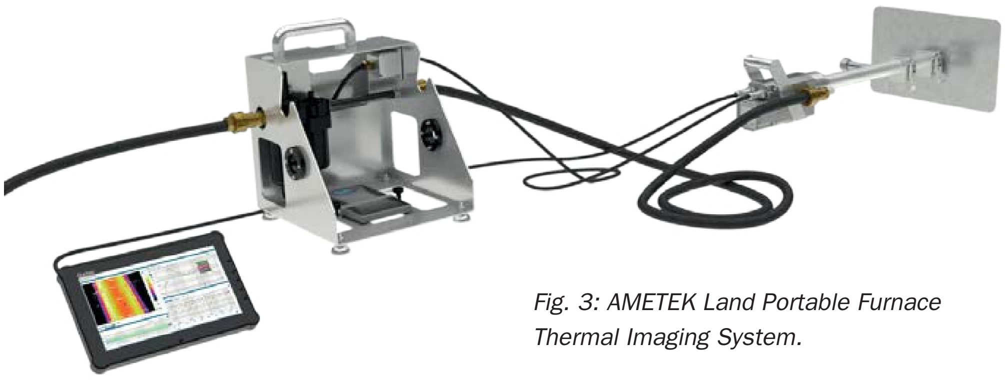


Fig. 3: AMETEK Land Portable Furnace Thermal Imaging System.

Portable and fixed non-contact measurements

Many plants operate conservatively to reduce the risk of material failures. However, even running at 10°C (18°F) below design temperatures typically results in a 1% productivity loss on an SMR.

Throughout the syngas industry, pyrometers are used to perform the necessary temperature monitoring. The AMETEK Land Cyclops L portable handheld pyrometer (Fig. 2) is widely used in this market for this application and can be combined with other technologies to provide more accurate and comprehensive temperature

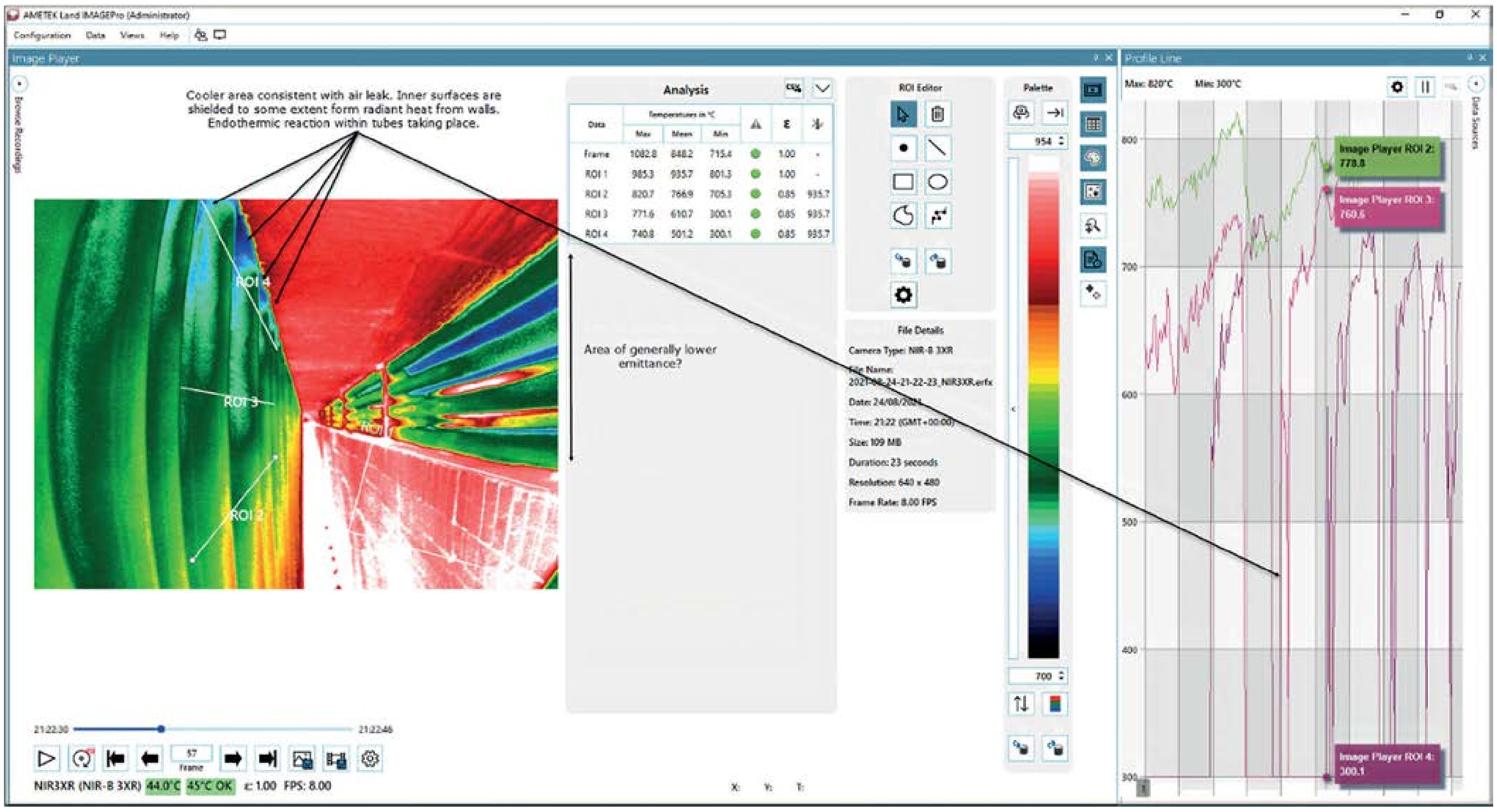


Fig. 4: Analysing air leaks and temperature data from an SMR using the AMETEK Land Portable Furnace Thermal Imaging System.

IMAGE: AMETEK LAND

data that meets new challenges and demands, especially with regards to emissions reduction.

Depending on the furnace design, if the pyrometer measurements show that SMR temperatures are approaching or surpassing the tube's design limits, firing can be reduced, burners can be gagged or, in extreme cases, burners may be shut off.

Since this is a labour-intensive, reactive approach, potentially concerning conditions are usually only be acted upon if observed and recorded by the inspection team.

Portable and fixed thermal imaging systems can both be used to produce high-resolution images or videos, and extensive temperature data in the SMR. However, while portable systems are valuable inspection and thermal survey tools – and can often see parts of the SMR that operators may not be able to see with the naked eye through peep-doors – the single-point, manual data collection they provide does not match the volume of information that can be supplied by a thermal imaging system.

Fixed thermal imager-based monitoring systems provide this comprehensive data in real-time, with automated image analysis and continuous monitoring of tube wall temperatures. They can also identify insulation, burner tip/tile condition, and potential hot bands or catalyst issues on SMRs. The continuous surface temperature data allows remaining tube lifetime to be calculated.

> **Accurate temperature monitoring is essential to ensure maximum efficiency, save energy costs, extend the lifespan of the reformer tube, and improve operator safety."**

A thermal imager using a borescope can take measurements through a small hole in the furnace wall, causing far less interference with the process than an open peephole.

A wide-angle field of view allows measurement of multiple reformer tubes simultaneously, delivering a real-time, high-resolution image with tens of thousands of individual temperature measurement points.

AMETEK Land's recommended solution for thermal imaging in SMRs is the NIR Borescope (NIR-B) 640-EX, a short wavelength radiometric infrared borescope imaging camera which measures temperatures in the single range 600 to 1,800°C (1,112 to 3,272°F) and utilises the latest wide dynamic range imaging technology.

This is ideal for industrial gas applications where high differential temperatures exist in the field of view, such as tube and furnace walls.

Other measurement solutions

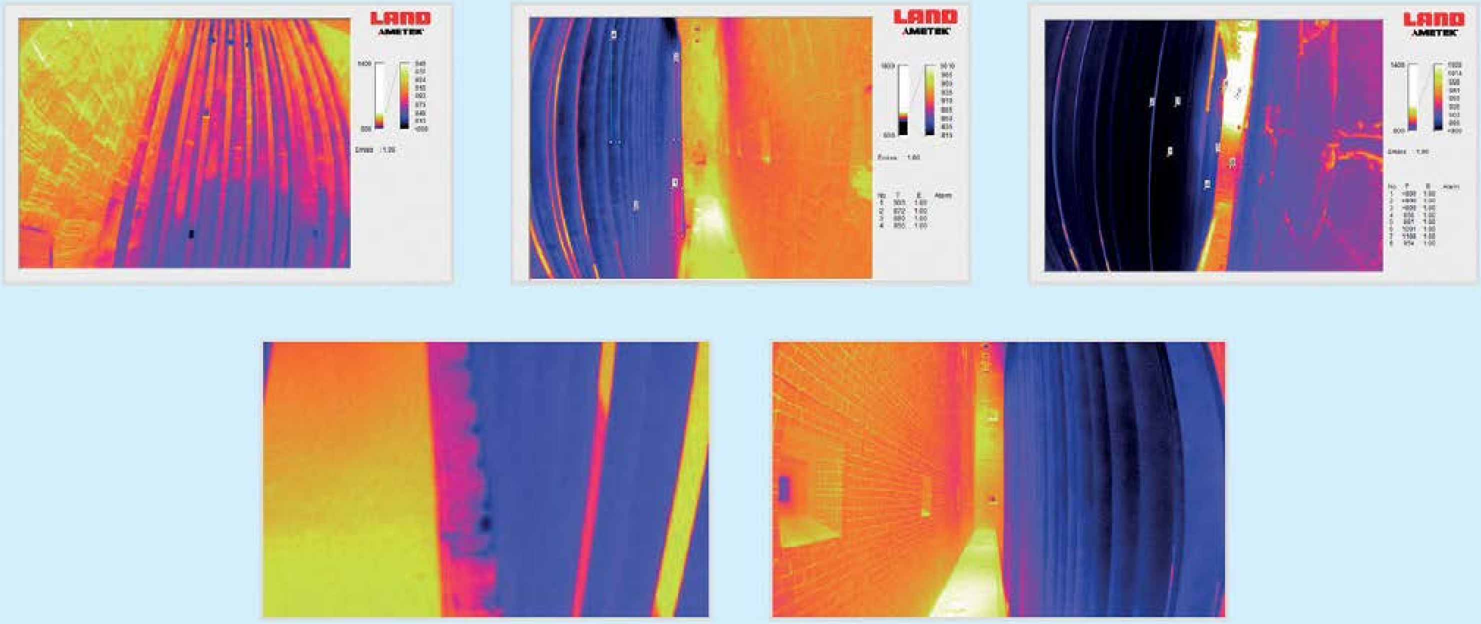
AMETEK Land offers a Portable Furnace Thermal Imaging System (Fig. 3), with optional air-cooling, that enables regular, easy, and quick inspections, along with thorough temperature data that can be analysed and archived (Fig. 4).

