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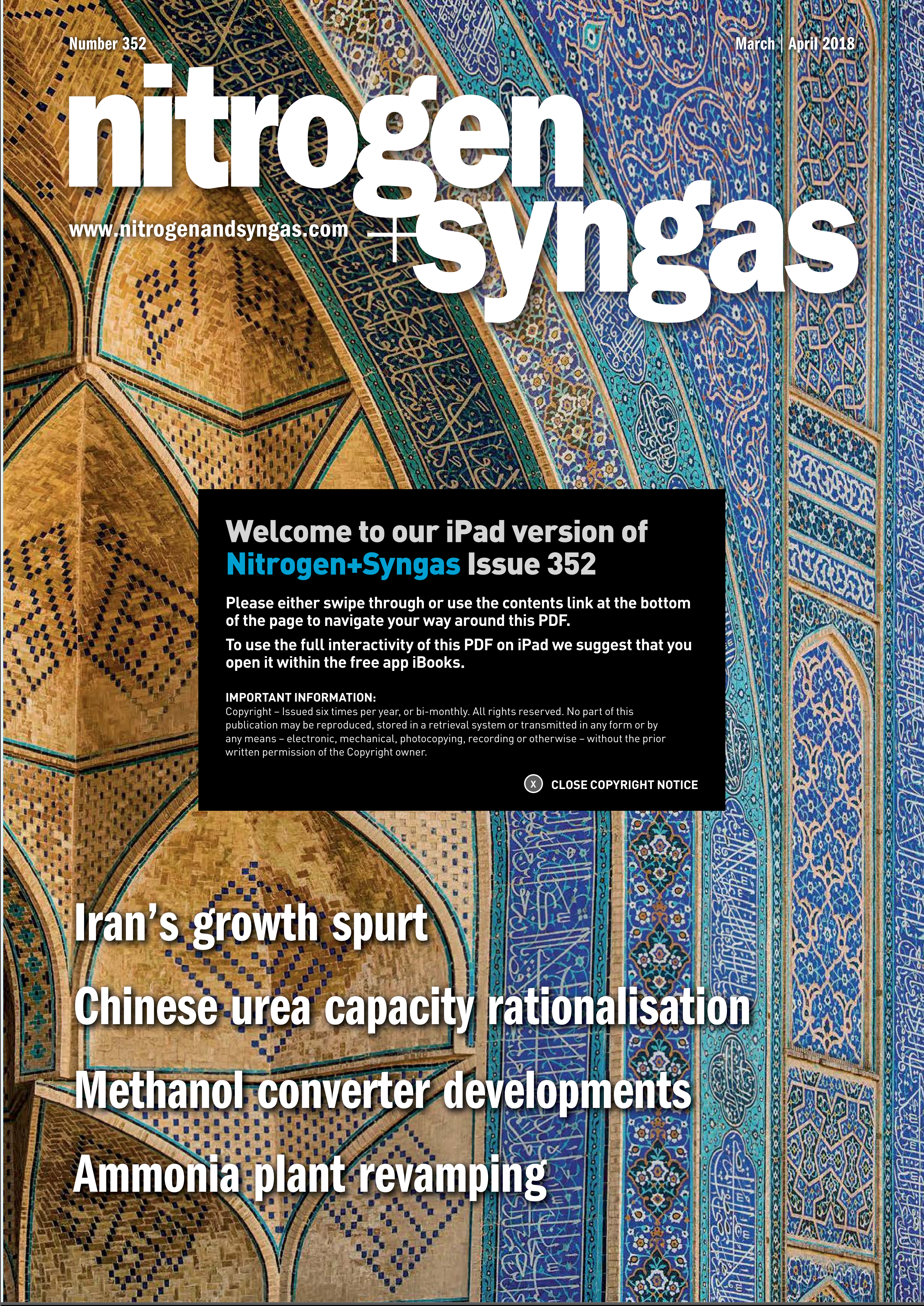

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Iran's growth spurt

Chinese urea capacity rationalisation

Methanol converter developments

Ammonia plant revamping


JM

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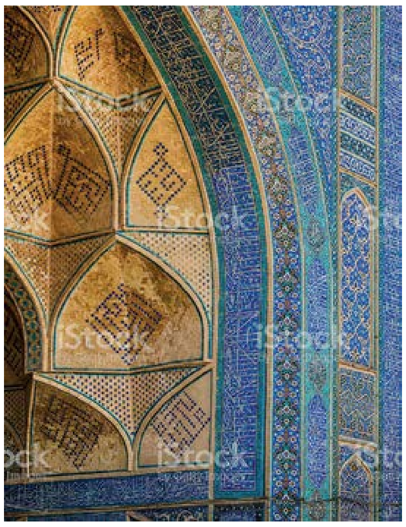

Cover: Interior detail, Jameh Mosque, Isfahan, Iran.
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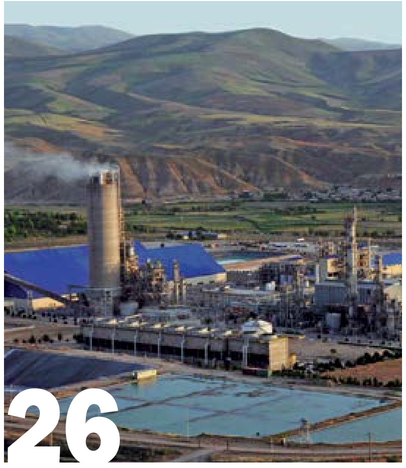


Iran's new capacity

Ambitious expansion plans in an uncertain political climate.

Methanol converters

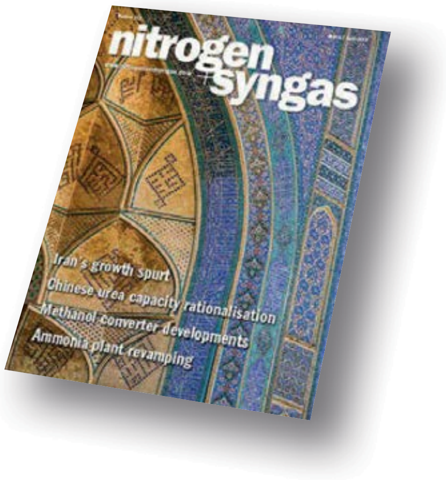
Recent improvements in efficiency and performance.

REGULARS

Read this issue online at: www.nitrogenandsyngas.com

Published by:
BCInsight

Editorial



China still setting the pace – for now

> **China's programme of urea capacity rationalisation may be the key determinant of where urea markets go over the next few years.**

At the recent Nitrogen+Syngas conference in Gothenburg, Doug Hoadley of CRU noted in his nitrogen market presentation that China remains the price setter for urea markets, as it has done for a decade since it took over that role from the Black Sea producers, especially Ukraine. China's rapid industrialisation has left it with a huge overhang of relatively high cost, coal-based capacity that has become a dominant force on export markets. And for the time being, that still seems to be the case; China remains the swing producer and has a large reservoir of idled or semi-idled capacity that can start up again as global prices permit. However, that situation is changing far more rapidly than anyone could have anticipated even just a couple of years ago, and as we discuss in our article this issue (pp 21-23), the progress of China's programme of urea capacity rationalisation may be the key determinant of where urea markets go over the next few years.

China is cracking down on pollution, especially from plants operating new major population centres, and trying to end its over-use of nitrate fertilizers and boost nutrient use efficiency in order to get the best from its relatively small (compared to its population size) area of arable land. At the same time, it is trying to move to lower carbon energy sources and away from coal. There has been an amazing programme of investment in wind and solar power, and a push for power producers to move from coal to gas-based generation which has also pushed up gas prices and reduced availability for urea producers. The high cost of coal – Chinese coal prices rose more than 50% during 2017 – is also having an effect as China seeks to rationalise its coal industry, which is also burdened with massive overcapacity.

This has already eroded China's position as the largest exporter of urea; Chinese urea exports have fallen by nearly 10 million t/a in just two years from their peak in 2015, and last year it even imported 300,000 tonnes – the first significant imports for many years. This has supported urea prices at the end of 2017, and may do so further going forward. CF Industries said recently that it expects China's net urea exports to drop even further this year because of continued government enforcement of environmental regulations, and that many plants that have been shut down due to environmental regulations will not be brought back into production, as the cost associated with the scrubbing and elimination of NOx emissions is so high. It could be that in a year or so China will only be exporting 2 million t/a of urea or less, probably seasonally, and the largest exporters will be Russia, Iran and other Gulf states like Qatar. Iran in particular, as we also examine this issue (pp26-29) is, barring major political upset, due to add another 5 million t/a of export-oriented urea capacity over the next few years. While China will probably still be the highest cost producer, this could be a dramatic change in the global market.

And at the same time, things are also changing rapidly in the major importers. US capacity building based on low cost shale gas has dramatically reduced import demand there; North American urea imports fell by 37% and UAN imports 24% in 2017 as compared to 2016. And in India, still the largest importer of urea, the government's self-sufficiency drive is aiming to eliminate imports completely within five years, or at the very least dramatically reduce them.

All of these factors are reshaping the urea market in a way which has not been seen since China's rise to dominance a decade or more ago, and could see a very different global outlook by the start of the next decade. We have become used to China setting the pace in most commodity markets, but in urea those days could be numbered.

Richard Hands, Editor

Price trends

MARKET INSIGHT

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

NITROGEN

The nitrogen market began 2018 on a quiet note, in contrast to the buzz that surrounded NFL's urea import tender on 22 December 2017. Urea prices increased internationally following the Indian tender, putting an end to several weeks of uncertain price direction.

There were expectations even in December that another Indian import tender could be expected in mid-to-late January, however, this did not come to fruition and as a result other international sales were relatively slow. Demand was also slow from other major importers such as Brazil and the US, which kept urea prices flat over the course of January, with the Yuzhny f.o.b. price remaining at $223/t until demand began to pick up towards the end of the month.

In late-January, North African suppliers kick-started activity in the urea market when they sold large quantities of urea to Europe totalling 200,000 tonnes, primarily to Turkey. Algerian producers sold a further 100,000 tonnes around the same time, after which price ideas increased in anticipation of spring demand from the northern hemisphere.

Another lull in market activity took place in February, with demand from the US and Europe slowing again, and exports from North Africa were limited. China had already been mostly absent from the international market due to its own structural factors, discussed in more detail below, but the Lunar New Year celebrations muted activity even further in February.

Then, after a lengthy build up, India's MMTC announced the country's first urea import tender of 2018, on 20 February. The tender closed on 27 February with 15 traders offering a total of 1.17 million tonnes. Iranian product made up the lowest offers of $271.92/t c.fr for west coast India, and $277.15/t c.fr for the east coast. These offers were higher than had been previously expected, and as a result prices elsewhere in the market also increased.

In total, 619,000 tonnes of urea were agreed for sale under MMTC's 27 February tender, of which 447,000 tonnes was expected to be supplied from Iran, and the remaining 172,000 tonnes from the Arab Gulf. Furthermore, in early March, MMTC was understood to be seeking an additional 60,000-70,000 tonnes of urea, split between Comzest and Midgulf.

Chinese producers remain almost exclusively out of the export market, with domestic prices around $40-50/t above international levels in the first two months of the year.

Chinese urea exports fell to a 55-month low in January 2018, driven by a dramatic reduction in domestic operating rates. This development was a culmination of structural reform in the coal and urea markets, coupled with seasonal winter heating pressures on feedstock markets. In the first two months of 2018, Chinese urea production is estimated to have totalled just over 8 million tonnes, and operating rates will need to increase over the course of the year in order to meet domestic requirements. Integer's estimate for domestic Chinese production to meet requirements is an average monthly production requirement of 5.2 million tonnes.

In a parallel development, in the opening months of 2018 the focus on Chinese feedstocks for urea production switched from coal to gas, driven by reduced gas availability to urea plants which forced a series of shutdowns. China became the world's second-largest importer of LNG in 2017 as it overtook South Korea.

Asian LNG prices reached a three-year high at the end of 2017 as environmental controls on the coal sector in China prompted consumers to switch to less-polluting gas-based heating methods. The shift led to sharp increases in gas demand, which China's relatively undeveloped storage and pipeline infrastructure was not equipped for. In the urea industry, gas-based producers suffered shutdowns as supplies were not sufficient to run plants, and heating industries were given preferential allocation.

Environmental measures on both the coal and urea industries remain in force in China, and are the underlying driving force behind lower urea production volumes and exports out of the country. In particular, mid-lump anthracite prices rapidly increased between November 2017 and February 2018 as gas shortages caused switching to other feedstocks in several downstream industries, including ammonia and urea.

In the ammonia market, prices softened in January following a strong end to 2017 when they were at their highest levels of the year. This was the result of reduced supply due to both planned maintenance and unplanned shutdowns that shortened supply. The Tampa ammonia contract price increased by $10/t to $355/t c.fr in January, continuing the firmer sentiment from December. However, in February, the Tampa price fell by $15/t to $340/t c.fr The price decrease was largely expected, as temporary shutdowns at plants came to an end, although Mosaic was originally seeking a $25/t reduction.

Table 1: **Price indications**

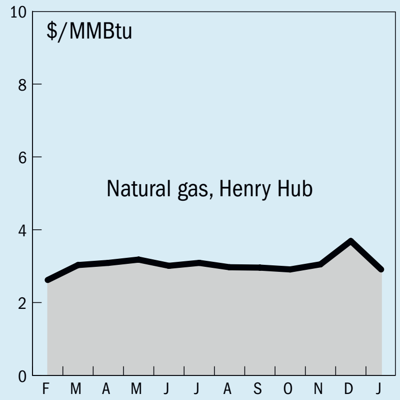
Cash equivalent	mid-Jan	mid-Nov	mid-Sept	mid-July
Ammonia ($/t)				
f.o.b. Caribbean	320	270	200	205
f.o.b. Arab Gulf	330-340	280-330	230-260	180-190
c.fr N.W. Europe	350-385	305-340	240-260	230-250
c.fr India	350-380	310-360	240-270	209-240
Urea ($/t)				
f.o.b. bulk Black Sea	215-225	240-250	224-234	181-190
f.o.b. bulk Arab Gulf*	242-250	259-264	227-232	153-187
f.o.b. bulk Caribbean (granular)	233-235	250-260	190-198	160-183
f.o.b. bagged China	285-295	268-272	248-255	207-212
DAP ($/t)				
f.o.b. bulk US Gulf	395	375	333-337	344
UAN (€/t)				
f.o.t. ex-tank Rouen, 30%N	160-165	159-164	141-143	133-137

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

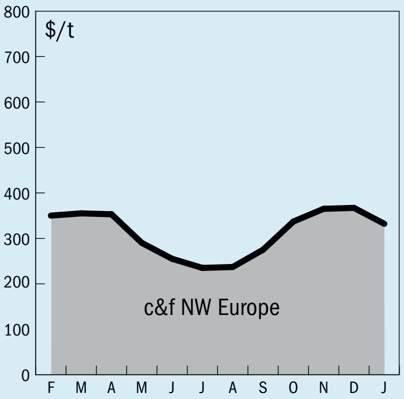
Source: Fertilizer Week

END OF MONTH SPOT PRICES

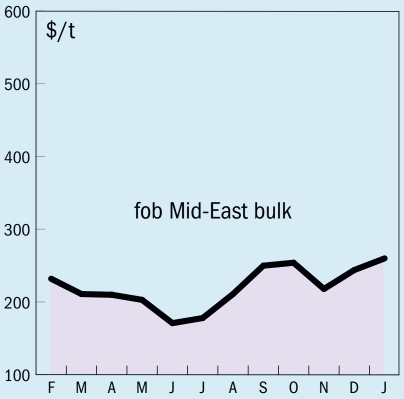
natural gas



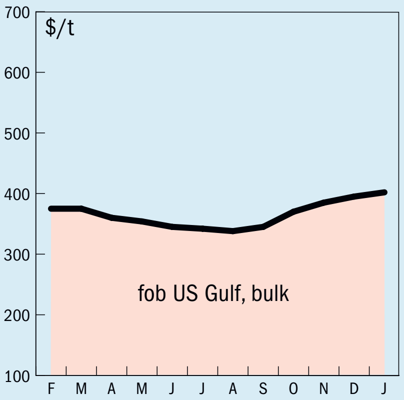
ammonia



urea



diammonium phosphate



MARKET INSIGHT

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

METHANOL

Spot methanol prices rose in the US, a result of production disruptions, but fell in all other regions in February.

In Europe, demand into formaldehyde was healthy and looks set to improve in 1Q 2018 as a whole, with healthy demand in Russia and Eastern Europe for man-made boards. Operating rates at acetic acid units were healthy in a market which is tight globally, following production outages in Asia and the US. European spot methanol prices (T2 f.o.b. Rotterdam) for February were down €13/t from their January level at €343/t over the month. The 1Q 2018 West European Contract Price was settled at €318/t, f.o.b. Rotterdam T2, up €62/t from the 4Q 2017 contract price. The ongoing suspension of duty on methanol arriving into the EU implemented by the European Commission is due to expire at the end of 2018. As yet, there is no guidance on whether the allowance will be extended or revert to previous levels.

In India, port prices averaged $369/t in February, up from $409/t in January. India port prices started the month at an average of $385/t c.fr T1 and finished the month $25/t lower at $360/t; domestic prices decreased due to fairly good supply and no real change in demand.

The Americas average operating rate declined in February, falling to 80% as a result of the Celanese/Mitsui JV unit going down for a planned outage while a ruptured line at the Linda HyCO unit in La Porte, TX caused the La Porte Methanol unit to shut down and then run at reduced rates for the remainder of the month.

On the demand side, the acetic acid market remained relatively tight with Celanese still on 100% sales control in the western hemisphere. The explosion at Linde's Hydrogen/CO plant in La Porte that disrupted the methanol production has also disrupted production of acetic acid at the site; Lyondell has gone into *Force Majeure* in the western hemisphere and is allocating product at 70%. IHS Markit expects strong wood product demand into construction over the next several months.

The official posted reference prices from the major producers for March are $1.49/gal for Methanex (a decrease of 3 cents from last month) and the same for Southern Chemical (a rollover from last month). Month-on-month weighted average spot prices in the US Gulf for February increased by 4.28 cents/gal from December to $1.2675/gal (nominal $421/t). IHS Markit Chemical's contract net transaction price for March is officially posted at $1.49/gal (nominal $495/t). This is a decrease of 1.6 cpg from January.

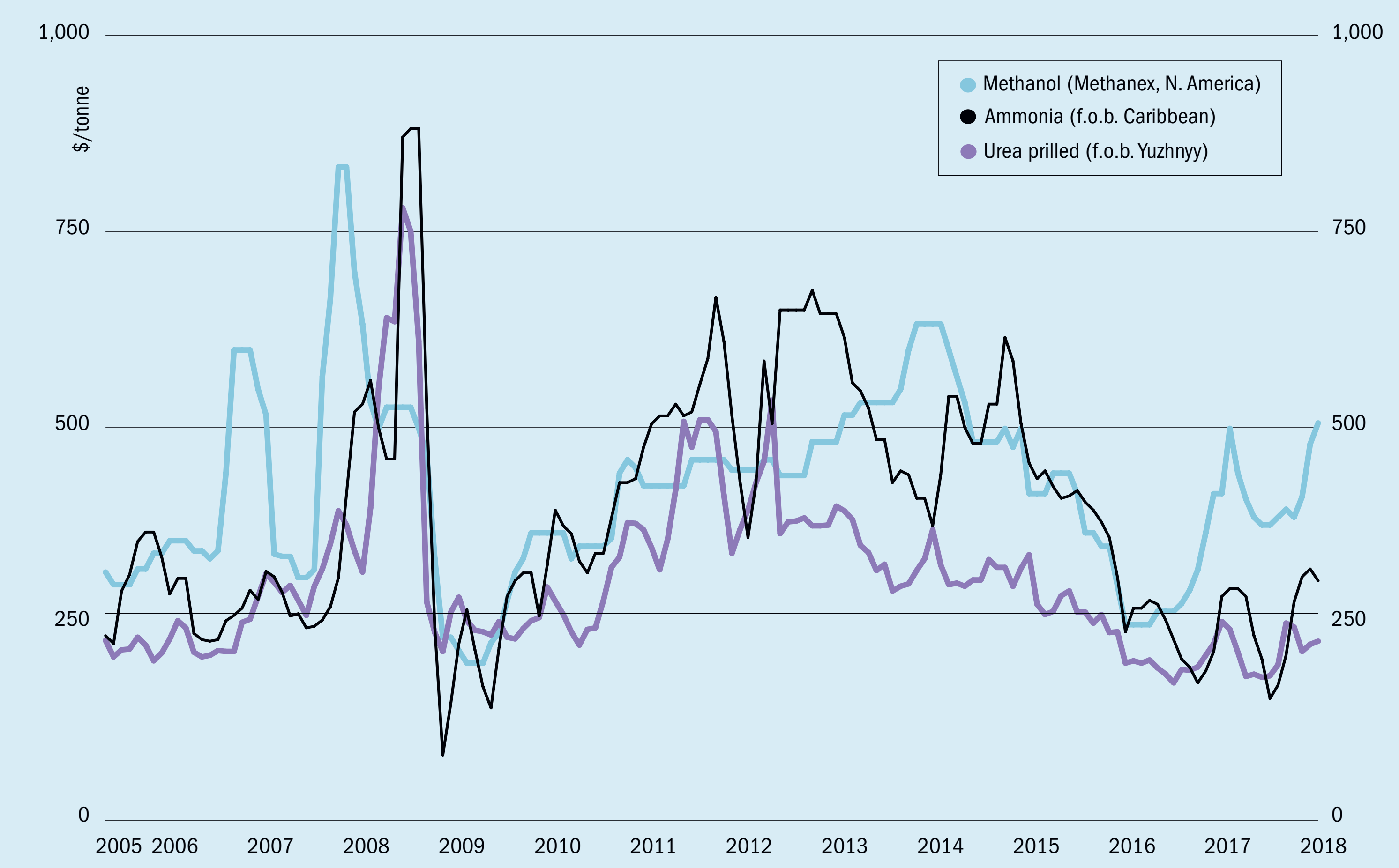
In Southeast Asia, methanol units ran to plan in February. Petronas's number two unit (1.7 million t/a) may have a turnaround in the second half of 2018. In China, overall capacity utilisation was stable in February at around 54% of nameplate capacity or 69% of effective capacity. Shaanxi Yulin Natural Gas Chemical's gas-based unit remained offline for the whole month. One line of Boyuan Unichem also remained offline. A new 1.0 million t/a methanol unit, Hualu Hengsheng commissioned at the end of September, and ran normally during February. Coking gas-based methanol producers in North China ran at 41% utilisation in February on average and coal-based methanol plants in Northwest China at 64-66% during last month, with environmental controls still in place. Some gas-based methanol plants in East China and Southwest China were affected by seasonal natural gas restrictions, remaining offline in February; the average natural gas-based operating rate in February was 27%.

Methanol consumption into the MTO sector increased in February, averaging around 76%. Zhejiang Xingxing (1.8 million t/a methanol consumption) restarted before the Lunar New Year holiday following an eight-week outage. Formaldehyde demand in China weakened towards the end of February and operating rates decreased to the lowest level this year during the Lunar New Year holiday. However, the formaldehyde sector will welcome its peak reason in March, with healthy consumption rates into man-made boards and coatings industries expected.

Asian prices in February traded lower by $22/t, in a weekly aver-age range of $391-406/t, c.fr; c.fr China weekly average prices were down $17/t in a range of $376-401/t. ■

Market outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- After a tight fourth quarter to ammonia markets in 2017 due to several planned and unplanned shutdowns, the merchant ammonia supply-demand balance is forecast to loosen further in the remainder of Q1 2018 and into Q2, which will bring softer prices until the emergence of US refill application demand in Q3.
- This makes for a bearish 2018 for ammonia, unless further supply unexpected corrections unfold.
- The situation in Trinidad over gas contracts between NGC and the island's ammonia plants could provide some potential upside to the market if it prompts reduced operating rates or some complete plant closures such as the recent shutdown of the CNC Point Lisas facility.
- In early February, the nitrogen producer was continuing talks to try and secure a deal to be able to restart its 655,000 tpy ammonia plant.

UREA

- Following India's latest tender on 7th March, the next price drivers in the urea market are expected to be spring buying in the US and Europe.
- US demand is forecast to keep supporting prices in early Q2 before the usual lull in demand that summer in the northern hemisphere usually signals.
- In the US, buyers typically import 1.5-2 million tonnes in February and March in advance of farmer application in the spring.
- However, increased domestic supply in the US will likely offset this import requirement, particularly if capacity expansions in the US such as Koch, Enid and Dakota Gasification hit start up milestones in time for the season.
- Two key export-oriented plants in Central Asia – SOCAR in Azerbaijan and Turkmenhimya in Turkmenistan – are forecast to start up in the second half of 2018, which will put downward pressure on international price levels.

METHANOL

- As the winter eases in the northern hemisphere, gas supply restrictions in China are starting to be relaxed, and that may lead to re-starts in China's mainly idled natural gas-based methanol capacity. However, environmental restrictions on coal-based plants remain in force for the time being, and are helping to keep Chinese methanol supply tighter.
- Demand for methanol for methanol to olefins production in China continues to be fairly strong in spite of relatively high methanol prices and a recent slip in propylene and ethylene prices, while demand for formaldehyde appears to be robust in the major consuming markets of China, Europe and the US.
- Some unplanned outages in the US have also helped to support methanol prices there, and this has been boosted by lack of availability from Trinidad, where capacity remains constrained by gas availability.

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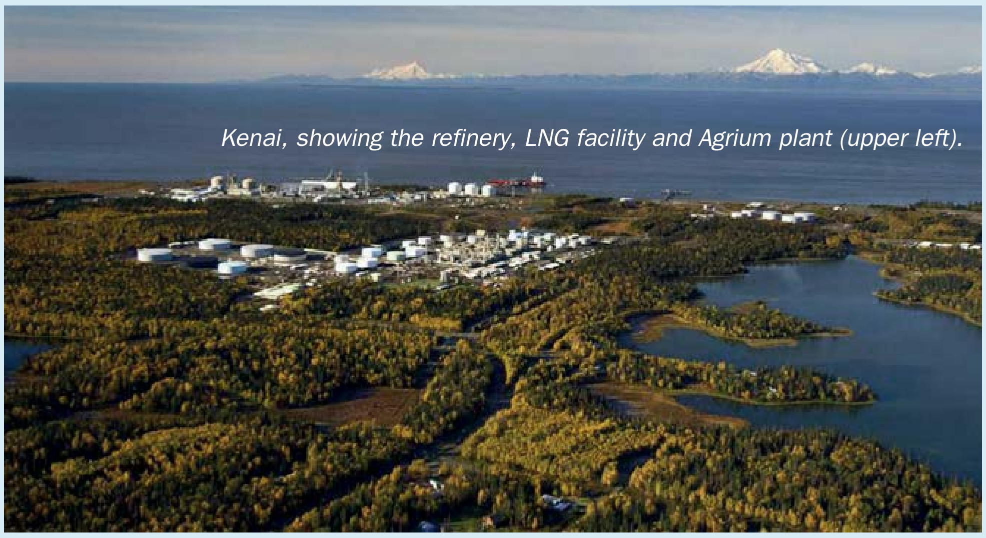
Nitrogen Industry News

UNITED STATES

Re-start for Kenai?



Kenai, showing the refinery, LNG facility and Agrium plant (upper left).

Newly minted fertilizer major Nutrien, the result of the merger of PotashCorp and Agrium last year, is reportedly once again considering a re-start for the Kenai ammonia-urea facility in Alaska. Kenai, owned and formerly operated by Agrium, shut down in 2007 due to being unable to secure sufficient natural gas feedstock. However, since then the region has seen something of a renaissance in terms of new drilling and gas production. Kenai has two ammonia-urea trains, with a combined capacity of 3,800 t/d of ammonia and 3,300 t/d of urea when in operation, as well as access to a Pacific deep water port which could supply markets in China, North and South America and Southeast Asia. It could also take advantage of the merged company's extended reach in terms of distribution and marketing.

Agrium said in 2016 that it was considering re-starting one, or possibly even both lines, and said that getting the plant in condition to operate again could cost $275 million. Key to the proposed restart, however, would be a sufficient supply of gas at a competitive price. At full capacity the plant consumed 155 million cfd of natural gas, while Cook Inlet gas production ran at 850 million cfd at its peak in 1991 and also fed an LNG facility as well as local power production. However, this had fallen by 2/3 by 2010, and local gas prices also rose from $1.20/MMBtu in 1999 to $5-7.00/MMBtu by 2007-10, prompting the closure of both the urea plant and the LNG train. Now fracking from onshore well pads is helping to boost production and reduce prices. Total proved and probable reserves are currently put at 1.2 tcf, with the USGS estimating another 19 tcf may lie undiscovered in the region. The Alaskan state government has also tried to help encourage a re-start for Kenai, passing a bill allowing credits against corporate income tax for an in-state facility that manufactures ammonia or urea from natural gas produced from state oil and gas leases. At the moment, however, it is not certain whether this will be enough to persuade Nutrien to refurbish the Alaskan facility. ■

West, Texas to receive damages from AN manufacturers

The city of West, Texas, site of the 2013 ammonium nitrate fire and explosion at a local distribution warehouse which killed 15 people, has settled its claims with the companies which manufactured the AN. The town's lawsuit accused the companies of negligence in selling ammonium nitrate to West Fertilizer, owners of the plant. The companies denied responsibility but settled before the case went for trial on January 16. The settlement will see CF Industries pay $6.4 million and El Dorado Chemical $3.9 million. Adair Grain, which owned West Fertilizer, will pay $143,000 as part of the settlement.

The report on the incident by the US Chemical Safety Board (CSB) found fault with city, state and federal agencies, all of which could have taken steps that would have made the disaster less likely, and the state of Texas has also since passed a law regulating storage and inspection of ammonium nitrate and granting authority to the Texas Commission on Environmental Quality and local fire marshals to effect and enforce such regulation.

INDIA

New investor in large scale urea project

Genetec Technology Bhd, the Malaysian subsidiary of Canadian surveillance and industrial equipment manufacturer Genetec, says that it will invest in a new large scale urea plant in India being developed by VBC Fertilizers and Chemicals Ltd. The Memorandum of Understanding, signed with the Malay Chamber of Commerce Malaysia (MCCM), China Rainbow International Investment Co Ltd (CRIIC), and VBC Fertilisers & Chemicals Ltd (VFCL) will provides the opportunity for Genetec to supply its system automation solutions and services within the project scope. Genetec will also facilitate CRIIC's participation in the project, and CRIIC will in turn nominate the engineering, procurement, construction and commissioning (EPCC) contractor, and provide funding totalling 30% of the project development cost. VFCL is to look after approvals, permits, licences, land and other matters in the project site in Andhra Pradesh state.