The system is available with a range of multiple wavelengths, borescope lengths, and Fields of View (FoV), ensuring it is suitable for many petrochemical processes. The wavelength must be correct for the gas atmosphere; the borescope should extend through the peep-door comfortably, and the FoV should match the peep-door design and tube layout.

Portable pyrometers and thermal imaging systems provide repeatable data, but reference measurements are also required to verify the accuracy of the temperature data produced.

For this, AMETEK Land provides the Gold Cup (Fig. 6), a water-cooled three-metre-long probe that creates near black body conditions at the measurement point,

Fig. 5: **Thermal images showing reformer issues, including refractory damage and flame impingement**



Source: AMETEK Land

ensuring repeatable, reliable reference temperatures.

If the environment has a hotter background – as is usually the case in an SMR – compensation for both surface emissivity and incident radiation is needed to ensure accurate non-contact infrared measurements. Designed only for periodic reference measurement readings, the Gold Cup uses a hemispherical reflector to deliver a measurement which is independent of emissivity and incident radiation.

Case study

Air Liquide, the world leader in gases, technologies and services for industry and health, employed AMETEK Land's NIR-B-640-EX thermal imager to continuously measure the temperature of tube walls within its SMRs.

The SMRs are used to produce hydrogen and carbon dioxide industrial gases, and their reliable, safe operation is of paramount importance. However, they are very challenging assets to maintain and operate.

Some of the common problems in reformer operation are burner, flue gas distribution and catalyst issues (Fig. 5), which can all directly affect Tube Wall Temperatures (TWT), overall tube lifespan, and cause premature tube failure. They can also lead to excessive caution over TWT, resulting in valuable production being lost annually.

Air Liquide required a solution to deliver a highly accurate and more complete measurement of the equipment and process, compared to spot temperature measurements, capable of operating in a hazardous environment.

AMETEK Land's NIR-B-640-EX provides a high-resolution thermal image with real time high accuracy temperature measurements of both the tube wall and refractory wall surface, allowing for background compensation.

It was developed specifically to operate in the hazardous environment of an SMR and is ATEX and IECEx approved, and CSA certified.

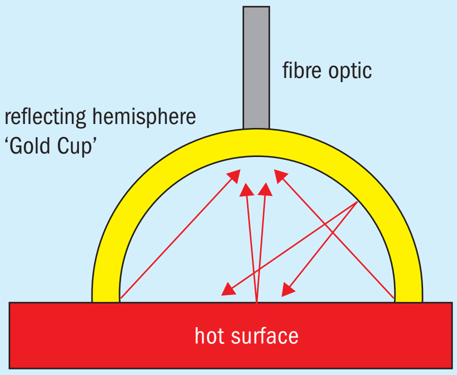
Air Liquide initially undertook a live trial of the NIR-B-640-EX at one pilot plant, with the full support of AMETEK Land's team in Spain. This enabled the operators to fully test the instrument within their specific, harsh environment.

Through this testing, Air Liquide confirmed the thermal imager's suitability, demonstrating the critical role it could play in enabling and enhancing understanding of tube conditions.

The borescope was installed through the furnace wall in front of the tubes within the chamber. Via a field connection box, the thermal imager is connected to the control room.

Air Liquide's main drivers in investing in the NIR-B-640-EX were to extend tube and catalyst life, which was achieved as a result of the testing. Continuous data relating to the SMR which enabled correct balancing and monitoring of their main, critical asset.

Fig. 6: **AMETEK Land Gold Cup against the hot surface of a tube**



Source: AMETEK Land

Extensive functions available within the system's thermal imaging software enabled continuous monitoring of TWT, and early warning of any increasing temperature, allowing Air Liquide operators to spot and respond immediately to problems such as hot spots and bands on the tubes, refractory damage, and any flame impingement.

With the furnace know-how provided by the NIR-B-640-EX's continuous temperature monitoring, the operators are able to make much more informed and confident decisions for greater plant reliability. ■


Maire Tecnimont
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KONTROLLTECHNIK INSPECTION SERVICES

Using technology to protect the heart of the plant

Thomas Fortinberry

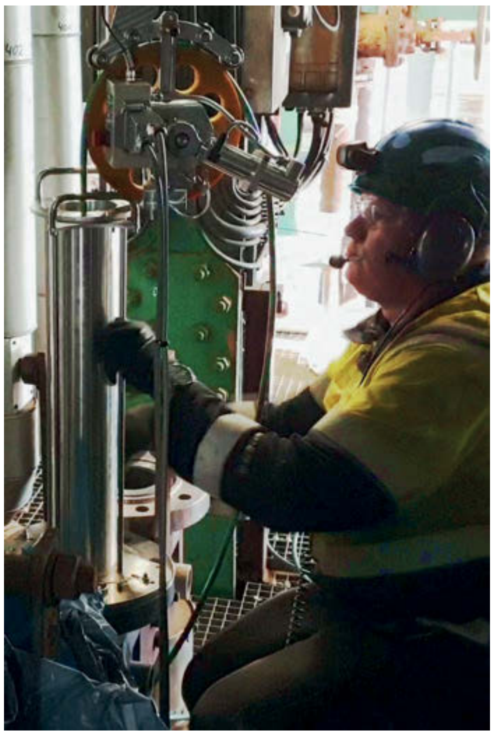

PHOTO: KONTROLL TECHNIK

Fig. 1: Reformer pipe scanner operator.

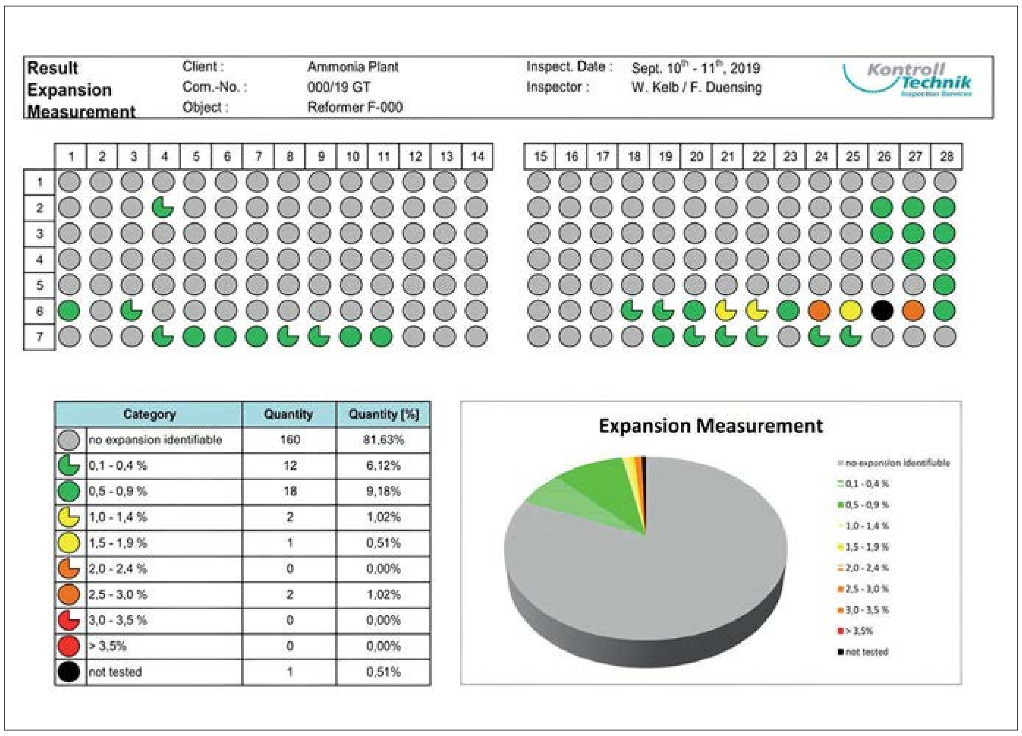

IMAGE: KONTROLL TECHNIK

Fig. 2: Tube expansion overview.