The proposed facility is a twin train ammonia-urea plant with two 2,500 t/d ammonia and two 4,000 t/d urea plants and is projected to cost $1.5 billion. VFCL says that it has all necessary permissions from the Indian government following a feasibility study by Projects & Development India Ltd (PDIL) and has agreement with the Gas Association of India Ltd for supply of 5 million scf/d of natural gas. It also says that a 400 t/d ammonia surplus could also be later used for nitric acid and ammonium nitrate production. VFCL's parent VBC – India's Vizag Bottling Company – is a diversified conglomerate with interests in fertilizers, metals and power generation. It is being partnered in VFCL by two Malaysian companies; Isometrics sdn bhd and Malaya Fertilizer plant sdn bh.

India's could become world's fourth largest market for AdBlue

The Indian government has been proactive in taking steps to prepare the market for the introduction of its Bharat Stage VI (equivalent to Euro-VI) vehicle emission standards on April 1st 2020, according to a new report by Integer Consulting. The standards will be enforced on the same date across the country, allowing businesses time to devise national investment strategies in a country that could become the fourth largest market for selective catalytic reduction (SCR) and 'AdBlue' urea solution in the world by 2023. Bharat VI will supersede the existing Bharat-IV standards that were enforced nationwide last year, and which have been in use since 2010 in some cities such as New Delhi and Mumbai. In order to meet the new Bharat-VI standards, many more vehicles are likely to require the use of selective catalytic reduction and hence the high-quality urea solution commonly referred to in Europe as AdBlue, or DEF (diesel exhaust fluid) in the US. At present, SCR is only used in heavy-duty trucks and buses in India, with around 20,000 such vehicles sold in 2017, but the new regulations could make this 2 million per year from 2021.

NIGERIA

KBR to license ammonia plant

KBR says that it has been awarded a contract from Indorama Eleme Fertilizer & Chemicals Ltd (Indorama) and Toyo Engineering Corporation (Toyo) for the second ammonia train at Indorama's Port Harcourt site in Nigeria. Under the terms of the contract, KBR will provide technology licensing, basic engineering design, proprietary equipment and catalyst for the plant.

"We are privileged to have the opportunity to work with Indorama and Toyo on Indorama's second fertilizer complex in Nigeria," said John Derbyshire, President, KBR Technology & Consulting. "This contract builds on our long-established relationship with Indorama and Toyo and further highlights our clients' trust in KBR's ammonia technology."

TRINIDAD & TOBAGO

CNC forced to shut down over gas supply

The Caribbean Nitrogen Company (CNC) has been forced to shut down its ammonia plant at Point Lisas after its gas supply was cut off by the National Gas Company of Trinidad & Tobago (NGC). According to NGC, this is because CNC's gas sales agreement has expired without a replacement having been agreed, indeed that it CNC's contract actually expired in October 2017 had been extended until January 2018 to allow the ammonia plant to continue operating during negotiations for another long-term gas supply contract. The two companies have reportedly been locked in argument for a year over a new gas contract but have not managed to find agreement.

CNC CEO Jerome Dookie said that NGC "has been unresponsive to the many concessions CNC has made and (was) unrealistic as to the global forces affecting not only CNC's exports but Trinidad's exports of ammonia, which must compete in the international marketplace. The NGC is unfortunately making Trinidad the world's marginal producer of ammonia with its uneconomical pricing policies." CNC said that it was willing to pay \$4.00/MMBtu at current ammonia prices, but noted that its competition in the US was paying less than \$3.00/MMBtu.

UKRAINE

New gas supply for OPZ

The Odessa Port Plant (OPZ) resumed ammonia and urea production at the end of January after a new gas supply deal was agreed with the All Ukrainian Energy Company, according to local media. The company had shut down in November when its previous gas supply deal ran out. OPZ operates 900,000 t/a of ammonia and 660,000 t/a of urea capacity at Odessa, but has operated intermittently in recent years due to gas supply issues, and government attempts to privatise the company have failed over its huge overhang of debt.

MEXICO

New ammonia plant secures gas deal

Gas y Petroquimica de Occidente SA (GPO), G2X Energy and CFEnergia say that they have signed a 15-year natural gas transportation and supply contract in support of the new ammonia plant to be built by GPO in Topolobampo, Sinaloa. The contract with CFEnergia, an affiliate of the Comisión Federal de Electricidad created as a result of Mexico's recent energy reforms, will see CFEn supply 81,000 MMBtu/day for GPO's new 770,000 t/a ammonia facility. The gas will be sourced either domestically or from across the border with the US. The GPO plant is being developed by Swiss-based Proman, which is involved in methanol and ammonia production in the US, Trinidad and Oman, as well as being involved in plant services, petrochemical and power plant construction, product marketing and logistics, and project management. It will be the first ammonia plant on Mexico's Pacific coast – the others are at Cosoleacaque in southeastern Veracruz state.

SAUDI ARABIA

Daelim confident of winning contract for new Ma'aden plant

Daelim Energy says that it expects to secure the EPC contract for building a \$1.0 billion ammonia plant at Ras Al Khair in Saudi Arabia. The projected 3,300 t/d ammonia plant will form part of an expansion by project owner Saudi Arabian Mining Company (Ma'aden) to develop more phosphate mining and diammonium phosphate production by 2024 at a total cost of \$6.4 billion. Maaden Waad Al-Shamal Phosphate Company, (MWSPC), a Ma'aden subsidiary, has signed a financing agreement to borrow \$240m from the Saudi Industrial Development Fund (SIDF) to cover part of the financing cost. As well as Daelim, pre-qualified bidders include Hyundai Engineering and Construction, GS Engineering and Construction, Samsung Engineering, Hanwha Engineering and Construction, China Huanqui Contracting and Engineering Corporation, SNC-Lavalin, and Intecsa Ingenieria Industrial SA. Front end engineering and design was performed by thyssenkrupp Industrial Solutions. The plant is slated for completion by the first quarter of 2021.

GERMANY

Yara opens world's largest AdBlue plant

Yara International ASA, the world's largest producer of urea-based fuel additive AdBlue, says that it has opened the world's largest production facility for the urea solution in Brunsbüttel, Germany. The new €28 million facility has a production capacity of 1.1 million t/a of AdBlue, capable of removing up to 500,000 t/a of NOx, equivalent to the entire NOx emissions from the road transport sector in Germany, Austria and Switzerland combined, according to Svein Tore Holsether, president and CEO of Yara. The new plant includes a new deep water loading facility, a fully automated truck loading station operating 24/7 with a digitally controlled unmanned gate and a 17,500 m^3 AdBlue tank.

"The increased need for AdBlue in the segment of heavy duty vehicles and passenger cars in Europe and the US makes a reliable supply and on-time delivery crucial for our customers. We are committed to answering their needs. The new facilities confirm Yara's position as the leading and reliable AdBlue supplier," said Holsether.

The project was executed in less than three years, within budget, and with no safety incidents, according to Yara.

ZIMBABWE

Uralchem looking at African import and distribution deal

Russian fertilizer producer Uralchem is considering taking over distribution of fertilizers in Zimbabwe and Zambia, and increasing imports to the region from their current 100,000 t/a to 500,000-600,000 t/a. Uralchem chairman Dmitry Mazepin met both countries' leaders recently to discuss the plans. There is no firm timescale as yet, but Zambian president Edgar Lungu was reported by local media saying that his government wanted to "commence our cooperation as soon as possible". Meanwhile, new Zimbabwean president Emmerson Mnangagwa has been at pains to put the Mugabe years behind the country and said "the country is now opening for business, Russian included. In the last 16-17 years, we have been isolated due to the Western sanctions, but now the economy is entering a period of growth," he added. Zimbabwe was once known as "the bread basket of Africa" before government policies saw major drops in agricultural production, turning the country into a net food importer.

According to Uralchem, farmers in the two countries pay around $500 per tonne for fertilizer, and this deal would see the Russian company import and sell direct to end-users, at a price closer to the production and shipping cost of $300/t. In 2017, Uralchem produced a total of 6.3 million tonnes of fertilizer products, including 2.9 million tonnes of ammonium nitrate.

CHINA

Gas crisis continues to impact on ammonia plants

China's shortage of gas and the government's prioritisation of heating homes over the winter continues to leave gas-based ammonia-urea plants short of feedstock and operating at just 15% capacity, less than half of the already reduced 31% rate that they were at 12 months ago. The shutdown has led to shortages of urea on the Chinese market and led to price increases. At the end of January Chinese urea prices had reached $314/t, the highest in four years. Chinese fertilizer and chemical industry associations are said to be considering an appeal to the government to lower natural gas prices once winter is past to offset the effects of the supply shortages.

Jesper Nerlov, CTO of Haldor Topsoe (right) signs joint venture agreement with Zhou Liangxing (left) of SARNT and Hu Yidong, chairman of JITRI (centre).

Topsoe in joint venture to develop innovative technologies

Haldor Topsoe has signed a shareholder agreement with Jiangsu Industrial Technology Research Institute (JITRI) and Xiangcheng Suzhou District for a joint research and development company to be based in China's Jiangsu Province. Based on Topsoe's expertise in industrial application of catalytic technologies and surface science, the company will focus on the rapid commercialisation of new technologies and services, with special attention to the needs of customers in China in general and Jiangsu Province specifically. The joint R&D company's first project will be to develop more cost-effective NCA batteries (lithium nickel cobalt aluminum oxide) for use in electric cars. China is the largest and fastest growing market for electric cars. The company will also offer Chinese customers fast and efficient testing within hydroprocessing and emissions management (catalytic filtration) in a convenient location.

Topsoe is investing technology and know-how in return for a 60% share of the company, which is expected to reach 30-40 employees over five years. JITRI and Xiangcheng Suzhou District own the remaining shares and will invest $12.6 million over a five-year period.

"We are pleased to announce the joint venture with Haldor Topsoe and Xiangcheng Suzhou District," said says Liu Qing, President of JITRI. "JITRI has been part of many R&D collaboration agreements in the past, but this is first time we have chosen to go a step further and invest in a jointly owned company. Our decision is based on more than a year's talks with Haldor Topsoe, where we have been impressed by their high level of R&D work."

"We look forward to launching a fast-moving R&D company in the important Chinese growth market. China is a global industrial leader, and Topsoe's insights and experience will help continue this remarkable economic development, producing cleaner energy, and protecting the environment for the greater good of the Chinese society," added Bjerne Clausen, CEO of Topsoe.

UNITED KINGDOM

Atlas Copco acquires Walker Filtration Ltd

Atlas Copco has acquired Walker Filtration Ltd for an undisclosed sum. Family-owned Walker Filtration, based in Washington, near Newcastle, is a manufacturer of equipment for the treatment of compressed air, gas and vacuum. The company's headquarters and 12,000 m^2

main manufacturing plant is based there. It has around 220 employees worldwide and revenues of approximately £29 million in 2017. The business will continue to operate under the brand name Walker Filtration, as part of Atlas Copco's Medical Gas division in the Compressor Technique business area.

RUSSIA

New acid rail cars delivered to Uralchem

Russia's United Wagon Co says that it has delivered the first of 30 tank wagons of a new design developed to carry highly corrosive concentrated nitric acid for fertilizer producer Uralchem. The Type 15-6901 wagons, designed by UWC's All-Union Research & Development Centre for Transportation Technology, have a tank volume of 54·8 m^3 and an axleload of 25 tonnes, increasing the payload by a third compared to older designs. The wagons are designed for a service life of 40 years, compared to 20 years for the previous design, with maintenance intervals of 800,000 km or eight years compared to 210,000 km or two years. UWC estimates that there are currently around 200 nitric acid tank wagons in service in Russia, forming a critical part of the fertilizer supply chain. These have an average age of 32 years, and around 80% will reach the end of their life by 2022.

"Despite the small number of such wagons and the narrow market segment, the importance of these services cannot be overestimated", said Kirill Kyakk, CEO of the All-Union Research & Development Centre for Transportation Technology. The previous model of aluminium tank wagon was designed in 1963 and manufactured in the late 1980s, since when 'rail transport and industrial safety requirements have changed significantly."

"This project was a challenging one", Kyakk said. "At the design stage we considered not only the high performance characteristics and the level of hazardous freight insulation during transportation, but also the economic efficiency. In addition to the design works, we performed comprehensive testing of the new tank material and welded joints. As a result, a tank car with radically improved performance has been developed, certified and put into mass production.'

This is the second project undertaken by UWC with Arconik Russia, following the development of a grain hopper car certified last year.

BRUNEI

Stamicarbon to license Brunei urea plant

Stamicarbon has signed a license agreement for the construction of a greenfield urea melt plant owned by Brunei Fertilizer Industries at the Sungai Liang Industrial Park. The new plant project will support the government's long-term development strategy to diversify the country's economy by the development of downstream activities in the petrochemical industry.

The urea plant will have a nameplate capacity of 3,900 t/d and will use Stamicarbon's *LAUNCH MELT*™ pool condenser design, featuring Stamicarbon's unique pool condenser and a complete synthesis section fabricated in *Safurex*® stainless steel. Stamicarbon says that although it has built higher capacity urea plants, this is the highest nameplate capacity for a urea melt plant that it has licensed. The scope of the contract consists of a license, process design package (PDP) and proprietary equipment for the urea melt plant. Start-up of the plant is planned for 2021.

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UNITED STATES

Topsoe to be licensor for world's largest methanol facility

IGP Methanol LLC says that it will license technology from Haldor Topsoe for its new Gulf Coast methanol plant near the Mississippi River in Plaquemines Parish Louisiana. The 1.8 million t/a is intended to be the first of four identical units which will eventually have 7.2 million t/a of methanol capacity, making it the largest single site methanol complex in the world. For the project, Topsoe will license its *SynCOR*™ technology. James Lamoureaux, managing director of IGP Methanol, said that the *SynCOR* technology had been selected because it was "best in class" and offered "high single-line capacity with the lowest emission per ton of methanol produced and unrivalled economies of scale." He also said that it has "proven reliable and safe industrial operation", and "combines all the qualities we look for in an integrated solution."

Front end engineering and design (FEED) will be performed by CB&I, including producing a binding lump sum price for the complex. Each unit is estimated to cost $900 million. The contract also includes terms for exclusive selection of CB&I for the engineering, procurement and construction (EPC) of each train. The plant will take advantage of cheap gas feedstocks from US fracking. IGP says that as well as a replacement for gasoline and diesel for road vehicles and trains, it believes methanol will be a transformative fuel in ocean freight, reducing emissions by 95% compared to bunker fuel. IGP has already agreed a deal for ConocoPhillips to supply natural gas for the complex; Praxair will build, own and operate the site's air separation units; and Veolia will build and operate the water treatment and wastewater plant. IGP also says that it has secured a title V Air Quality Permit by the Louisiana Department of Environmental Quality, and the company has also secured natural gas supply, gas transportation, oxygen and nitrogen supply, as well as storage and loading partners for the Gulf Coast Methanol facility. The Federal Energy Regulatory Commission has approved the gas supply arrangements, allowing Transcontinental Gas Pipe Line Co. (Transco) to move 161 million cfd of natural gas to St. James Parish.

Although it is headquartered in Houston, IGP Methanol is backed by Chinese money via the Yankuang Group, the world's second largest producer of methanol, and parent company IGP Energy also has a joint venture with Yankuang, IGP YK New Energy Co., Ltd. Financing has come from a syndicate composed entirely of Chinese banks.