The primary reformer is considered by many as the heart of the petrochemical and fertilizer industry. Like the real heart, the reformer has its own arteries which are spun cast tubes that act as individual reactors within the reformer, and as you see in the heart it only takes one issue or failure to shut down the entire system. There are three main components to reformer tube damage: heat, pressure, and time. One can argue there are a variety of other damage mechanisms, but they all seem to relate back to these three main damage mechanisms. Reformer catalyst tubes are continuously subjected to extreme operating conditions of high temperature and pressure which over a prolonged period of time will cause various defects within the tube alloy. In this article two technologies are discussed that will allow the owner/operator of the plant to see how the plant is operating and make changes based on actual operating conditions and using reformer tube inspection data from a turnaround to help identify problems caused during operation.

Thermal surveys

The first technology to be discussed is thermal surveys using an IR camera. Reformer surveys are performed during operation to give the user an overview of how the reformer is preforming and highlight any issues found during the survey. This survey helps to identify problem areas within the radiant box, issues for example such as flame impingement on the reformer tubes, burner issues, catalyst issues within the reformer tubes, and flue-gas distribution issues. All of these issues can cause overheating of the tube surface, which in turn will negatively affect the life of the tube and could cause premature tube failure.

During a survey, infrared images are taken from view ports into the reformer of the tubes, reformer walls, burners, and tunnels within the radiant box. These images are stored and then analysed in a software program. From these images a report will be produced to discuss with the client. The report will highlight issues found during the survey and also show the areas where the process is working as expected. The goal of the survey is not just to identify problems but also give the operators the data to help balance the reformer. Regardless of how the reformer is operated either below or at design levels, it should always be a priority to operate a balanced reformer. By maintaining a balanced reformer this will help to make future maintenance and turnarounds more efficient and less costly.

Reformer pipe scanners

For inspection of reformer tubes during a shutdown KontrollTechnik has developed an innovative robotic dual technique NDT Scanner the "Reformer Pipe Scanner 360" (Fig. 1). There are two scanners the RPS-360-ID and the RPS-360-OD, both scanners use the dual technique of eddy current for crack detection and laser measurement for expansion.

The Reformer Pipe Scanner type RPS-360-ID is equipped with a powerful proprietary hybrid NDT technique for sensitive crack detection in reformer tubes up to 23 mm wall thickness. As the proprietary technique needs no couplant, the readings are repeatable from inspection to inspection. The inspection tool was developed to inspect reformer tubes from below the floor to the top of each tube to give complete inspection for creep and crack damage of each tube.

The diameter measurement results of the 360° laser for creep detection is performed simultaneously to the powerful proprietary technique testing in a 3-dimensional overview of each tube. The laser rotates thus giving a complete profile of the inside of the tube. As the inside of the tube is a machined surface this permits a more accurate expansion

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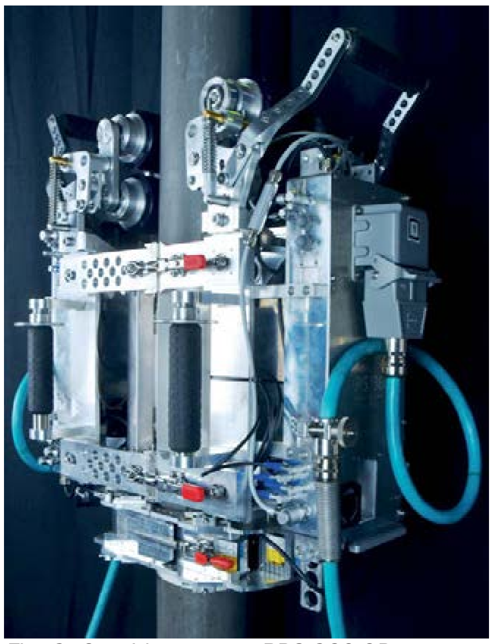


PHOTO: KONTROLL TECHNIK

Fig. 3: Outside scanner RPS-360-OD

measurement and allows problem areas to be detected much earlier than traditional methods of inspection (see Fig. 2).

Inspecting from the internal surface RPS-360-ID

Inspecting from the internal surface, the complete unit will be moved by a remote-controlled puller/pusher unit allowing the passage from the bottom of the tube to the roof assuring a fast and reliable inspection. The key benefits are:

- the only system offering 360° crack detection and 360° laser scan of entire tube length;
- accurate, robust, and reliable by computer-controlled data acquisition;
- powerful proprietary technique for sensitive crack detection;
- integrated rotating laser module for expansion measurement;
- high rate of inspection speed;
- accurate location and sizing of features;
- high repeatability allowing indication monitoring;
- on-site reporting.

The latest and most advanced technology for inspecting reformer tubes is now being introduced as the RPS-360-OD (see Fig. 3) an external automated scanning system that is equipped with a powerful proprietary hybrid NDT technique for sensitive crack detection in reformer tubes up to 23 mm wall thickness that inspects truly 360° around each tube. As the proprietary technique needs no couplant and is not dependent on tube cleanliness, the readings are repeatable from one inspection to the next inspection.

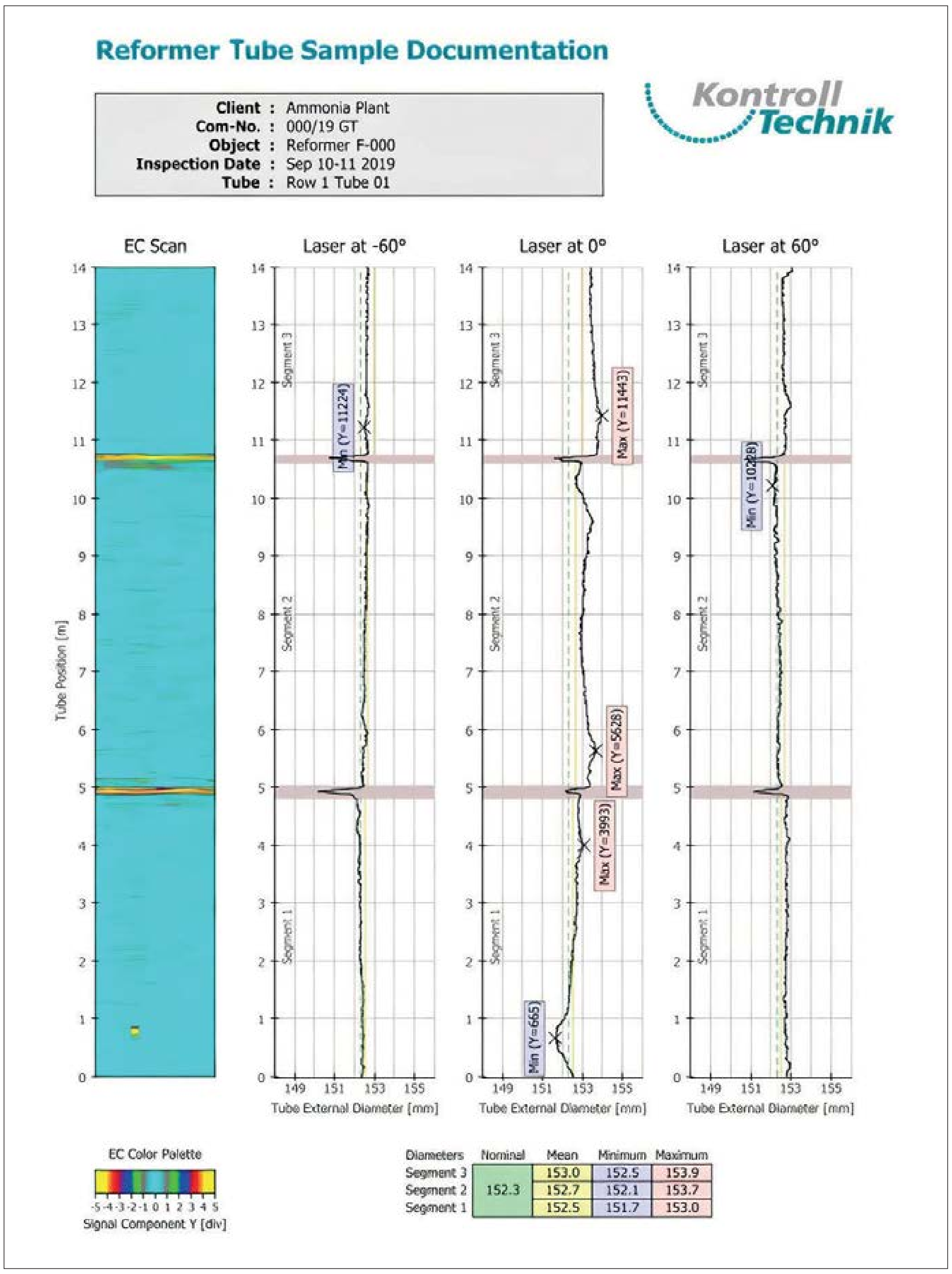


IMAGE: KONTROLL TECHNIK

Fig. 4: Reformer pipe scanner report

The diameter measurement inspection system is performed by using multiple lasers for creep detection and diametric growth. Both procedures are performed simultaneously to the powerful proprietary inspection technique at a fast rate. The laser modules are mounted on both sides of the scanner. By differential measurements a maximum of accuracy for the diameter measurement will be achieved and correlated with the crack detection system.