IGP says that preliminary construction work has already begun, and that it expects production from the first methanol train to begin in late 2020.

Celanese may have change of mind on new methanol plant

Celanese, which had indicated last year that it was no longer prioritising a second joint methanol plant at the Clear Lake, Texas site that it shares with partner Mitsui, may change its mind about that now that methanol pricing and margins are strong. During an analyst call in late January, the company's CEO Mark Rohr, credited with turning around the company's fortunes in the past couple of years, said that he was "inspired" by the current strength in the methanol market, and that it was "certainly on the table" again. Celanese and Mitsui started up their 1.3 million t/a joint venture unit in 2015 and at the time indicated that they were considering a second identical facility.

GTL plant seeks renewable fuel certification

Velocys plc says that ENVIA Energy believes that fuel produced at its Oklahoma City gas-to-liquids (GTL) plant has met the necessary requirements to be submitted for qualification under the Renewable Fuel Standard (RFS) in the US. As a result, the facility has submitted a certain number of Renewable Identification Number (RIN) credits to the US Environmental Protection Agency's (EPA) registration system. The process used at ENVIA makes a drop-in fuel that is made from a combination of renewable biogas and pipeline natural gas. Such a process is approved by the EPA for the highest value RINs under the RFS as it delivers the most significant greenhouse gas reductions called for under the programme. Subject to confirmation of the pathway compliance, it is expected that all necessary processes to trade the generated D7 RIN credits for maximum value will be completed in 1Q18. A significant contribution of the revenues of the plant could be derived from the ongoing sale of these RINs.

David Pummell, CEO of Velocys, said: "This is a major achievement and milestone for both ENVIA and Velocys. On confirmation of the pathway compliance, these will be the first RIN credits generated by our technology and also the first associated with a Fischer-Tropsch process on landfill gas. This in itself represents a significant commercial validation of our technology. The US renewable fuels market is a high value growth market with incentives at both Federal and State lev-

els in the form of tradeable fuel and carbon credits. Today's news demonstrates that Velocys has the capability to secure renewable fuel incentives that will enable Velocys to unlock the attractive renewable fuels market."

Final death knell for coal gasification plant

The Mississippi Public Service Commission has voted to finally kill the troubled Kemper County coal gasification plant after eight years of wrangling. The Mississippi Power Company plant never achieved successful commercial operation of turning lignite coal into syngas after the commission ordered that it could not operate the gasification front end of the plant. As a result the MPC facility has been run on natural gas since it was commissioned in August 2014. The plant's cost ballooned during construction from its initial estimate of $2.9 billion to $7.5 billion at the same time that the price of gas – which had been high during the conception of the plant during the heyday of 'clean coal' – had dropped to a fraction of its value due to fracking, and the PSC voted that it was not allowed to pass these costs on to consumers. The new ruling means that Mississippi Power and its parent, the Southern Co., will absorb $6.4 billion in losses, and operate the 660 MW power plant permanently on natural gas feedstock. Southern Co. will write off $3.4 billion on its books and recapitalise its operating company based in Gulfport. The company, which provides 190,000 people in Mississippi with power, said that it was "pleased" with the ruling by the Public Service Commission, which effectively settles all costs associated with the Kemper County facility.

JAPAN

Coal supply arranged for IGCC plants

International trading company JERA Trading says that it has signed a deal with Wyoming-based mining company Cloud Peak Energy to supply coal to two new gasification-based power plants in Japan. Cloud Peak said up to a million tons of coal would be shipped to Fukushima Prefecture in Japan over 30 to 40 months beginning at the end 2019, to feed two 540-megawatt IGCC (Integrated Gasification Combined Cycle) plants being developed by Mitsubishi Corporation Power, Mitsubishi Heavy Industries, Mitsubishi Electric Corp., Tokyo Electric Power Company Holdings, and Joban Joint Power Company Ltd. The first of these is due to begin operations in September 2020.

"Cloud Peak Energy is pleased to be part of the Fukushima IGCC project and to help support Japan's investment in next-generation coal technology," said Colin Marshall, Cloud Peak's president and CEO. "Today's announcement also demonstrates the strategic importance of American energy resources to key Asian allies."

KAZAKHSTAN

COG to supply gas to GTL plant

CaspiOilGas LLP (COG) has signed a presale gas agreement to sell gas to the NIPIneftegas Consortium in Kazakhstan over the 15 years. Under the agreement, COG will supply 6.2 billion cubic metres of gas per year (bcm/y) at "market price". The NIPI-led consortium will convert the feed gas into petroleum products through a proprietary gas to liquid (GTL) technology. The total capex for the GTL plant will be $360 million, with the first phase of plant operation expected to start in 2019. The pre-sale gas agreement allows for COG to take up an equity stake in the GTL plant at a later date if either party chooses to opt in.

CANADA

GTL plant option expires

Synstream Energy Corp. said that it would not be seeking to exercise its option to buy a license from Expander Energy Inc for the latter's EGTL gas to liquids technology. EGTL was to have formed part of a small-scale GTL plant in Alberta, producing synthetic diesel using the Fischer-Tropsch process. However, the company says that it is now "unlikely" to exercise the option before it expires on February 28th 2018.

MALAYSIA

Methanol plant proceeding

Sarawak Deputy Chief Minister and Minister for Industrial and Entrepreneur Development Datuk Amar Awang Tengah Ali Hasan confirmed at International Energy Week in Malaysia that the Sarawak state government is proceeding with the new methanol plant to be built at the Sarawak Industrial Park in Bintulu. Petronas and state-owned Yayasan Hartanah Bumiputera Sarawak (YHBS) signed a memorandum of understanding on the methanol project last year following successful completion of a joint feasibility study. Sarawak has 54% of Malaysia's natural gas reserves and is already home to nine LNG trains and two Petronas methanol plants. The new 5,000 t/d plant, costed at $800 million, is expected to be onstream by 2021. Financing is expected to come at least partly from the Chinese government under the latter's 'One Belt, One Road' initiative.

CHINA

Hangyang to supply ASUs for MTO project

Hangzhou Hangyang Group says that it has received an order for two 105,000 Nm^3/h air separation units (ASUs). The contract is for the Ningxia Baofeng Energy Group and the two ASUs will be installed at the Ningdong Industrial Park in Yinchuan in the Ningxia Autonomous Zone. These two plants are for the 2.2 million t/a coal to methanol methanol plant which will feed a 600,000 t/a methanol to olefins unit. Hangyang has previously supplied three 52,000 Nm^3/h ASUs to Baofeng Energy Group in 2013 for a prior 1.5 million t/a methanol project.

UNITED KINGDOM

Progress on waste gasification projects

Irish waste gasification to energy company EQTEC plc says that it has made progress with the company's "near-term project pipeline". Projects have been secured by way of an EPC contract and/or a memorandum of understanding, including the Reliable Energy Melton Hull and Reliable Energy Seal Sands projects and the Zebec Energy project, all in the UK. The Zebec Energy project is to be built in Usk, southeast Wales, and will have a capacity to process 42,000 t/a of wood waste with a power output of 6.4 MWe. Now known as the Usk Project, it is now to be built and operated by a consortium led by Brooke Energy, Ltd, a company that builds, operates and manages biomass-fuelled power plants in Wales and the southwest of England. EQTEC has renewed its agreements with the new operator of the project and has signed an MoU with the consortium containing Brooke, Exergon Sp. z o.o., a spin-off from the Silesian University of Technology in Poland, and RAFAKO SA, part of the PBG Group. Under the terms of the MOU, EQTEC will sell its patented EQTEC EGT gasifier technology to RAFAKO, who will be the EPC contractor for the whole power plant and will exclusively use EGT for the gasification and gas cleaning process. The Usk site has already in place gas engines, a biomass drier, absorption chiller and grid connection among other equipment and the new owner has chosen EGT to complete the project. Brooke will seek to secure equity finance for the project and RAFAKO will seek the debt financing. Financial close and the commencement of the project is expected in the first half of 2018.

Reliable Energy Solution, meanwhile, is focused on developing Melton Hull and Seal Sands, two 16 MWe energy from waste projects in the northeast of England. EQTEC says that the primary EPC contract was signed in July 2017 between Reliable and Energy China for both projects, specifying use of the EGT technology. The total project investment for the two plants is forecast to be approximately €210 million and each plant is expected to gasify 130,000 t/a of waste. EQTEC and Energy China have been working on the engineering of a revised scheme for the application of EGT coupled to a steam turbine instead of the previous scheme of coupling to a gas engine. The shift to a steam turbine is because initial indications show an increase on the projected returns of the project. A future benefit of this revised scheme is that the additional engineering work will enable the Company to compete in a wider range of projects with power outputs up to 50 MWe. As a result of the revision of the scheme, financial close and the commencement of both projects is now expected to occur during 2Q 2018, when the engineering works to develop the revised scheme for the application of EGT coupled to a steam turbine will be finished. Discussions are ongoing with China Construction Bank for debt finance for the projects and with a major third-party investor for the provision of equity for each project.

Luis Sanchez, CEO of EQTEC plc, commented: “We are pleased that our three near-term projects in the UK are all progressing well. The objective of our strategy of forming strategic alliances with major players in the energy infrastructure sector such as COBRA, Energy China and RAFAKO is to accelerate growth and increase scale in order to take advantage of the lack of domestic incineration and gasification capacity that is forcing the UK to pay European incinerators to take its waste. The strategic alliances also enable us to be in a prime position to win Energy from Waste projects in the UK, Spain, France and Croatia.”

SINGAPORE

Gasification plant to face carbon tax

The new coal gasification plant on Jurong Island will be subject to the carbon tax that begins to operate next year, and its emissions will be “closely monitored to minimise the impact on the environment”, according to Singapore’s Minister for Trade and Industry Lim Hng Kiang. Singapore’s government has designated 2018 the Year of Climate Action, and has pledged to cut its emissions intensity by 36% from 2005 levels by 2030. However, Mr Lim said the coal gasification plant was needed because to feed chemicals production in Singapore, including providing hydrogen for local refineries. Keppel Infrastructure Holdings has signed an agreement with Singapore Economic Development Board (EDB) to develop, own and operate the facility.

People

AMETEK Land has appointed **Christopher Leonard** to the role of Director of Development and Product Management. Mr. Leonard has over 20 years of experience in mechanical and process engineering gained in the oil and gas, chemical, energy, and mining sectors. He has held roles in industrial application engineering and product commercialization of instrumentation from concept to market-leading brands and has worked for a variety of global industry heavyweights, including Hydratight, Bridon International and most recently Oxford Flow. In his new role, he will head the company's global industry management and design engineering teams. Development efforts will focus on bringing new products to market that will help industries meet ever evolving quality requirements coupled with tighter emissions controls and reduced energy consumption targets.

As a result of Mr. Leonard's appointment, **Dr. Peter Drögmöller** takes up the new position of Director of Innovation and Technology. Dr. Drögmöller has a wealth of industry and product knowledge in industrial infrared camera systems for challenging applications and harsh environments. Dr. Drögmöller will continue to develop AMETEK Land's innovation relationships with strategic partners, universities and research centres globally to ensure that the company stays at the forefront of technology and remains the number one choice for temperature measurement and emissions monitoring instrumentation around the world.

The Mosaic Company says that **Rich Mack** will step down from his position as executive vice president and chief financial officer, and leave the company in May of 2018. **Tony Brausen** will serve as senior vice president – finance and interim CFO, effective immediately, until the position is filled permanently. He will also serve as the Company's designated principal accounting officer. Tony has led Mosaic's accounting, financial analysis and reporting, treasury, tax, information technology and business unit finance teams.

"On behalf of Mosaic's Board of Directors and our Senior Leadership Team, I would like to thank Rich for his 24 years of dedicated service and his contribution to many aspects of the company, from his Cargill years prior to Mosaic's formation through the very promising Vale Fertilizantes acquisition," said Joc O'Rourke, President and CEO.

Incitec Pivot Ltd has made changes to its executive team with effect from 30 January 2018**. Simon Atkinson**, formerly president of Dyno Nobel Asia Pacific (DNAP) and Incitec Pivot Fertilisers (IPF) has departed the Company. As a consequence of Mr Atkinson's departure, IPL says that it has taken the opportunity to reassess the structure of its executive team, resulting in the leadership of the DNAP and IPF businesses being separated. **Greg Hayne** will assume the role of president of DNAP. Mr Hayne has long experience in the explosives industry, having held a variety of operational and commercial leadership roles in both the Asia-Pacific and US explosives businesses since joining Dyno Nobel in 2000. **James Crough** will assume the role of president of Incitec Pivot Fertilisers in an interim capacity. Mr Crough has had extensive experience in the Fertilisers business since joining IPL in 2005. A recruitment process, including both internal and external candidates, has been commenced. Additionally, two new roles have been created. **Robert Rounsley** has been appointed Chief Technology Development Officer and will lead IPL's global technology group for both the explosives and fertilisers businesses. Mr Rounsley, an internationally recognised explosives expert who has been with the IPL Group for 20 years, will streamline the development of technology and product innovation, increasing the focus on value creation for IPL's customers. The new role of Executive Commercial Officer will be taken up by **Seth Hobby**. This role will focus on leading corporate level negotiations, providing corporate oversight for key business contracts and improving the commercial organisational capability. Mr Hobby has been with the IPL Group for ten years and had a key commercial role with the development of the Louisiana ammonia plant. ■

Calendar 2018

APRIL

9-12

IFA Global Technical Symposium, MADRID, Spain
Contact: IFA Conference Service, 28 rue Marbeuf, 75008 Paris, France
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

16-18

SynGas Association Meeting 2018, TULSA, Oklahoma, USA
Contact: SynGas Association
Tel: +1 225 922 5000
Web: www.syngasassociation.com

MAY

8-9

IFS Technical Conference, PRAGUE, Czech Republic
Contact: International Fertiliser Society, PO Box 12220, Colchester, CO1 9PR, UK
Tel: +44 1206 851 819
Email: secretary@fertiliser-society.org

17-18

European Conference on Sustainable Ammonia Solutions, ROTTERDAM, The Netherlands
Contact: Stichting NH3 event Europe, Karel Doormanweg 5, 3115 JD Schiedam, The Netherlands
Tel: +31 10 4267275
Email: nh3event@protonventures.com

JUNE

18-20

85th IFA Annual Conference, BERLIN, Germany
Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

SEPTEMBER

16-20

63rd AIChE Annual Safety in Ammonia Plants and Related Facilities Symposium, TORONTO, Canada
Contact: AIChE Customer Service
Tel: +1 800 242 4363/+1 212 591 8100
Fax: +1 212 591 8888
Email: xpress@aiche.org

16-21

Ammonium Nitrate/Nitric Acid Conference, CALGARY, Canada
Contact: Hans Reuvers, BASF, Karl Hohenwarter, Borealis
Email: johannes.reuvers@basf.com, karl.hohenwarter@borealisgroup.com
Web: www.an-na.org/2018-conference

OCTOBER

28-30

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

Plant Manager+

Problem No. 47 Active corrosion during blocking in

This discussion is about the risks of active corrosion or failure of passivation during a blocking-in situation of the high pressure synthesis section of the urea plant. It touches on many aspects searching for a possible cause of active corrosion during such a situation. The final outcome is of significant importance for all urea plants worldwide.

Cory Holt, process engineer at CF Industries in Canada, initiates the discussion: Could anyone share their expertise with respect to urea process passivation and the possible modes of failure and has anyone ever worked at a plant where passivation has failed. Our facility has recently shown physical signs of passivation failure in our reactor although all process data shows that we had oxygen in the system and proper passivation. We recently have come out of a scheduled shutdown and upon starting up we had a higher than normal N/C ratio as well as periods where we sat full in our HP loop while maintenance worked on some start-up issues.

Mark Brouwer of UreaKnowHow.com, the Netherlands, asks for some further clarification: Did you block in the synthesis while solving the start-up issues? If so, for how long and how many times and what was the interval between the block-ins?

Cory replies: There were a couple of issues and we attempted to start up three or four times. The longest period was a 22 hour period at which we know our N/C ratio was greater than 4.

For the first start-up we were nine hours into start-up when we went down for six hours. Then we attempted the second start-up over a three hour period and went down for five hours. The third start-up was over a two hour period and then we went down for 22 hours. We attempted the fourth start-up over a 22 hour period when we were again forced to go down due to our leak detection system ringing in exposing a leak. When we shut down to look at the leak we realised our vessel had been stripped of its regular iron oxide coating due to passivation. Upon vessel entry we realised we had many more pinholes and advised that they were a result of active corrosion at accelerated rates. This tends to point a finger at loss of passivation but our DCS trends show that we had oxygen in our system for the duration of the start-ups.

We are wondering if our high N/C ratio had something to do with losing passivation in the reactor or if it was consumed by a contaminant, perhaps something from turnaround cleanings.

Mark provides his experience: I've never heard that a high N/C ratio causes active corrosion. On the contrary, Saipem states a high N/C ratio reduces corrosion rates.

Blocking in is always a situation where hot carbamate solution is in a vessel and no new oxygen can enter. The existing oxygen will be consumed by the normal passive corrosion and a chromium oxide layer will form as a passive layer. When the blocking in time is too long the amount of oxygen becomes insufficient and active corrosion starts.

Stamicarbon and Saipem claim that blocking in times should be limited to maximum 72 hours.

Your remark of a contaminant consuming oxygen is interesting, although I have never heard of that phenomenon.

Does anybody else have similar experiences of blocking in right after start up and seeing active corrosion?

To see many new pinholes after such a short time seems strange to me. One should realise that a pinhole itself is anyhow an area of low oxygen refreshment even if the bulk liquid has sufficient oxygen. That its growth is accelerated so much seems odd.

Further stop-start and start-stop situations cause big stresses on the liner due to temperature differences between the liner and the carbon steel wall and weaker areas could create a leak.

Cory responds: Thank you for your expertise, it does allow us to eliminate our N/C ratio concern. The active corrosion is odd to us too but we had the reactor inspected and did some repairs during the turnaround which would not have missed these pin holes. We have found between 30 to 50 significant pin holes in just the bottom head alone and are inspecting the remaining zones now.

Muhammad Farooq of SABIC-SAFCO in Saudi Arabia asks some further questions:

- What is the material of the liner of your urea reactor and how long has it been in operation?
- What is the inspection frequency period?
- What procedure did you apply for the repair of previous pinholes and is it your practice that defects are removed first time? Did you monitor the liner thickness ever year?
- What is your feeding sequence and ammonia feeding temperature at start up?
- Did you analyse the temperature profile in a recent start-up of the urea reactor, especially at the reactor bottom?

Cory answers Muhammad's questions:

- The lining material is 316-SS and when we have made repairs we use 25-22-2 SS as a weld material after grinding out the cavity. This liner is approx. 35 years old and the reactor was scheduled for re-lining in 2015.
- We inspect on every scheduled maintenance outage which is every three to four years but due to other maintenance issues this has been every two years lately.
- Repairs are always done as explained in my first point. As mentioned in the previous discussion, we were just coming out of a turnaround where minor repairs were done and we had Stamicarbon do a pre-start-up inspection. They are currently doing our inspections now as well.
- We usually warm the HP loop by feeding CO_2 and steam (CO_2 having oxygen from air blowers @ 0.6 vol-%) until we achieve 270°F (132°C) at the top of the reactor. Then we feed in ammonia.

- Yes, we looked at the temperature profile and actually realised we achieved the fastest heat up we have ever seen. Usually the heat up takes three to four hours but we almost achieved 270°F (132°C) within two hours. We are currently trying to prove whether the instrumentation was working properly as we cannot explain the accelerated temperature increase.

We are currently looking at our DCS data to see if during our start-up attempts and block-ins we mismanaged the pulling of feed sequence or if somehow our instrumentation failed to show us loss of actual air. Initial data pulled has shown we were adding the right amount of air to our CO_2.

A question arising from this is whether circulating ammonia through the HP loop without CO_2 (which means no oxygen) may have somehow disrupted the passivation layer?

Muhammd Kashif Naseem of SABIC in Saudi Arabia shares his experience: I think your heating rate is very high. Keep it around 30°C/hour and use fresh air instead of a mixture CO_2/air for heating time passivation. I think the CO_2 mixture during heating with steam as water is creating the corrosion issues.

Both materials SS316-L UG and 25-22-2 SS are OK. Your licensor can advise you further with regard to materials.

We also operate a plant that is 30 years old. Every two years we inspect the plant and replace the liner material in the areas with the highest corrosion rates (vapour section). The original material was SS316-L UG and the top portion has been relined with 25-22-2 SS.

Cory comes back: I agree that the heat up rate is too high. We usually stay at around 30 to 50°F for the heat up. With our process it is impossible to have the heat up rate that we had with just steam or CO_2 and we are not sure why it got as high as it did. We have our vendor involved to find out how we reached such a high heat up rate (almost 107°F/hour). We looked at our instrumentation to see if it was functioning fine and it looks like it was.

Not sure if the heat up rate has anything to do with active corrosion. All of our process data shows we had passivation (oxygen). We are wondering if we had a contaminant that gave us an exothermic reaction that affected the passivation and give us a lot of heat?

Mark shares his experience and asks some further questions: Heat can be generated via condensation of steam and by the formation of carbamate from NH_3 and CO_2. What are the pressures where you see a high temperature increase? Do you see a temperature increase at all thermowells or only certain ones? I do not see that circulating ammonia without CO_2 would cause problems with the passive layer. Is there any chance that chlorides or sulphur could have entered the synthesis? These components cause problems to the passivation layer.

Cory replies: When the temperature took off, the loop pressure was roughly 1.4 bar (80°F/24°C) and increased to approx. 4 bar (240°F/115°C) within 1.5 hours. We have seen the temperature increase on all four thermowells in the reactor as well as the overhead gas line. The CO_2 flow was around 1,130 kg/h during this time. So far we have not found any indication of chloride or sulphur contamination.

Mark continues the discussion: Do you have graphs of the various temperatures versus time?

Passivation of stainless steels can be hindered by heat tints (result of welding) or by fouling caused by corrosion product (iron and chromium oxides) or metal parts (grinding).

Once active corrosion of carbamate starts it cannot be stopped and one needs to stop the plant, drain and re-passivate the surface.

Is it possible that heat tints and/or fouling is playing a role?

Essa Norozipour of Khorasan Petrochemical Company in Iran shares his experience: All equipment in the synthesis section requires at least two hours of oxygen injection for passivation. If the plant is started and then stopped before two hours of passivation has been carried out, the synthesis cannot be blocked in and must be drained completely and re-passivated. Did you check the interval of the start-up, shutdown and block in of your plant?

Cory replies: We do have trends, I have been trending every reliant DCS tag looking for discrepancies.

It may be possible that we have had grinding or welding contaminants as we did do some repairs during the scheduled turnaround before these start-up events. This has been discussed and we are looking into it. What baffles us still is the significant heat up rate.

We have looked at the time intervals and discussed them with our vendor and everything looks like it was in place and confirmed with our DCS data showing we had oxygen.

Mark responds: It is not easy to control the temperature rise at the beginning. I believe this occurs in other plants where the temperature increase is higher than the recommended 30°C/h.

Muhammad Farooq shares his experience: I also agree that the temperature rise during start-up when the pressure is 20 bar and temperature is more than 100°C (after passivation and heating) increases quickly especially during the first hour. However it is normal start-up behaviour in many plants.

My other observations are that the reactor liner is very old and needs early replacement.

The issue of passivation and heating of the synthesis loop needs to be sorted out with the vendor's help. It is not clear what the impact is on other equipment such as the stripper, carbamate condenser and scrubber.

The inspection frequency needs to increased to once per year.

Note: This above case was presented during the licensor's conference and the lessons learned are:

1. Any time the urea plant goes down and the loop is not drained, monitor the vessel temperatures for any heat increases. If the temperatures increase by more than 20°F, the synthesis loop must be drained immediately.
2. Ensure positive isolation of CO_2 when the loop is blocked in by monitoring the loop pressure. If the loop pressure starts increasing, and the temperature in the vessel remains stable, operators can investigate according to their own judgment. If the vessel temperatures also start increasing, the loop must be drained down as above.
3. Ensure operators close the isolation valve downstream of HIC-1201 (CO_2 inlet to reactor).
4. Modify the urea plant start-up procedure to include lab analysis of the stripper bottoms for metals found in the stainless steel liner, specifically Fe, Ni, and Cr. The first sample must be taken within 12 hours of start-up and the second 24 hours later. If the values are stable or decreasing, no action is required. If the values are increasing, the plant will be shut down and drained.

PHOTO: NARVIKK/ISTOCKPHOTO.COM

Chinese urea capacity rationalisation

China is in the process of one of the most profound changes to its fertilizer market in years as it seeks to combat air, soil and water pollution and increase fertilizer use efficiency. In the process its status as the world's largest urea exporter seems likely to come to an end.

China has come to set the pace for the world urea market, with Chinese anthracite-based urea capacity, now at the top of the global cost curve, acting as swing capacity in the way that Black Sea producers used to do in the 1990s. Chinese exports of urea reached a peak of just under 14 million tonnes in 2015, representing 29% of all urea trade. But that situation now seems set to change as the country tries to manage the next stage of its development; urea exports fell to 8.5 million t/a in 2016, a fall of nearly 40% year on year, and the final figure for 2017 looks set to be lower still at around 4.5 million t/a.

Urea has been one of the staples of Chinese fertilizer production. The country has a population of 1.3 billion, around 20% of the world's total, but contains only 8% of the world's arable land. As a consequence, since the famines of the 1960s, Chinese government policy has been to be self-sufficient in fertilizer production, particularly nitrogen fertilizer. Initially this was achieved via relatively simple ammonium bicarbonate production, and some of that legacy capacity still remains, but since the 1970s it has increasingly met its nitrogen needs via urea. In spite of a rolling programme of new builds, China's urea industry actually lagged behind the nation's very large nitrogen demand through the 1980s and China became one of the world's largest importers of urea. However, Deng Xiaoping's economic reforms allowed greater access to capital and imported technologies, and eventually led to a burst of new capacity built in the 1990s, much of it based on natural gas, before rising gas prices and shortage of availability led to a move back towards coal gasification again (albeit now by more modern technologies). By 1997 China had become self-sufficient in urea, and exports have gradually climbed over the course of the 21st century to their peak in 2014-15.

But urea capacity addition has actually continued far above the increase in domestic demand over the past two decades, to

the point where urea capacity in China reached close to 100 million t/a, far above the 60-65 million t/a actually produced, or the 55-60 million t/a actually required. Compared to an average industry operating rate of about 85%, this would represent more than 20 million t/a of excess urea capacity in China.

Government initiatives

Prior to the present Five Year Plan, Prior to the present Five Year Plan, the Chinese government had taken steps to try and rationalise domestic urea production. From 2012, new natural gas-based plants were no longer approved, in an attempt to ring fence meagre domestic gas resources for power generation and winter heating. A minimum plant size for new urea plants of 300,000 t/a was set to encourage larger, more efficient plants to be built which, it was hoped, would supplant some of the old, small-scale inefficient capacity still left. Larger, more modern plants are also able to use lower quality, bituminous coal, rather than more expensive anthracite, which can then be preferentially used for power production and home heating. However, this current, 13th Five Year Plan has seen a new focus on the environment and what president Xi Jinping calls China's "ecological civilization". The aim now is not to focus on headline growth figures, but shift to "higher quality growth" at a more modest level (6.5% GDP growth per annum seems to have become the new default target). This new environmental focus has implications for agricultural and energy policy as well as environmental pollution, and is having and will have dramatic effects on China's fertilizer industry.

Agriculture

On crops, the government is trying to move from the previous policy of providing enough grain by large scale application of fertilizer and pesticide. While population pressure in China itself has eased thanks to the success of the 'One Child' policy, in order to cope with the population's increasing wealth and desire for protein China has been driven to import more and more meet, and even started buying up land in Africa to secure access to this in a world where increasing population may drive up prices. More serious is the loss of existing farmland in China; China lost 6% of its farmland from 1997-2008 due to increasing urbanisation according to the UN FAO, and 20% of what remains was recently found by a government report to be contaminated by pollutants. The government is moving to greater use of manures and organic fertilizers and more balanced nutrient application. Nitrogen consumption actually fell last year, and the government has set a target of no consumption growth past 2020 as it ends wasteful application practices which have led to large scale nitrogen leaching into water courses.

Energy policy

As part of the Paris Climate Accords, China pledged to lower the carbon intensity of its GDP by 60-65% by 2030. The current Five Year Plan includes a commitment to cap total energy consumption at 5 billion tonnes of coal equivalent by 2020, equivalent to a 15% percent reduction of energy use per unit of GDP by 2020. Coal use as a percentage of total energy will be reduced to 58% from 64%. The NDRC is closing 800 million t/a of coal mine capacity, and coal consumption peaked in 2013 and has fallen by an average of 4.9% per year since. The fall in coal production has led to increased coal prices which have in turn led to shutdowns among some of the less efficient anthracite-based producers – anthracite prices were $40/t up this winter.

In the meantime, some 70% of new electricity generation capacity installed since 2013 has been zero carbon - solar, wind, hydro-electric or nuclear. Only natural gas consumption has risen, by 18%, as electricity generators switch from coal to gas-based generation, and this in turn, in spite of a 12% increase in Chinese gas production from sour gas, tight gas, coalbed methane and other unconventional sources, has led to shortages of natural gas and an interruption of supply to natural gas-based urea plants, whose operating rates have been as low as 25% this winter. Shortages of gas have also led to increases in LNG imports, which tend to be more expensive than domestic gas production and which has pushed gas prices over $8.00/MMBtu for some gas-based urea producers, further eroding their cost base. Consultants CRU say that they estimate 9.7 million t/a of gas-based urea capacity was suspended in December 2017 over and above the 2.3 million t/a that was idled or closed during 2017.

Pollution

Finally, China is taking measures to tackle its endemic problem with smog and air pollution in its major cities by reducing coal burning and forcing the closure of polluting industries near major population centres. The Ministry of Environmental Protection (MEP) has plans to idle fertilizer, steel and aluminium production in 28 cities across five regions during winter (November to February), and ban coal imports via Tianjin, the main port for these cargoes. The regions affected by the ban are some of the most populated and most smog-plagued: Beijing, the port of Tianjin and the neighbouring province of Hebei, as well as Shandong, Shanxi and Henan. These regions hold 36 million t/a of urea capacity, representing 45% of China's output.