Testing from the external surface RPS-360-OD

For testing from the external surface, the complete unit will be moved by a remote-controlled scanning system allowing the passage from the furnace floor to the roof assuring a fast and reliable inspection.

Key benefits of the OD crawler are:

- 100% OD coverage of each reformer tube with our 360° crack detection;
- 6-point laser inspection over entire length of inspected tube;
- collects millions of data points during each tube inspection;
- all recorded data can be used in Reformer Tube Assessment 360;
- repeatable, accurate and fast inspection;
- 100% crack detection coverage of each reformer tube;
- manufacturing flaws – early warning of problems before tube failure;
- Provides baseline measurements for new tubes;
- Identifies failure mechanisms in individual tubes: creep strain, bulging, manufacturing flaws.

After the inspection the recorded data is analysed, and a report is generated to present to the client during the close out meeting. In the report overviews are presented for both the expansion measurements and the eddy current crack detection results (Fig. 4).

Result documentation

EC-testing

- eddy current result presentation in colour scan mode for the entire tube circumference;
- easy identification of defects.

Laser testing

- evaluation of minimum, maximum and mean diameter for each tube section at the whole circumference (internal reformer tube testing);
- evaluation of minimum, maximum and mean diameter for each tube section at three circumferential positions (external reformer tube testing);
- comparison of maximum diameter to nominal and/or mean diameter for each tube section;
- comparison of data with previous or fingerprint laser testing data.

Conclusion

With the advancements in reformer tube metallurgy and catalyst life the time between shutdowns is being increased, increasing the importance of technology to monitor reformer health.

Combining online reformer surveys and inspection data obtained during shutdowns helps to give a complete overview of reformer health, allowing plant management to make better informed decisions on operation and maintenance moving forward.

BD ENERGY SYSTEMS

SMR performance improvements for efficiency and safety

Joe Price

The steam methane reformer (SMR) is an energy intensive system and is the largest and most expensive equipment item in a conventional syngas plant. Many of the components of the SMR and the related heat recovery system require high grade materials to ensure safe and reliable operation in conjunction with a satisfactory operating life. Proper operation coupled with a good maintenance/inspection program will maximise the operating life of these components and increase the reliability and safe operation of the SMR as well. With the current focus on environmental emissions, proper operation will also minimise the greenhouse gas emissions through the stack via more efficient operation. A large number of studies and projects have been conducted by BD Energy Systems (BDES) personnel to improve the operation, reliability, and safe operation of steam-methane reformers. The following is a summary of areas that should be considered in operating and maintaining the SMR and related equipment to increase reliability, reduce downtime, and reduce emissions.

Mechanical

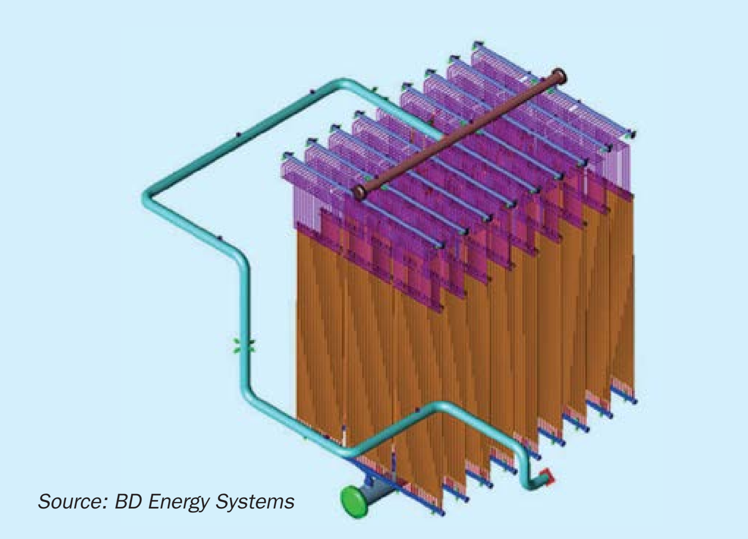
Hot/cold balancing

Before a multi-row reformer is commissioned after replacing the catalyst tubes, a cold radiant coil balance is performed to ensure that the weight of the system is properly and evenly supported to reduce stresses before the furnace is placed into service. After the reformer is in operation at stable conditions, a hot balance is performed to again ensure that weight is evenly supported in the hot condition and the stresses on the catalyst tubes, risers, and outlet manifolds are minimised. These balances are critical to overall radiant coil health and longevity of these components.

Inlet/outlet system stress analysis

A thorough stress analysis of both the inlet feed piping system to the catalyst tubes as well as an analysis of the catalyst tube effluent piping system is recommended. BDES has seen several outlet support systems that did not perform well after re-tubing, even though the change in mass of the tubes and catalyst was marginal. Fig. 1 is a representative illustration of an inlet/outlet systems that includes the catalyst tubes and associated supports.

Fig. 1: **Representative stress analysis model of an SMR inlet/outlet system**



Source: BD Energy Systems

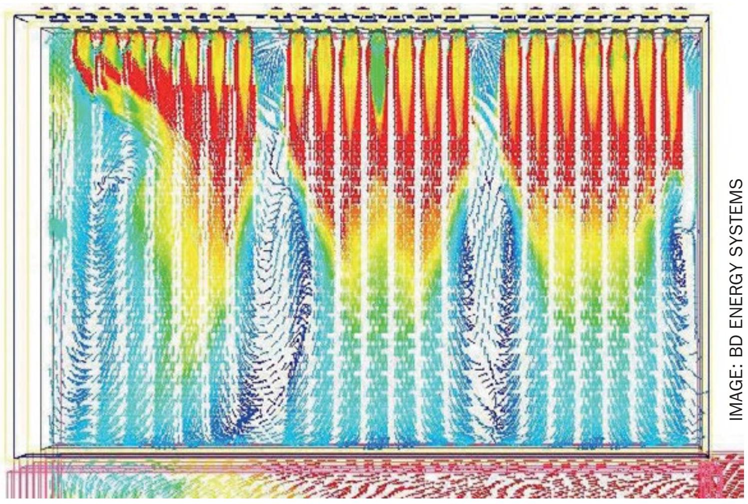


IMAGE: BD ENERGY SYSTEMS

Fig. 2: CFD analysis showing severe recirculation flue gas flow pattern and resulting burner flame pattern

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SMR process and mechanical evaluation

This evaluation is a survey of the reformer furnace and its associated equipment that addresses the current level of instrumentation, control methods, and mechanical features and compares them with different recommended levels with explanations given for the recommendations. It includes discussions with plant personnel to address any specific concerns regarding design and operations. This study begins with a field survey of the reformer and its equipment and review of the current mechanical drawings and addresses:

- recommended minimum instrumentation required for efficient operation;
- recommended instrumentation to allow optimised operation more completely;
- recommended SOPs and operator instruction regarding what to observe while on their shifts;
- a field survey will be conducted on each reformer noting missing instrumentation, potential mechanical issues or observed anomalies, discussions with operations concerning current operating practices vs general industry standards;
- recommended minimum instrumentation required for efficient operation;
- mechanically related recommendations (if any) for increased reliability.

Design deficiencies

SMRs are utilised for the production of syngas for various end products such as ammonia, hydrogen, methanol, and reducing gas. Each of these processes vary in intensity with regards to pressure and temperature and as such, each process requires design margins and considerations to far exceed those recommended in API-560 and API-530. These margins affect:

- outlet systems;
- convection sections;
- high temperature components;
- equipment design margin issues.

Personnel and safety

SMR training

BDES has assembled a comprehensive curriculum on reformer furnaces that includes topics on reaction kinetics, operations, and mechanical design. BDES offers this training on-site or at its main office in Houston, Texas over a three-day period. This course is designed for plant personnel in all disciplines to attend whether it's maintenance, operations, or engineering.

Operator Training

On site operator training is available and can be tailored for any specific topics that the client requests or to target specific problem areas. The training can be designed to provide training such that all shifts are trained. Some representative training topics that have been presented are:

- burner balancing;
- operator rounds;
- understanding heat transfer.

Tube growth monitor (TGM)

TGM is a permanently installed method for monitoring catalyst tube temperature and provides for a practically immediate response mechanism to alarm of tube overheating and imminent tube failure.

Process analysis

SMR studies

This study is a comprehensive analysis of the reformer system and includes (if present) the reformer, convection coils, auxiliary boiler, air preheater, FD and ID fans, and associated drivers. This study includes an analysis of radiant section efficiency, calculation of the tube metal temperatures, calculation of the temperature margins of all tubes and coils based on current operating conditions, efficiency of the convection coils, pressure drops, flame patterns, FD/ID fans, and specific conclusions and recommendations regarding any areas of concern or actions that need to be taken.

The study results can also be utilised to assess the reformer and associated equipment for increased production, reduced energy consumption. or other different operating scenarios.

> "Catalyst tubes in the areas with higher TMTs will have a shorter tube life."

Furnace balancing

Furnace balancing involves balancing the heat distribution throughout the radiant and convection sections of the reformer. The maldistribution of heat in the radiant section can lead to several operating and mechanical problems such as inconsistent process outlet temperatures (for multi-row reformers) and inconsistent catalyst tube metal temperatures (TMTs). There can be several factors that affect the heat distribution including deficiencies in the existing combustion air and/or fuel gas flow control and distribution systems that must be addressed in order to carry out a proper balancing of air and fuel to the burners.

CFD modelling

CFD modelling may be used in studying an unbalanced furnace, but it is also useful in many other applications. CFD analysis can be utilised anywhere in the reformer from the air preheat system all the way through to the stack. Areas of analysis include:

- heat transfer and heating uniformity;
- study the effectiveness of mixing elements used for NOx control;
- assess burner flame and flue gas flow patterns (Fig. 2);
- assess combustion air flow patterns;
- burner compatibility with reformer design (Fig. 2).

Tramp air study

Tramp air is any atmospheric air that enters the flue gas stream without passing through the burner. The effect of tramp air is a reduction in overall reformer efficiency due to the fact that heat from the flue gas is wasted by heating the atmospheric air instead of heating the catalyst tubes and/or the convection coils. A further decrease in efficiency occurs because the ID Fan must remove this excess air requiring more energy to do so and decreases real fan capacity. In some cases, the tramp air can have a very large effect on efficiency while also imposing a limit on plant capacity.

A tramp air study will quantify the amount of air infiltration into the reformer system and identify the sources of tramp air access into the reformer. Recommendations of corrective measures that can be taken are also advised.

Flue gas tunnel study

The flue gas tunnels, or coffins, have a necessary function in the design of a downfired reformer furnace. A properly

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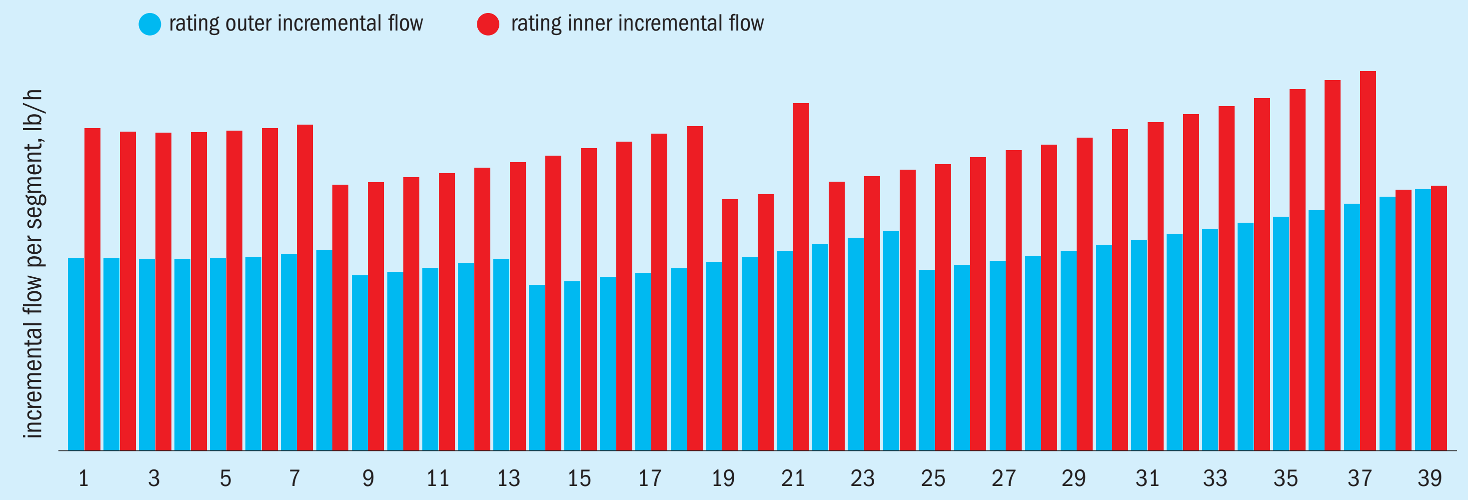
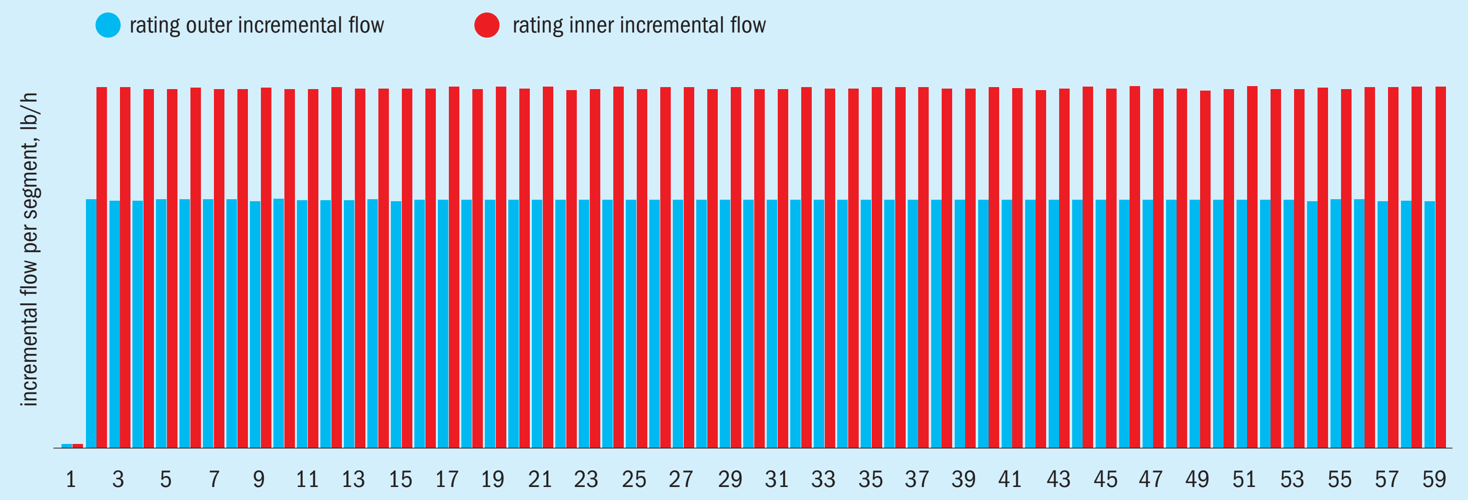
Fig. 3: **Incremental flow into tunnel per segment – conventional tunnel design**



Source: BD Energy Systems

Fig. 4: **Incremental flow into tunnel per segment – TOP™ tunnel design**



Source: BD Energy Systems

designed tunnel will remove flue gas from the radiant section in a uniform manner such that all flue gas flow is evenly distributed over the length of the tunnel and radiant coil. A tunnel that is not properly designed or is operating far above its original design capacity will cause a maldistribution of flue gas flow patterns which in turn can result in a maldistribution of heat transfer to the catalyst tubes. This type of operation can cause areas where the catalyst tube TMTs are lower than average and some areas where the TMTs are higher than average. Studies have shown that the catalyst tubes in the areas with higher TMTs will have a shorter tube life and may fail prematurely.

A tunnel study will assess the current design of the tunnels based on current and/or future operating rates. This assessment will be compared to recommended changes to the tunnels to alleviate the maldistribution and limitations will be stated with regards to the current tunnel design.

A comparison will also be made to a TOP™ (Tunnel Optimal Performance) designed tunnel utilising new tunnel design software and materials by BDES. These tunnels have been developed and designed to allow near-perfect even flow into the tunnels with superior structural stability.

Figs 3 and 4 are illustrations of the CFD analysis of a conventionally designed tunnel compared to a TOP™ designed tunnel for the same SMR.

Summary

The proper operation and maintenance of a steam-methane reformer will increase the reliability and safety of the unit. Scheduled turnarounds for upgrades, repairs, and component replacement are a critical aspect of maintaining the overall health and longevity of an SMR and its associated equipment items. But just as important are regularly scheduled studies and analyses that are performed while the unit is operating which can reveal operating problems or drifts away from good operating practice before they become major issues. Having regularly scheduled maintenance activities and studies will enable the SMR to operate at its best and safest potential.

ONPOINT – A KOCH ENGINEERED SOLUTIONS COMPANY

Stay in the loop – new capabilities to optimise steam methane reformers

Eric Huelson and Eric Gebhard

As reformer operation moves into the automated future, there remains a gap in real-time, detailed information about the combustion process within the heater. Increasing visibility of key parameters in locations within the firebox, combined with real-time quantitative insights about the health and operation of the heater, can enable operations to make simultaneous improvements of emissions, safety, reliability, and profitability and move control of the asset away from manual, inspection-based manipulations and into the future of automated control.

Steam methane reformers have many critical parameters. Optimising these systems beyond a base-case can be especially challenging. Optimisation efforts often focus on a single area of interest, and the steps taken can result in subsequent issues that negatively impact safety and reliability. Many combustion-related safety and reliability issues can be difficult to observe directly, and they often increase in severity over time.

Technologies are now available to cost-effectively monitor and automate large industrial heaters. Traditionally, these heaters have relied on a handful of point sensors to represent a multitude of combustion and process control parameters, typically at the global level. While this is generally sufficient for small heaters, the lack of available data for larger heaters with many zones of combustion results in blind spots of furnace operation. Measurements from single sensors are often falsely assumed to represent all the combustion products in the heater. Alternatively, new monitoring technologies, such as the ZoloSCAN™ system, exist which can economically detect total products of combustion at multiple locations to help remove the uncertainty from limited downstream sensors and correct common combustion-related problems.