On top of this, the Chinese government has implemented a more aggressive regimen of environmental inspections of industrial facilities of all kinds, and a number of fertilizer plants were forced to close or make upgrades to environmental remediation measures. There is particular concern around plants along the Yangtze River

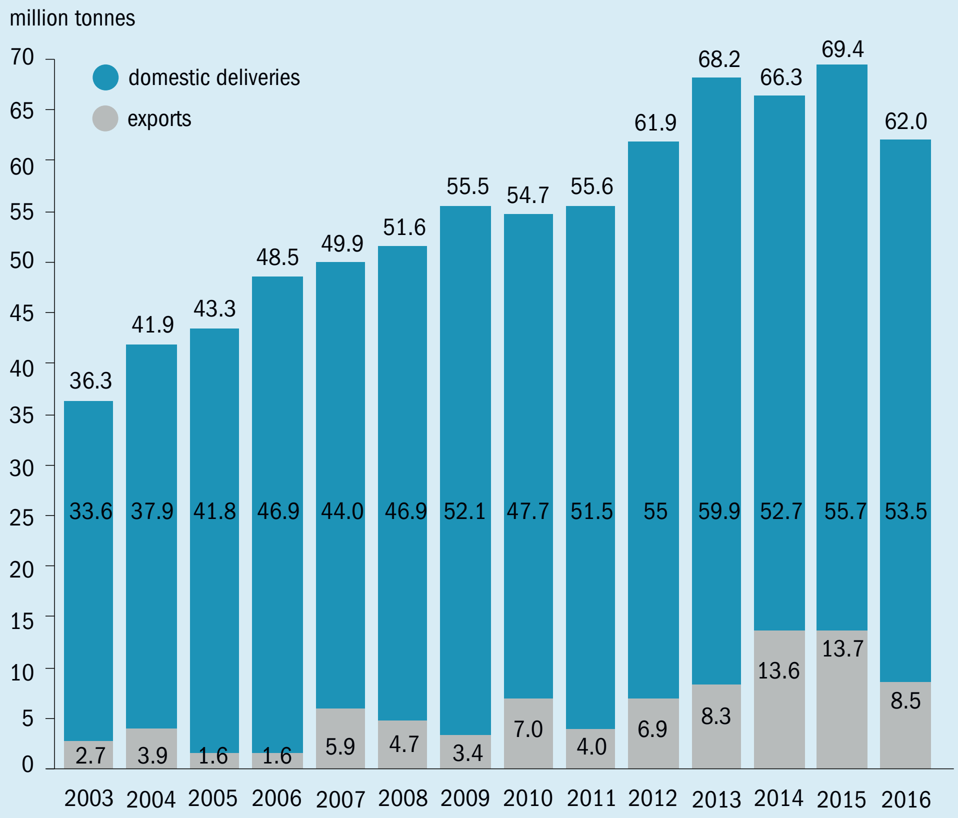
Economic Belt, and plants close to the river in Hubei province have been told to move at least 10 km away. This affects five ammonia plants, one of which has an associated 400,000 t/a urea plant, and could take them out of operation for 18 months or more during the relocation, or force permanent closure. There is also talk of an annual emissions ceiling for nitrogen fertilizer plants which could force closure for some of the more polluting facilities for some of the year.

Urea capacity closures

The upshot of all of this is that, on top of the seasonal closure of gas-based urea capacity and coal-based capacity near major population centres, there is also in effect due to rising feedstock prices, higher domestic freight rates and increased costs of environmental compliance a rolling programme of rationalisation of older and less efficient urea plants which has seen by CF Industries' estimates 26 million t/a of urea capacity closed from 2014-2016 (although an estimated 36 million t/a of new capacity also opened during that time). In the past local governments have often been content to let these plants operate, accruing debt, because the jobs that they provide have been valued as a social good over and above any commercial value. This led to the phenomenon of so-called 'zombie' plants which keep on going when any 'normal' enterprise would have folded. As jobs outside the industrial sector become available and the Chinese system moves towards more of a service economy, there has been less impetus to keep these plants open, and they have been allowed to fail, especially as new, more modern plants have opened in other parts of the country to balance the capacity closures.

The key question now for the urea market is how much more capacity will close over the coming years, and whether it will more than offset the continuing expansion of new, larger plants. CF put 2017 shutdowns at around 8 million t/a, although at this stage it remains unclear how many of these are permanent. Consultants Integer Research also note that six new urea plants started up in China during 2017, leading to a net capacity addition of around 500,000 t/a. However, going forward the new urea plant pipeline is relatively limited, and there is a large tranche of capacity which remains 'at risk'. Around 13 million t/a of urea capacity is more than 30 years old and another 10 million t/a over 20 years old. Integer puts the overall number for 'at risk' urea capacity at 16.9 million t/a, some or all of which could be forced to close over the coming years, while CRU is estimating 15 million t/a of closures over the period 2017-2022, removing most of the plants now at the top of the urea cost curve.

Fig. 1: **Chinese urea production, consumption and exports, 2003-16** (million tonnes)



China's share of world urea production:
- 31% 2003
- 40% 2015

China's share of world urea exports:
- 9% 2003
- 29% 2015

Source: Integer Research

Even so, this would still leave several million tonnes of notional urea overcapacity in China, and at that point the question becomes what kind of operating rates are going to be sustainable in the long term. If China is willing to accept an operating rate of 70% then this may mark the end of closures, but if its urea industry becomes more market sensitive, then more of a shakeout may still lie ahead.

An end to exports?

As Figure 1 shows, China has been a major urea exporter for most of the 21st century, with exports peaking in 2015 at just under 14 million tonnes in 2015, representing 29% of all urea trade. However, this fell 40% to 8.5 million t/a in 2016, and is expected to show a further fall of 45% to 4.5-4.7 million t/a for 2017. Chinese total urea production, which stood at 69 million t/a in 2015, dropped to 62 million t/a in 2016, and IFA estimates that it fell dramatically to 55 million t/a in 2017 due to the combined effect of all of the closures – temporary and permanent – that we have discussed above.

Over the next few years, Chinese demand is likely to slowly fall due to the improvements in nutrient use efficiency we have discussed, but the main effect on availability will continue to come from rationalisation of capacity for environmental or economic reasons. It is difficult to predict this with certainty, but it seems likely that a considerable tonnage of swing capacity may remain in China, producing during summer when feedstock prices are lower and demand is higher, and Chinese exports – while they are unlikely to end completely – may fall to a relatively low level, with availability more seasonal, and the tag of world's largest urea exporter may shift back to Russia, or even Iran. For many years, China has been something of a 'special case', but it seems that China's urea industry is now adjusting towards market norms.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46
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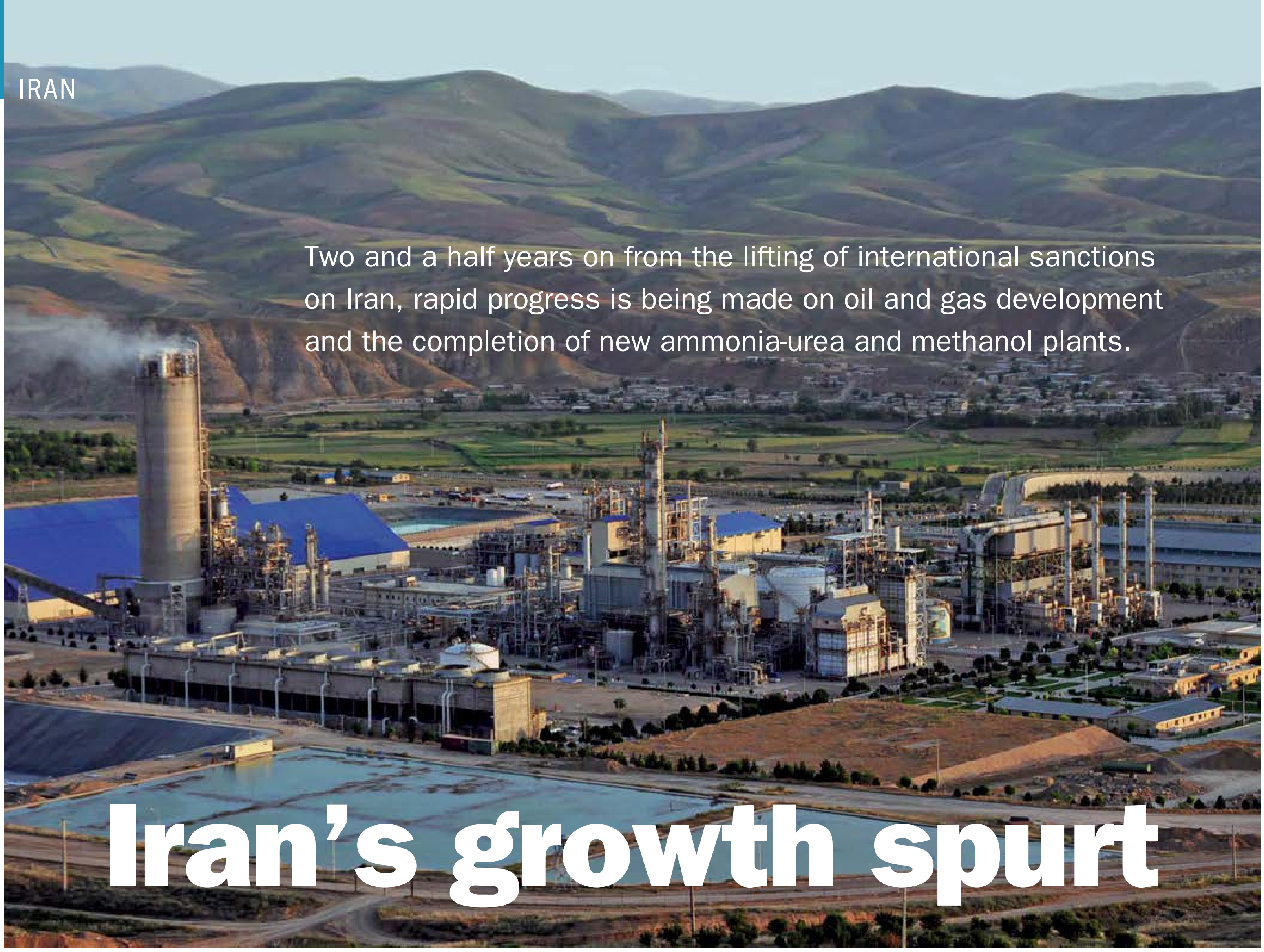

Two and a half years on from the lifting of international sanctions on Iran, rapid progress is being made on oil and gas development and the completion of new ammonia-urea and methanol plants.

Iran's growth spurt

Iran's return to the international fold following the 'Joint Comprehensive Plan Of Action' deal on its nuclear weapons programme in 2015 has been a disruptive one for many markets, but while it has had an effect on keeping oil prices lower, the potential effect on urea and methanol markets promises to be greater still.

Undoubtedly the biggest boost to Iran has come from increased oil sales. The World Bank estimates that the Iranian economy grew by 12.5% in 2016, most of that increase coming from oil sales (the comparable GDP growth figure for 2015 had been a contraction of 1.3%). Oil and gas production rose significantly during the year, contributing to a 25% rise in industrial production. However, non-oil growth was a more modest 3.3%, and now that the one-off boost from oil exports has come and gone, the overall GDP growth figure for 2017 is similarly expected to come in at around 3.5%. Current World Bank projections are for this to slowly rise towards 4% by the end of the decade, all other things remaining equal. In the meantime, the Iranian economy also faces many structural problems. Inflation is running at 9% and unemployment remains at a seemingly intractable 12.7% (according to government figures – actual figures are believed to be higher). The oil, gas and petrochemicals sector generate impressive returns for the government, but are not large job creators. Iran has also been trying to wean its economy of subsidies, which account for 27% of government spending, and this has pushed up prices and led to hardship among the populace, which in turn has been a major contributory factor in the protests which broke out towards the end of 2017 in many Iranian cities. President Rouhani, widely credited on the Iranian side with delivering the lifting of sanctions and Iran's return to the international fold, was re-elected in May 2017, and continues to push economic reforms, but as with many Middle Eastern countries must deal with finding jobs for the large numbers of young people entering the workforce. Like Saudi Arabia, Iran is a young country; 40% of Iran's 80 million people are under 25, and 800,000 new people enter the workforce every year, while only 490,000 new jobs per year have been created since 2013.

Oil and gas production

Iranian oil production rose by 18% during 2016 according to BP figures, reaching 4.6 million bbl/d, allowing Iran to overtake China, Iraq, the UAE and Canada to become the world's fourth largest oil producer, after the USA, Saudi Arabia and Russia. Refined production grew only 1.3%, but this now represents almost 95% capacity utilisation – refinery capacity remained unchanged – and Iran still has to import gasoline. As a result, one of the key targets for the government is to achieve self-sufficiency in fuel production. Iran is currently involved in an overhaul of its refinery capacity, with the aim of taking the 380,000 bbl/d Abadan refinery up to 540,000 bbl/d with $2.7 billion of Chinese financing, as well as changing the fuel slate from the current one which produces 40% of its output as 'mazut' – a heavy, poor quality fuel. The first phase of the Persian Gulf Star refinery also became operational in May 2017, with an output of 120,000 bbl/d of Euro-V quality fuel. The plant was constructed by Khatam-al Anbia, the economic arm of Iran's powerful Islamic Revolutionary Guards Corps. The second phase is due for completion this year or next. Iran is aiming to be a net exporter of refined products by 2019.

On the gas side, Iran's natural gas reserves remain the world's largest, representing around 18% of the world's total, just ahead of Russia. Natural gas production grew by 6.6% in 2016, to 202 billion cubic metres, continuing a growth rate that has averaged 6.4% over the past decade. Gas consumption was put at 200 bcm by BP for 2016. Iran's gas production has mostly come from development of the huge 9,700 km^2 offshore South Pars Field, which has around 40% of the country's gas reserves. The 28-phase development of the field began in the 1990s but is now running towards its final phases. Iran says that it expects to be producing 360 bcm per year of natural gas in March 2019 when all of the phases are currently scheduled to be complete, although this completion date has been something of a moveable feast. The country still hopes to increase gas output to 420 bcm per year by 2020. Currently around 50% of this gas is consumed for domestic heating, some 30% goes towards electrical power generation, and the remaining 20% goes to industry, with the country's ammonia and methanol plants consuming a significant proportion of this.

As gas production increases, some of this will go to feed new ammonia and methanol capacity and power production, but Iran is also looking towards gas exports. There are some gas exports to Turkey (7.7 bcm in 2016), but Iran also takes gas from Turkmenistan. There has also been some export to Iraq to help tide the country through the winter. There is considerable pipeline infrastructure in place ready to take advantage of these export routes and also to Armenia. Iran has also built its side of a proposed export pipeline to Pakistan, but the Pakistani side remains incomplete and now the subject of a legal dispute between the two countries. There are also plans for an undersea pipeline to Oman. Unlike many of its Gulf neighbours, Iran has not so far become an exporter of LNG. Plans to use a floating LNG barge for export via a joint venture with Hemla Vantage AS of Norway are currently on hold after contractural disagreements about gas pricing. There are plans to develop an LNG plant at Tombak, north of Assaluyeh, but another $4 billion in financing is still required to get this project moving.

Iranian feed gas prices are now based on a formula which averages the price of domestic gas consumption in other sectors with the price of gas traded at international gas hubs. At present this stands at around $1.65/MMBtu, comparing very favourably to most of the rest of the world, and discounted gas from associated oil production is still available at much lower rates (ca $0.50/MMBtu). This makes Iran very competitive internationally from a feedstock point of view.