Steam methane reformers

Steam methane reformers historically are large heaters with many burners, commonly over 100, installed in the roof of the heater and down fired (see Fig. 1). It is typical for these systems to be operated with both a forced and an induced draft fan (balanced draft system) and preheated combustion air for improved efficiency and control. The burners are installed in multiple lanes, or rows, with process tubes located between each burner lane. This is illustrated in Fig. 2 with the rows of process tubes identified as the green lines. The burners in the outer lanes, left and right side of Fig. 2, are typically designed to fire between 50-65% of the heat release of the inner lane burners.

As burner technology has changed over the last several decades from pre-mix or conventional raw-gas burners to ultra-low NOx, the basic design of reformers has stayed the same. To meet more stringent emissions requirements, the changes in burner design have resulted in longer flame lengths that are more susceptible to adverse internal flue gas recirculation patterns within the heater.

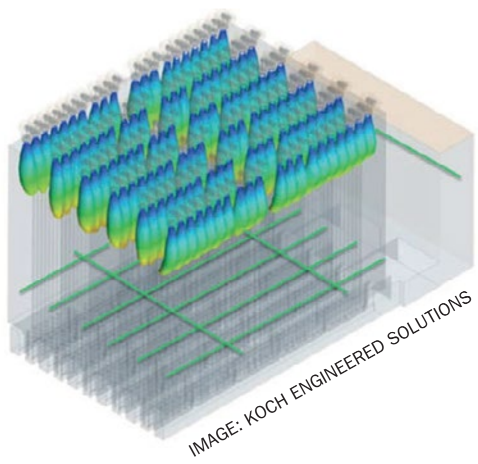
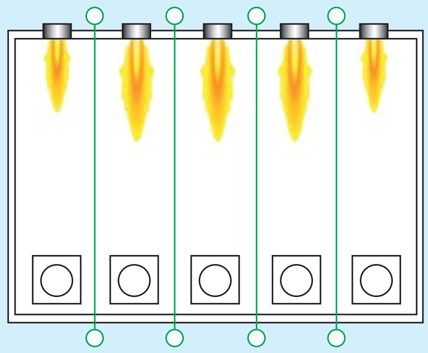


Fig. 1: ZoloSCAN reformer laser grid – represented installation.

Fig. 2: **Typical down-fired reformer**



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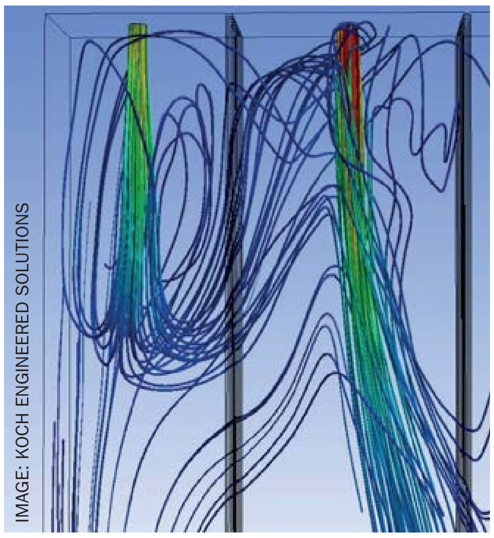

Fig. 3 Unproportioned flue gas flow path.

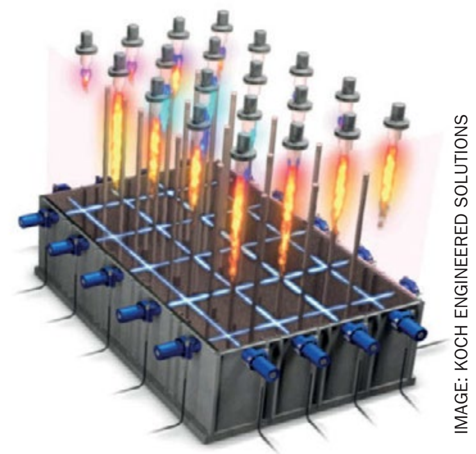

Fig. 4 Laser grid distribution on a downfired reformer, paths depicted to each measure temperature O_2, CO, CH_4 and H_2O and provide a distribution of combustion in the heater.

Common issues

There are several common issues observed in steam methane reformers. Many of these issues are related and cause compounded issues such as decreased efficiency, flame impingement, and localised hotspots on tubes that cause decreased tube life and limited production rates.

Perhaps one of the most common issues found in combustion systems is the maldistribution of the combustion air delivered to the burners[1]. Combustion air maldistribution results in variation of the air-to-fuel ratio for each burner. In some forced draft systems, these air-to-fuel ratio imbalances can be observed from one row of burners to the next, as well as down the length of each burner row. The impact of varying air-to-fuel ratios per burner can result in some burners operating below the stoichiometric limit causing large flames and increased CO emissions levels. Other burners operating with too much excess air can result in increased NOx emissions.

Another common issue found in combustion systems is adverse flue gas patterns. Unproportioned burner momentum per available firebox area often results in flue gas patterns which cause the flames from the outer lanes to be pulled through or across the process tubes to adjacent inner lanes. Ultra-low NOx burners tend to exacerbate this problem due to their longer flame lengths. In Fig. 3, the flue gas is represented using particle streamlines in a CFD modelling simulation of a steam methane reformer. Momentum is illustrated by colour with the scale transitioning from high momentum (red streamlines) to lower momentum (blue streamlines). The higher momentum of the inner lane flue gas (right side of figure) draws the flue gas from the outer lane through the process tubes near the roof of the reformer. In many cases, adverse flue gas patterns create undesirable hot spots on the process tubes. Prolonged hot spots can lead to tube failure.

Optimisation and outcomes

One typical operational target for a combustion system is to reduce the global excess oxygen (O_2) to increase efficiency. When optimising for a low global excess O_2 level without knowledge of individual burner or O_2 distributions, an operator could unknowingly create a situation where burners have sub-stoichiometric combustion. This can result in an increase in burner flame lengths and potential impingement on process tubes, unburned fuel being drawn into a different zone of the reformer before combusting, and ultimately reduced efficiency of the reformer due to improper heat distribution on the process tubes.

ZoloSCAN laser grid

To the adage, "you can't improve what you can't measure," combustion monitoring tools are now available to quantify products of combustion directly within the firebox. The new technologies address a root cause of many of the issues reviewed above, specifically undiagnosed local variations in combustion. Most notably, the ZoloSCAN combustion monitor utilises tunable diode laser absorption spectroscopy (TDLAS) technology to simultaneously measure temperature, O_2, CO, CH_4 and H_2O in real-time, directly in a reformer (see Fig. 4) or large process heater, along multiple laser paths. Measurements can be used to provide a more accurate and representative quantification of combustion gases in a furnace vs. traditional, single-point thermocouples or ZrO_2 sensors. This is possible by orienting laser paths below reformer burner rows to provide path average measurements of each burner row in the firebox. This information can then be used to make control improvements of fuel and air distributions.

While each combustion monitoring system is unique, the ZoloSCAN system operates by simultaneously transmitting multiple laser wavelengths for multiple constituents measured on each laser path. The result is a path-average value for each constituent for that path. The paths are monitored sequentially, with all constituents measured first on path one, then on path two, until all the paths have been measured, typically in less than two minutes total time. The sequence then starts over again.

In-furnace combustion data benefits operators and process engineers by reducing the need to run at higher than desired excess oxygen setpoints. Reduced excess oxygen results in reduced fuel consumption, the potential to increase production, or a combination of both. Assets utilising the ZoloSCAN system commonly control excess oxygen in the range of 1.5 to 2.0% across the heater while simultaneously maintaining minimal CO_2. This compares to traditional heaters that usually run above 4% excess O_2. Additionally, TDLAS temperature measurements allow for improved heat distribution across the firebox, thereby reducing tube metal temperature deviations. The temperature profiles may be optimised for uniform heat flux to allow for increased capacity and increased tube life via the reduction of temperature hot spots[3].

Sensor to solution

Ultimately a sensor alone will not result in reformer process improvements. For the best effect, ZoloSCAN data, or any monitoring system, needs to be integrated into an advisory or automated process control loop to result in a meaningful and sustained operational solution. For deployments on steam methane reformers, this control loop often comes in the form of an advanced process control (APC) package for closed loop control or OnPoint's Ember™ software for open loop control.

Either option is relatively straight forward from a control perspective. For APC, data from the ZoloSCAN system is continuously transferred via OPC or Modbus to the plant's historian. Once integrated, often the visibility of combustion data allows for new tuning and maintenance evaluations not previously possible. With an initial tuning of the heater, target operation of the heater can often be sustained with more simple control loops, like fan damper biasing, biased O_2 and CO distributions within the firebox[4]. Each reformer is unique and integration plans may vary. For open loop combustion control, Ember outputs direct air register recommended setpoints which can be applied in the field by operators or engineers to optimise combustion for reduced global O_2 and improved temperature and oxygen distribution.

Conclusion

The tools for local or zonal quantification of in-furnace combustion now exist. While not as necessary for small heaters, laser grid-based combustion monitoring technologies fill a critical gap in large reformers where aggregate downstream measurements can only represent the entirety of the heater combustion and give no indication of the local variations. Augmenting existing sensors with distributed combustion feedback inside the firebox, coupled with simple control strategies, can result in sustained, efficient, and productive operation of a reformer. ■

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QUEST INTEGRITY

Reformer tube management: combining life assessment and diagnosis of operational issues

Alice Young, Charles Thomas and Tim Hill

For any plant that counts a steam reformer among its assets, plant reliability is invariably linked to management of the reformer catalyst tubes. The output of the reformer is often a key determining factor for downstream production rates, so a single catalyst tube failure can bring an entire plant down for a week or more and have an economic impact in the millions of dollars. In the reformer furnace environment, the primary threat to catalyst tube integrity is progressive creep damage. The rate of damage accumulation is determined by the reformer operating conditions. An accurate tube condition assessment and remaining life prediction methodology that can also aid in identifying operational issues can therefore play a significant role in overall plant reliability. The LifeQuest Reformer™ methodology and software package developed by Quest Integrity uses a unique approach to life assessment that fulfils both of these criteria.

LifeQuest Reformer

LifeQuest Reformer was born from the inability to accurately predict catalyst tube service lifetimes using conventional creep life assessment methods such as the Omega method or the Larson-Miller approach. The general methodology is consistent with the requirements for an API 579-1/ASME FFS-1 Fitness-for-Service Level 3 assessment[1], but there are two key aspects that make LifeQuest Reformer unique.

First, it was recognised that the typical approach of using constant material property values in creep life assessments was not valid for the HP alloys widely used for catalyst tubes. It is known that during exposure to service temperatures, the microstructure of HP alloys changes considerably due to aging. This in turn decreases creep strength over time[2]. LifeQuest Reformer captures this effect through a dynamic creep model that accounts for the thermal exposure of the material and the resultant aging effect. This model was developed from a proprietary creep test database created by Quest Integrity for aged and as-cast catalyst tube materials and has been

Fig. 1: **Illustration of LifeQuest Reformer back-calculation of effective tube metal temperature and remaining life prediction**

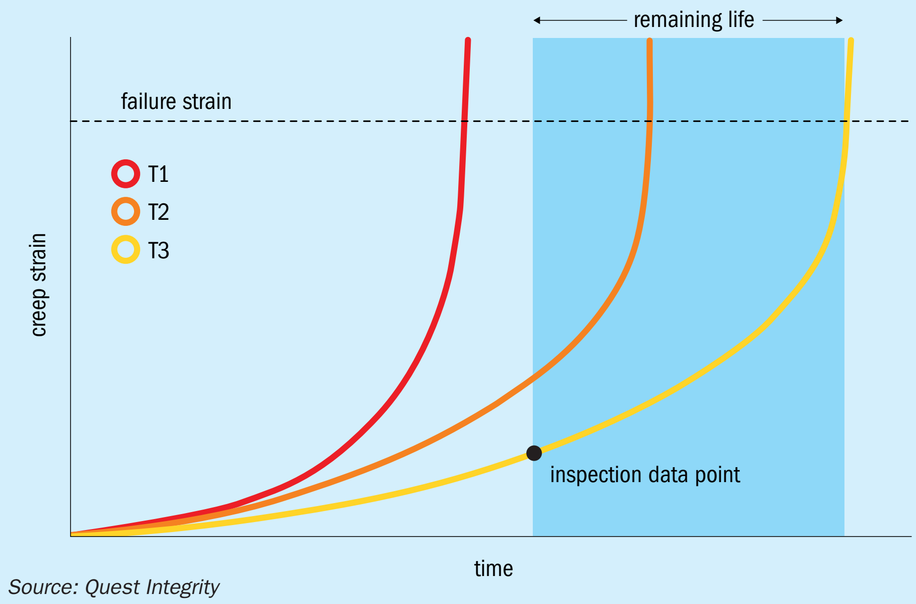

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Fig. 2: **Flow chart illustrating overall LifeQuest Reformer methodology and assessment outputs**

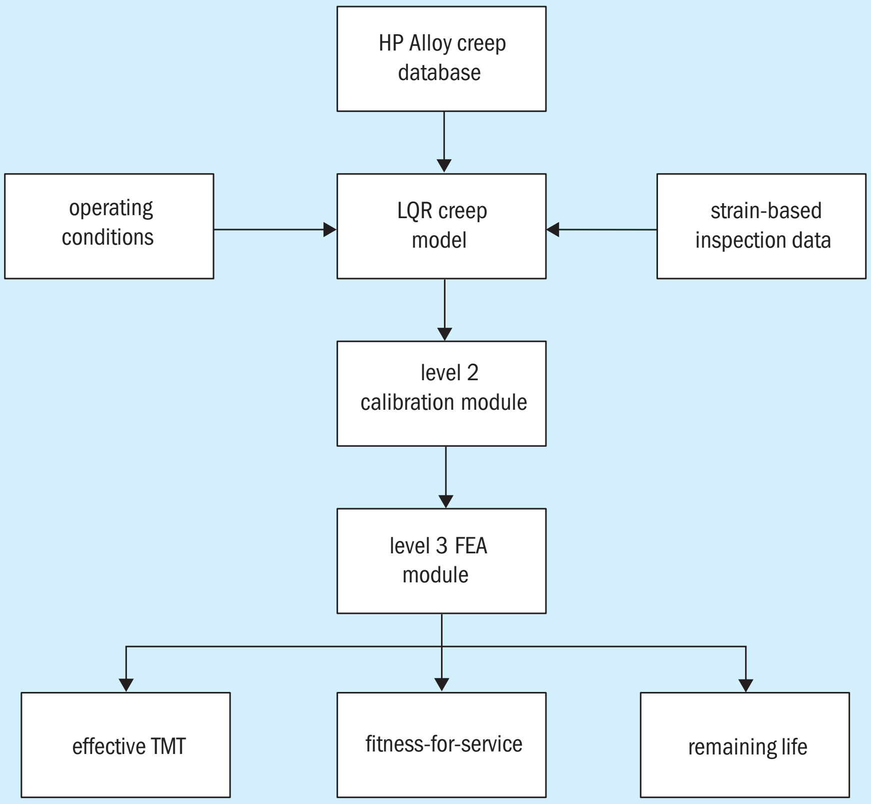

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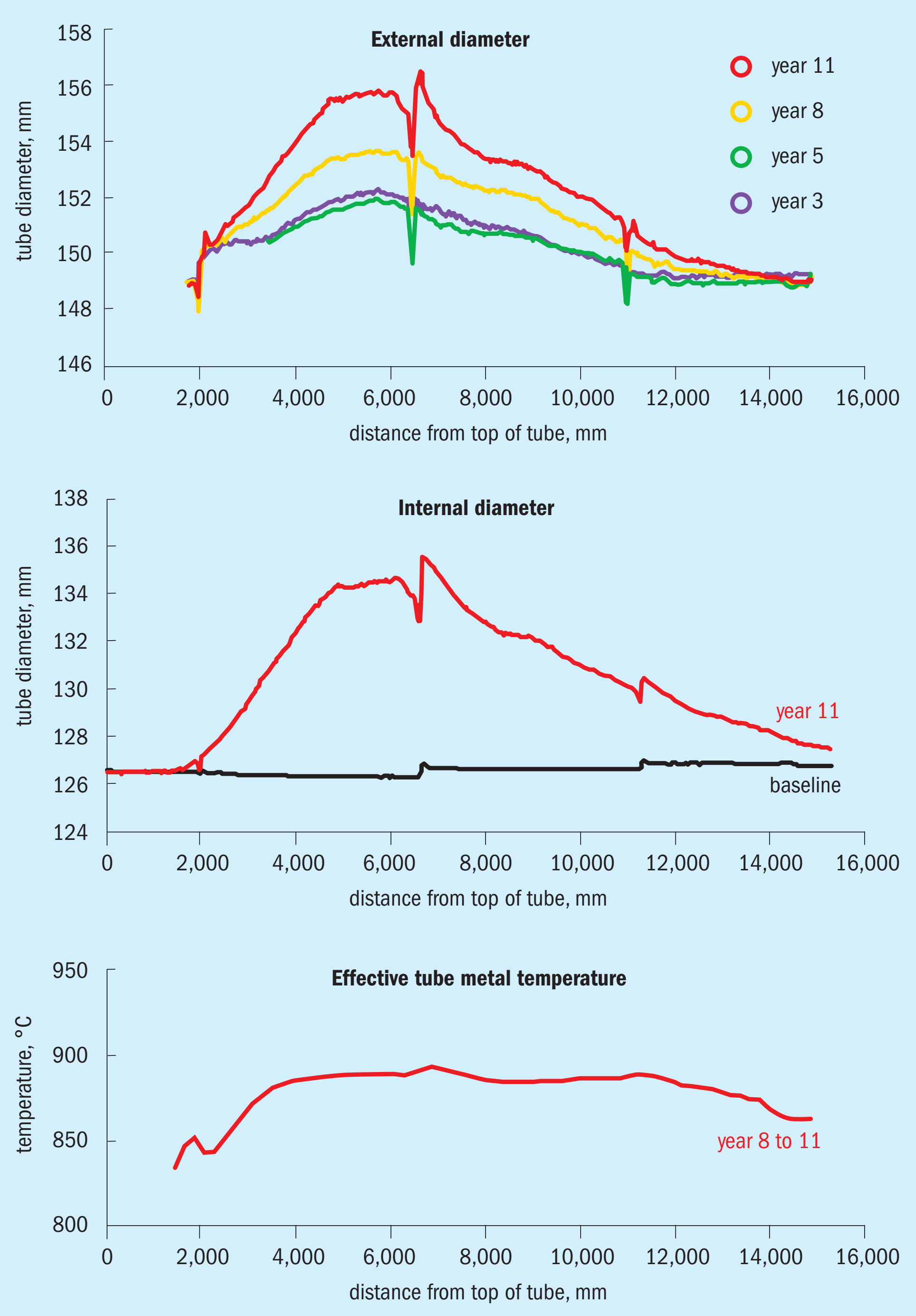
Fig. 3: **Example external and internal diameter inspection data from all historical inspections and calculated effective temperature profile for Year 8 to Year 11 period**



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validated through both laboratory testing and in-service assessment of well over 100,000 individual catalyst tubes.

Second, LifeQuest Reformer removes the conventional creep life assessment requirement for temperature data as an input. Accurate measurement of tube metal temperature (TMT) in a reformer furnace is inherently difficult and typically has large associated uncertainties that can lead to variations of -75% to +300% in remaining life calculations[3]. However, given an accurate material creep property model and a known stress, a unique strain-time curve can be generated for any chosen temperature. If creep strain is measured at a known time, the unique curve that passes through that data point can be identified and the "effective" TMT determined. This is the temperature that would produce an equivalent amount of strain over the time period considered. Remaining life is then calculated by extrapolating the strain-time curve to the failure point. An illustration of this methodology is provided in Fig. 1. Multiple data points and changes in operating conditions can also be accommodated by stitching together a sequence of partial strain-time curves.

The full LifeQuest Reformer methodology and assessment outputs are summarised in Fig. 2. Any diametric inspection data can be used as an input, provided a pre-service baseline diameter has been measured or can be estimated. Quest Integrity has also developed a Rapid Assessment version equivalent to an API 579-1 Level 2 assessment that can be used during plant turnarounds to provide tube replacement plans within 24 to 48 hours of inspection. The Rapid Assessment is typically undertaken when it is anticipated that tube replacements will be required during the turnaround, but the tubes to be replaced need to be verified or there is no prior assessment identifying these tubes. The full Level 3 assessment then provides a more detailed analysis of inspection and operating data, operating risk and uncertainties, replacement planning for future turnarounds, and recommendations for future operation including TMT operating limits.

Case study: Diagnosis of operational issues

Another notable advantage of the LifeQuest Reformer methodology is that it can identify reformer operational issues. A series of inspections and assessments undertaken by Quest Integrity on a reformer furnace illustrates this valuable feature.

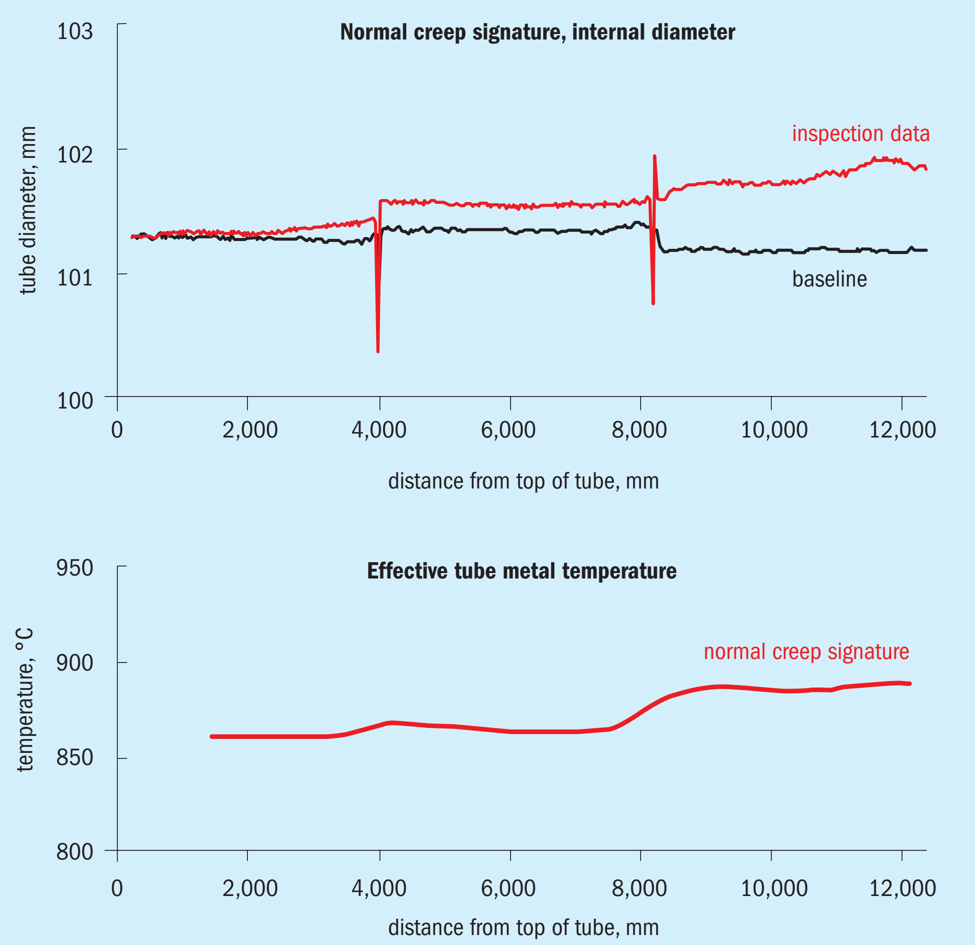
The reformer in question contained 64 catalyst tubes and had a history of tube failures and temperature issues. The key events over the 11-year period from tube commissioning to the most recent inspection are summarised as follows:

In Year 3 of operation, three tube ruptures occurred during a start-up. Significant abnormal creep damage was also identified in the majority of tubes. Replacement of the failed tubes was scheduled for the next available opportunity in Year 5, and one additional tube was removed from service due to the risk of failure prior to Year 5.

In Year 5, 23 tubes were replaced after being predicted to reach the damage threshold for retirement before the next tube replacement opportunity in Year 11.

In Year 8, hotspots consistent with catalyst deactivation were observed on multiple tubes, and temperatures well above design were recorded over a period of several days. The catalyst in all tubes

Fig. 4: **Example of a "normal" creep strain signature and corresponding effective temperature profile, from a different reformer**



Source: Quest Integrity

was replaced, which resolved the issue. Five tubes were removed from service after being identified as being at high risk of failure due to creep damage before the Year 11 turnaround.

In Year 11, three more tubes ruptured during a start-up. Again, significant levels of abnormal creep damage were widespread throughout the reformer. Thirteen tubes were replaced, and a further eight removed from service due to the predicted failure risk and a lack of sufficient spare tubes.

External diametric inspections of all tubes were carried out in Year 3, Year 5, Year 8, and Year 11. Internal diameter data was recorded for all tubes before entering service, and again in the Year 11 turnaround. Examples of diameter profiles from all inspections are shown in Fig. 3. The corresponding calibrated effective TMT profile for the Year 8 to Year 11 period is also shown. Similar profiles were calculated for the period prior to Year 3 and the Year 5 to Year 8 period. For reference, a "normal" catalyst tube creep signature and calibrated effective temperature profile from another reformer is shown in Fig. 4.

The diameter and temperature profiles in Fig. 3 illustrate trends consistently observed throughout this reformer: abnormally high levels of creep damage in the upper catalyst tube sections in all operating periods except Year 3 to Year 5, and corresponding high effective temperatures in the same locations (relative to the expected "normal" profile represented by Fig. 4). The hotspots observed in Year 8 offered a feasible explanation for the creep damage recorded in the Year 5 to Year 8 period, but no such issues were identified in the period prior to Year 3 or the Year 8 to Year 11 period. Regular online monitoring of TMTs also indicated that tube temperature profiles throughout these periods were generally consistent with a "normal" profile similar to that shown in Fig. 4.

This latter point was a key indicator that the issues causing the abnormal creep damage in these two periods actually lay outside normal operation in the reformer start-up procedure. The mismatch between the effective and measured TMTs suggested that there had been one or more events outside of the monitoring windows where the upper sections of the tubes had overheated, but then returned to normal operating temperatures. The start-up sequence was the only point in operation where this could feasibly have occurred. In this reformer, TMTs were not monitored during transients such as start-up so there were no obvious indicators that might have alerted operators to any issues. Further evidence to support this conclusion was provided by the tube failures themselves: both the Year 3 and Year 11 failures had occurred in the top third of the tubes where any overheating effect during start-up would have been most potent, the appearance of the failures was characteristic of short-term overheat, and all had occurred during the start-up sequence.

The lack of creep damage accumulated in the Year 3 to Year 5 period indicated that the overheating issues prior to Year 3 had been resolved. However, this was evidently temporary as shown by the later re-surfacing of the problem. This prompted a root cause analysis of the tube failures in Year 11, which unearthed a number of red flags in the operational data from past start-ups. From this, Quest Integrity was able to provide recommendations on targeted actions to reduce the likelihood of future overheating events.

Concluding remarks

This case study illustrates how the LifeQuest Reformer methodology can play a critical role in providing insight into reformer operational issues. The combination of this diagnostic capability with a technically sound and proven life assessment approach has significant benefits for catalyst tube integrity management. Ultimately, these benefits feed down into improved overall plant reliability. The costs of a high-quality tube inspection and assessment program are not negligible, but they are still small in comparison to those incurred by an unscheduled plant shutdown. Consequently, there is little justification for failing to make use of the operational advantages afforded by tools such as LifeQuest Reformer. ■

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ISSN: 1750-6891

Design and production:
JOHN CREEK, DANI HART

Printed in England by:
Buxton Press Ltd
Palace Road, Buxton, Derbyshire, SK17 6AE

Published by: BCInsight Ltd
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