Fig. 1: **Iranian syngas-based chemical plants**

KEY
Existing ammonia, urea and methanol sites (see Table 1):
1. Bandar Imam (Razi, Fanavaran)
2. Assaluyeh (Zagros, Pardis)
3. Bojnurd (Khorasan)
4. Kermanshah (Kermanshah Pet. Co.)
5. Kharg Island (Kharg. Pet. Co.)
6. Shiraz (Shiraz Pet. Co.)
7. Dayer (Kaveh Methanol Co.)

New and proposed ammonia/urea plants (see Table 2)

New and proposed methanol plants

Nitrogen fertilizers

Iran is a large producer of nitrogen fertilizers, but produces far more than it can consume domestically. In 2016, domestic urea consumption was 2.07 million tonnes, while production was 5.2 million t/a, up from 4.3 million t/a in 2015. The country is a net importer of cereal crops, with annual imports of 11-16 million tonnes of cereal. At the same time, nitrogen fertilizer application rates in Iran have fallen to 18kgN/hectare, compared to an average of 86kgN/ha for the rest of the world, and also compared to a pre-sanctions value of 53kgN/ha for Iran. There is thus plenty of potential for extra nitrogen demand within Iran.

In the meantime, Iran has tried to monetise its plentiful gas resources by building export-oriented urea capacity, especially in the Pars Special Economic Energy Zone at the port of Bandar Assaluyeh, which has become a massive petrochemical hub as shown in Table 1. The lifting of sanctions has given a boost to attempts to develop new ammonia-urea capacity in Iran, which had proceeded very slowly during the past decade, with abortive tie-ups with Venezuela and India coming to nothing. Sanctions have made the licensing of technology and in particular the financing of these plants difficult, and remaining banking sanctions mean that getting payments into or out of Iran remain extremely problematic for companies.

Most of the new plants are along the coast, aimed at the export market, and the past year has seen two of them start up – Marvdasht (actually in the interior), a subsidiary of Shiraz Petrochemcials Co, and Pardis at Assaluyeh, Another plant, at

Table 1: **Existing gas-based chemical plants in Iran**

Company	Location	Product	Capacity (t/a)	Year operational
Fanaravan	Bandar Imam	Methanol	1,000,000	2004
Kaveh Meth Co	Dayer	Methanol	2,300,000	2018
Kermanshah	Kermanshah	Ammonia	396,000	2007
		Urea	660,000	2007
Kharg Pet. Co	Kharg I	Methanol	660,000	1999
Khorasan	Bojnurd	Ammonia	330,000	1996
		Urea	495,000	1996
Marjan Pet Co	Assaluyeh	Methanol	1,650,000	2018
Marvdasht Pet C	Marvdasht	Ammonia	675,000	2017
		Urea	1,075,000	2017
Pardis	Assaluyeh	Ammonia	675,000	2007
		Ammonia	675,000	2010
		Ammonia	675,000	2017
		Urea	1,075,000	2007
		Urea	1,075,000	2010
		Urea	1,075,000	2017
Razi	Bandar Imam	Ammonia	330,000	1970
		Ammonia	330,000	1977
		Ammonia	677,000	2007
		Urea	595,000	1977
Shiraz	Shiraz	Ammonia	432,000	1985
		Urea	48,000	1963
		Urea	495,000	1985
		Methanol	84,000	1990
Zagros Pet. Co	Assaluyeh	Methanol	1,650,000	2006
		Methanol	1,650,000	2010
Total capacity		**Urea**	**6,593,000**	
		Methanol	**8,910,000**	

Source: BCInsight

Lordegan, was reported in January 2018 by Iran's Association of Petrochemical Industry Corporations (APIC) to be "83% complete", an expected to come on-stream later in 2018. These three plants, each with 1.08 million t/a of urea capacity, will take Iranian urea capacity to 7.7 million t/a, a potential excess of over five million t/a of urea.

A further six identically-sized plants and one smaller unit have been begun or are at various stages of development. Those that have achieved at least 25% completion according to the National Iranian Petrochemical Company are shown in Table 2. There are other stalled plants at Golestan and Hormuz, as well as some apparently abandoned projects.

If all of these projects came to fruition, they would represent an additional 5 million t/a of urea production in Iran in addition to the 6.6 million t/a already completed or in commissioning, which would make Iran the third largest producer in the world, after only China and India's massive capacity, and the fifth largest nitrogen producer, with Russia and the USA also coming in higher.

Methanol

While urea has been a key focus for attempts to monetise Iranian natural gas, methanol appears to have become even more so. As can be seen from Table 1 – Iran's methanol capacity now exceeds 8 million t/a with the start-up of the Kaveh Methanol Company plant at Dayer – now in commissioning, and the largest single train methanol plant in the world.

As with ammonia, there are wildly ambitious plans for new methanol production, which could add 10 million t/a of capacity over the next few years if all of the plants in Table 2 come to fruition. Can methanol markets actually absorb so much product? The answer, surprisingly, may be 'yes'. Global methanol markets have grown rapidly over recent years to a total of 80 million t/a, as China has looked to use methanol as an intermediate in olefins production, but demand growth from 2017-2020 is estimated by consultancy IHS to be another 17 million t/a, 7 million t/a of that coming from new Chinese MTO capacity. Plants scheduled to be completed during that timeframe include 4 million t/a of capacity in China and about another 4 million t/a in the US, Russia and elsewhere around the world, excluding Iran, so almost 9 million t/a of Iran's potential 10 million t/a might find a market. Furthermore, Iran is also looking to use methanol to olefins production as a way of generating olefins and monetising its natural gas reserves. At Chabahar, the first of these MTO complexes is planned as part of the new Mokran petrochemical hub development, associated with another new methanol plant, with an olefins capacity of 1.25 million t/a. It is understood from SPI International, the company managing the finance and engineering contracts for the Mokran petrochemical project, that the Iranian National Petrochemical Company will no longer issue new licenses for standalone methanol plants, and up to 17 MTO projects are under consideration across the country, although so far only the Mokran plant is under serious development.

Joint ventures

From a capital expenditure point of view, construction and labour costs are lower in Iran than most other places in the world, and there are established domestic construction and engineering firms such as PIDEC which are capable of doing the work. While it costs up to $2.0 billion to build a new world scale ammonia-urea plant in the US and $1.3 billion in some other regions, some argue this could be as low as $500 million in Iran. Costs of production of $100/t of urea have been floated, comparing very favourably even to current depressed international markets for fertilizer.

However, the major issue is one of financing. Iran's petrochemical sector is mostly privatised and while there is considerable state assistance, economics

Table 2: **Ammonia/urea and methanol projects under development in Iran**

Company	Location	Product	Capacity (t/a)	Status
Bushehr Olefin & Methanol	Assaluyeh	Methanol	1,490,000 t/a net	90% complete 2018
				Target onstream 2018
Lordegan Petchem Co	Lordegan	Ammonia	680,000 t/a	83% complete 2018
		Urea	1,075,000 t/a	Target onstream 2018
Sabalan Petchem Co	Assaluyeh	Methanol	1,650,000 t/a	50% complete 2017
				Target onstream 2018
Masjid Soleiman Pet Co	Masjid Soleiman	Ammonia	680,000 t/a	50% complete 2017
		Urea	1,075,000 t/a	Target onstream 2019
Zanjan	Ijrood	Ammonia	680,000 t/a	47% complete 2017
		Urea	1,075,000 t/a	
Persian Gulf Petchem Co	Assaluyeh	Ammonia	680,000 t/a	40% complete 2017
		Urea	1,075,000 t/a	Target onstream 2019
Dena Methanol Co	Assaluyeh	Methanol	1,650,000 t/a	40% complete 2017
Middle East Kimiya	Assaluyeh	Methanol	1,650,000 t/a	30% complete 2017
				Target onstream 2019
Siraf Methanol Co	Dayer	Methanol	1,650,000 t/a	25% complete 2017
				Target onstream 2019
Kermanshah Petchem Co	Kermanshah	Ammonia	400,000 t/a	25% complete 2017
		Urea	660,000 t/a	Target onstresm 2020
Veniran Apadana	Assaluyeh	Methanol	1,650,000 t/a	25% complete 2017
Total		**Urea**	**4,960,000 t/a**	
		Methanol	**9,740,000 t/a**	

Source: National Iranian Petrochemical Company

are a real factor in spite of the gas and capex cost advantages. Some projects are already fully financed, but most of those that are still in the earlier stages of construction or development are short of cash and looking for new investment money, with many foreign companies still put off by the volatile political situation.

In order to overcome these challenges, Iran has been keen to try and develop joint venture ownership structures to move projects forward. There has been a long history of trying to develop JV ammonia and methanol plants in the country, but so far there has been with little success. Plans for a collaboration with India for an ammonia-urea plant on Kharg Island foundered in the 1990s over gas price wrangles. The VenIran joint venture methanol plant developed with Venezuela was hampered by Venezuela's slow slide into economic chaos and the sanctions regime on Iran, although it now survives as the Veniran Apana plant in Table 2. Various proposed collaborations with Russia, Oman, Indonesia and Turkey also all came to nothing. Since the easing of sanctions India has discussed a number of projects, foremost among which is the Chabahar ammonia-urea project, part of a development at the Chabahar Free Trade Zone. India aims to spend $500 million to develop the port in Iran's south-east as a regional trade hub. Three Indian companies are involved in the fertilizer project; Rashtriya Chemicals and Fertilizers (RCF), Gujarat Narmada Fertilizers and Chemcials (GNFC) and Gujarat Chemicals and Fertilizers (GSFC), but again progress has been slow.

An uncertain future

In spite of the new spurt of growth in Iranian oil, gas and petrochemicals projects, there are still clouds on the horizon. A major one is the regional political situation – Iran is fighting Saudi Arabia in a number of proxy conflicts across the Middle East, most notably in Yemen, but both countries are also backing rival factions in Iraq and Syria. Iran's increased influence in Syria and Lebanon has alarmed Israel, and Prime Minister Netanyahu made a great deal of Israel's recent downing of what was alleged to be an Iranian military drone over northern Israel. President Trump, while a mercurial figure whose policies can be hard to pin down, has made no secret of taking the Saudi and Israeli sides in these conflicts and distrusting Iran, and has threatened to tear up the nuclear agreement and re-impose sanctions on Iran. All of this could abruptly change the economic situation for Iranian companies, and any foreign companies that have deals with them. Iran's domestic politics also remain fractious, with President Rouhani treating a difficult balancing act between the demands of reformers on the one hand and the strong voices of conservatism among the religious elite and powerful Revolutionary Guard.

Iran thus remains something of a wild card in petrochemical markets. The projects in Table 2 would virtually double Iran's urea and methanol production in the course of just a few years, and make it an even bigger player on international markets than it currently is. However, events could see these plans delayed or even cancelled if geopolitics leads to a re-imposition of international sanctions. ■

Urea storage under construction at the Pardis ammonia-urea plant in Iran, completed in September 2017.

Nitrogen+Syngas's annual listing of new ammonia, urea, nitric acid and ammonium nitrate plants shows that the key areas for new project developments are Iran, India, Russia and central Asia, while the surge of new capacity in the United States is now coming to its end. New projects have also been announced in Brunei, Malaysia, and Saudi Arabia.

Nitrogen project listing 2018

Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
ALGERIA							
n.a.	Casale	Fertial	Arzew	Ammonia	1,000	RE	2018
AZERBAIJAN							
Samsung	Haldor Topsoe	SOCAR	Sumgait	Ammonia	1,200	UC	2018
Samsung	Stamicarbon	SOCAR	Sumgait	Urea	2,000	UC	2018
BELARUS							
thyssenkrupp I.S.	thyssenkrupp I.S.	Grodno Azot	Grodno	Nitric acid	1,200	UC	2018
thyssenkrupp I.S.	thyssenkrupp I.S.	Grodno Azot	Grodno	Ammonium nitrate	3,500	UC	2018
BOLIVIA							
Samsung	KBR	YPFB	Bulo Bulo	Ammonia	1,200	C	2017
Samsung	TEC	YPFB	Bulo Bulo	Urea	2,100	C	2017
BRAZIL							
Technip, TEC	Haldor Topsoe	Petrobras	Uberaba	Ammonia	1,500	BE	On Hold
Tecnimont	KBR	Petrobras	Tres Lagoas	Ammonia	2,200	UC	On Hold
Tecnimont	Stamicarbon, TKFT	Petrobras	Tres Lagoas	Urea	3,600	UC	On Hold
BRUNEI							
thyssenkrupp I.S.	thyssenkrupp I.S.	Brunei Fertilizer Ind.	Sungai Liang	Ammonia	2,200	UC	2021
thyssenkrupp I.S.	Stamicarbon, TKFT	Brunei Fertilizer Ind.	Sungai Liang	Urea	3,900	UC	2021
CANADA							
Casale	Casale	CF Industries	Courtright, ON	Urea	1,100	RE	On hold
CHINA							
n.a.	Casale	Hubei Yunhuaan Chem Co	Wuxue	Ammonia	1,200	UC	2020
n.a.	Casale	Hubei Sanning Chem Co	Yichang, Hubei	Ammonia	2,020	UC	2020
n.a.	Casale	Yichang Xingjiang	Yichang, Hubei	Ammonia	1,250	UC	2018
n.a.	Casale	Hubei Yihua Fert	Yichang, Hubei	Ammonia	1,820	UC	2018
n.a.	Casale	Henan Jindadi Chem	Luohe, Henan	Ammonia	1,800	UC	2018
Hualu Engineering	Stamicarbon	Jiujiang Xinlianxin	Jiujiang, Jiangxi	Urea	2,330	BE	2019
n.a.	Stamicarbon	Inner Mongolia Huajin	Panjin	Urea	2,860	UC	On Hold

Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
CROATIA							
Casale Project	n.a.	Petrokemija	Kutina	Nitric acid	n.a.	RE	2018
EGYPT							
Tecnimont	KBR	Kima	Aswan	Ammonia	1,200	UC	2019
Tecnimont	Stamicarbon	Kima	Aswan	Urea	1,575	UC	2019
GABON							
Technip	Haldor Topsoe	Gabon Fertilizer Co	Port Gentil	Ammonia	2,200	DE	On hold
Technip	Saipem/TKFT	Gabon Fertilizer Co	Port Gentil	Urea	3,850	DE	On hold
HUNGARY							
thyssenkrupp I.S.	thyssenkrupp I.S.	Nitrogenmucek	Petfurdo	Nitric acid	1,150	C	2017
thyssenkrupp I.S.	thyssenkrupp I.S.	Nitrogenmuvek	Petfurdo	Ammonium nitrate	1,550	C	2017
INDIA							
PDIL	KBR	Matix Fert & Chem	Panagarh	Ammonia	2,200	C	2017
Saipem	Saipem	Matix Fert & Chem	Panagarh	Urea	3,850	C	2017
n.a.	thyssenkrupp I.S.	Deepak F&C	Dahej, Gujarat	Nitric acid	900	UC	2018
n.a.	thyssenkrupp I.S.	Deepak F&C	Dahej, Gujarat	Ammonium nitrate	1,140	UC	2018
n.a.	Casale	GSCF	Vadodara	Urea	520	RE	2018
Engineers India Ltd	Haldor Topsoe	RCFL	Ramagundam	Ammonia	2,200	UC	2019
Engineers India Ltd	Saipem	RCFL	Ramagundam	Urea	3,850	UC	2019
TEC	KBR	Chambal Fert & Chem	Gadepan	Ammonia	2,200	UC	2019
TEC	TEC	Chambal Fert & Chem	Gadepan	Urea	2 x 2,000	UC	2019
n.a.	Casale	Zuari AgroChem	Goa	Ammonia	1,050	RE	2020
n.a.	KBR	Mangalore Chem & Fert	Panambur	Ammonia	1,000	RE	n.a.
n.a.	KBR	RCF	Trombay	Ammonia	n.a.	RE	n.a.
INDONESIA							
TEC	KBR	PAU	Sulawesi	Ammonia	1,900	UC	2018
IRAN							
STAC	KBR	Pardis Petrochemical	Assaluyeh	Ammonia	2,050	C	2018
STAC	Stamicarbon	Pardis Petrochemical	Assaluyeh	Urea	3,250	C	2018
Hampa	Casale	Lordegan Petrochemical	Lordegan	Ammonia	2,050	UC	2018
Hampa	Stamicarbon	Lordegan Petrochemical	Lordegan	Urea	3,250	UC	2019
PIDEC	Casale	Masjid Soleyman	Masjid Soleyman	Ammonia	2,050	UC	2019
PIDEC	n.a.	Masjid Soleyman	Masjid Soleyman	Urea	3,250	UC	2019
Hampa	Casale	Zanjan Petrochemical	Zanjan	Ammonia	2,050	UC	2022
Hampa	Stamicarbon	Zanjan Petrochemical	Zanjan	Urea	3,250	UC	2018
Namvaran	KBR	Kermanshah Petchem	Kermanshah	Ammonia	2,400	UC	2020
Namvaran	Stamicarbon	Kermanshah Petchem	Kermanshah	Urea	4,000	UC	2020
PIDEC	Haldor Topsoe	Hengan Petrochemical	Assaluyeh	Ammonia	2,050	UC	2021
PIDEC	Saipem, TKFT	Hengan Petrochemical	Assaluyeh	Urea	3,250	UC	2021
Hampa	Stamicarbon	Golestan Petrochemical	Golestan	Urea	3,250	BE	On hold
n.a.	n.a.	Indo-Iranian JV	Chabahar	Ammonia	2,200	P	n.a.
n.a.	n.a.	Indo-Iranian JV	Chabahar	Urea	3,800	P	n.a.
IRAQ							
NFC	KBR	NFC	Baiji	Ammonia	1,200	RE	On hold
NFC	Stamicarbon	NFC	Baiji	Urea	2,250	RE	On hold

KEY

BE: Basic engineering
C: Completed/commissioning
CA: Contract awarded
DE: Design engineering
FS: Feasibility study
n.a.: Information not available
P: Planned/proposed
RE: Revamp
UC: Under construction

Conversion:
1 t/d of hydrogen = 464 Nm^3/h
1 t/d of natural gas = 1,400 Nm^3/d

1 47
2 48
3 49
4 50
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9 55
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Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
MALAYSIA							
MHI	Haldor Topsoe	Petronas	Sipitang	Ammonia	2,100	C	2017
MHI	Saipem/TKFT	Petronas	Sipitang	Urea	3,500	C	2017
n.a.	n.a.	Sabah Oil Gas Dev.	Sipitang	Ammonia	4,090	P	2021
n.a.	n.a.	Sabah Oil Gas Dev.	Sipitang	Urea	7,300	P	2021
MEXICO							
Proman	KBR	GPO	Topolobampo	Ammonia	2,200	CA	n.a.
NETHERLANDS							
Tecnimont/Yara	TKFT	Yara	Sluiskil	Urea	1,625	RE	2018
NEW ZEALAND							
n.a.	Casale	Ballance Agri-Nutrients	Kapuni	Urea	1,400	RE	Cancelled
NIGERIA							
TEC/Daewoo	KBR	Indorama	Port Harcourt	Ammonia	2,400	C	2017
TEC/Daewoo	TEC	Indorama	Port Harcourt	Urea	4,000	C	2017
TEC	KBR	Indorama	Port Harcourt	Ammonia	2,400	CA	n.a.
TEC	TEC	Indorama	Port Harcourt	Urea	4,000	CA	n.a.
Saipem	Haldor Topsoe	Dangote Fertilizer Ltd	Agenbode	Ammonia	2 x 2,200	UC	2019
Saipem	Saipem/TKFT	Dangote Fertilizer Ltd	Agenbode	Urea	2 x 3,850	UC	2019
OMAN							
SNC Lavalin	Linde/Haldor Topsoe	Salalah Methanol	Salalah	Ammonia	1,000	DE	2020
POLAND							
n.a.	thyssenkrupp I.S.	Grupa Azoty	Pulawy	Nitric acid	600	CA	2021
ROMANIA							
Casale Project	Stamicarbon	Azomures	Targu Mures	Urea	1,425	RE	2017
RUSSIA							
Tecnimont	Stamicarbon	KuibishevAzot	Togliatti	Urea	1,500	BE	2020
n.a.	Casale	KuibishevAzot	Togliatti	Nitric acid	1,350	BE	2021
n.a.	Casale	KuibishevAzot	Togliatti	Ammonium nitrate	1,500	BE	2021
NIIK	Casale	JSC Metafrax	Gubakha	Ammonia	1,000	UC	2019
NIIK	Casale/MHI	JSC Metafrax	Gubakha	Urea	1,700	UC	2019
n.a.	Casale	OJSC NAK Azot	Novomoskovsk	Ammonia	2,000	RE	2018
Tecnimont	KBR	EuroChem	Nevinnomyssk	Ammonia	2,700	BE	n.a.
Casale	Casale	EuroChem	Nevinnomyssk	Urea	1,600	RE	2018
Casale	Casale	Togliatti Azot	Togliatti	Urea	2,200	DE	2021
Tecnimont	KBR	EuroChem	Kingisepp	Ammonia	2,700	UC	2018
NIIK	Haldor Topsoe	Uralchem	Kirovo-Chepetsk	Ammonia	2,000	RE	2017
n.a.	KBR	Acron	Dorogobuzh	Ammonia	2,100	RE	2019
n.a.	Stamicarbon	Uralchem	Perm	Urea	+770	RE	2021
Saipem	Sapiem, TKFT	Baltic Urea Plant	St Petersburg	Urea	3,500	DE	On hold
MHI/Sojitz	Haldor Topsoe	PhosAgro	Cherepovets	Ammonia	2,200	C	2017
Casale Project	Stamicarbon	PhosAgro	Cherepovets	Urea	1,500	C	2017
SAUDI ARABIA							
eTec	thyssenkrupp I.S.	Safco IV	Al Jubail	Ammonia	3,670	RE	2018
Al Jubail Fert Co	Stamicarbon	Al Jubail Fert Co	Al Bayroni	Urea	n.a.	RE	2019
Daelim	thyssenkrupp I.S.	Ma'aden	Ras al Khair	Ammonia	3,300	CA	2021
SLOVAKIA							
Casale Project	Haldor Topsoe	Duslo Sala	Sala	Ammonia	1,600	RE	2018
SWEDEN							
Casale Project	Casale	Yara	Koping	Nitric acid	685	UC	2018
TANZANIA							
Ferrostaal	Haldor Topsoe	Tanzanian Petroleum	Mtwara	Ammonia	2,200	DE	n.a.
Ferrostaal	n.a.	Tanzanian Petroleum	Mtwara	Urea	3,800	DE	n.a.

Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
TURKEY							
n.a.	Haldor Topsoe	Eti Bakir	Mardin	Ammonia	300	C	2017
TURKMENISTAN							
MHI/Gap Insaat	Haldor Topsoe	Turkmenkhimiya	Garabogaz	Ammonia	2,000	UC	2018
MHI/Gap Insaat	Saipem/TKFT	Turkmenkhimiya	Garabogaz	Urea	3,500	UC	2018
UNITED STATES							
KBR, Casale	KBR, Casale	Agrium	Borger, TX	Ammonia	1,900	RE	2017
KBR	Stamicarbon, TKFT	Agrium	Borger, TX	Urea	1,800	RE	2017
IHI	Stamicarbon	Dakota Gasification	Beulah, ND	Urea	1,000	C	2018
Black & Veatch, KBR	Stamicarbon	Koch Nitrogen	Enid, OK	Urea	2,200	C	2018
Linde	Linde	Simplot Phosphates	Rock Springs, WY	Ammonia	600	C	2017
thyssenkrupp I.S.	KBR	Cronus Chemical	Tuscola, IL	Ammonia	2,200	CA	2021?
thyssenkrupp I.S.	Stamicarbon	Cronus Chemical	Tuscola, IL	Urea	3,850	CA	2021?
KBR	KBR	BASF/Yara	Freeport, TX	Ammonia	2,270	UC	2018
n.a.	Stamicarbon	PCS Nitrogen	Geismar, LA	Urea	+450	RE	2018
Matrix Service	n.a.	Fortigen LLC	Geneva, NE	Ammonia	90	UC	2018
Saipem	Haldor Topsoe	Pacific Coast Fertilizer	Longview, WA	Ammonia	660	P	2021
UZBEKISTAN							
MHI	Haldor Topsoe	NavoijAzot	Navoij	Ammonia	2,000	UC	2019
MHI	Saipem, TKFT	NavoijAzot	Navoij	Urea	1,750	UC	2019
n.a.	Casale	NavoijAzot	Navoij	Nitric acid	1,500	UC	2019

Improving the reliability of steam methane reformers

The reliable and continuous supply of hydrogen to a refinery is of major importance. **Dr M. Scholz** and **M. A. Smith** of thyssenkrupp Industrial Solutions discuss how the reliability of the hydrogen manufacturing unit can be improved by equipping it with a PSA bypass, which is triggered in case of a PSA trip. Consequently, the raw hydrogen is recycled to the steam reformer as fuel. In this way the plant is kept in operation while solving the issues that led to the PSA trip and a fast restart of the plant is possible with minimum shut down time.

Hydrogen manufacturing units (HMUs) are an integral and important part of a refinery. These units supply high quality hydrogen to refinery operations such as hydrocrackers and hydrotreaters. The reliable and continuous supply of hydrogen is of high importance for the operation and economics of the entire refinery. Without hydrogen the refinery has to be shut down and associated costs are estimated with up to approximately one million US dollars per day (depending on the capacity of the refinery).

Today's HMUs commonly consist of a desulphurisation section, a steam reformer (SMR), a shift converter and a pressure swing adsorption unit (PSA). The PSA unit purifies the raw hydrogen into a pure hydrogen product stream (>99.9 vol-% H_2) and a PSA off-gas (also referred to as PSA tail gas). The entire PSA off-gas is used as a fuel to provide the required heat for the endothermic steam reforming reaction. In fact, the major energy required for the steam reforming reaction is provided by PSA off-gas. Natural gas, naphtha, refinery fuel gas or a mixture of these gases supply the balance energy required.

HMUs have high on-stream factors and typically run for periods of four to five years between two planned shutdowns for plant maintenance and catalyst exchange. Various events initiate emergency shut downs which transfer the plant into a safe state and ensure the integrity of the plant. One shutdown is triggered by the loss of the PSA unit. The malfunction of the PSA results in the loss of the product gas and in addition PSA off-gas is lost. Consequently, the heat requirement of the steam reforming reaction has to be provided by a different source.

Fig. 1: **Top-fired tkIS Uhde steam reformer with the PSA offgas line and the offgas manifold in the foreground**

PHOTO: tkIS

Why is a PSA bypass required?

In hydrogen plants the major part of the energy (~80%) required for the endothermic reaction is supplied by the PSA off-gas. Fig. 1 shows a top-fired tkIS Uhde steam reformer with the PSA off-gas line and the off-gas manifold in the foreground. Due to the high integration of the PSA and the steam reformer system, a trip of the PSA has two major impacts on the steam reformer operation.

Firstly, the loss of PSA off-gas results in strong fluctuations of the box pressure and the pressure controller has to adjust the louvres upstream of the flue gas fan or the variable frequency drive (VFD) of the fan accordingly. This particular pressure

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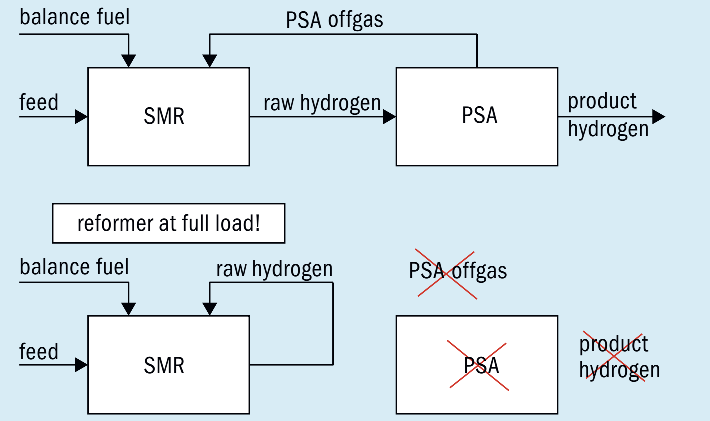
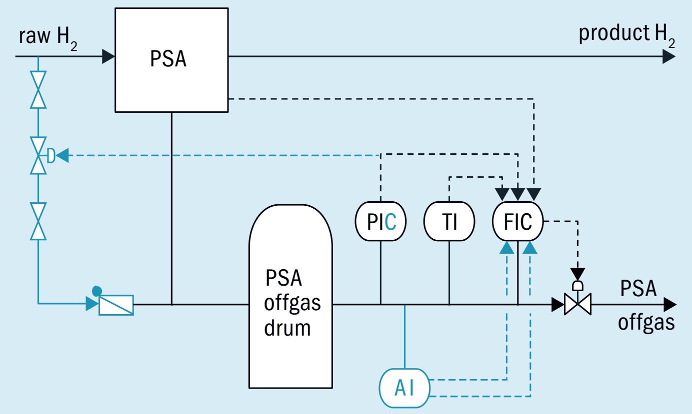
Fig. 2: **Normal operation of the HMU is shown on the top. In case of a PSA trip the bypass enables the operation of the steam reformer at full load shown at the bottom**



Source: tkIS

Fig. 3: **The required plant modifications are depicted in blue. Only minor modifications are required on instrumentation and piping**



Source: tkIS

fluctuation can be reduced by closing the off-gas flow control valve within a certain period of time (range is within seconds).

Secondly, the major portion of the heat for operating the reformer is provided by the PSA off-gas. Often the balance fuel system of a steam reformer is not designed to provide the energy for full capacity alone. Hence, operations have to reduce the plant load to fulfil the heat requirement of the reforming reaction by using the maximum allowable fuel flow rate. Even if the balance fuel system is designed to supply sufficient fuel for full load operation the flue gas flow rate differs significantly from operation using PSA off-gas. As a result the convection bank might not be able to preheat, evaporate and superheat the process media sufficiently.

PSA bypass concept

To overcome this limitation a PSA bypass can be installed. In case of a PSA trip the raw hydrogen stream upstream of the PSA is routed to the PSA off-gas header upstream of the PSA off-gas drum. In this way the pressure in the PSA off-gas header can be maintained and sufficient heat is provided to the reformer to operate at full load. The surplus of raw hydrogen is vented to the site flare system.

In Fig. 2 normal operation of the HMU is illustrated on the top. In case of a PSA trip the bypass enables the operation of the steam reformer at full load which is illustrated at the bottom.

Advantages of a PSA bypass

Keeping the steam reformer under hot conditions at full load has several advantages. The main advantage is that the problems which have led to the PSA trip can be solved and the time for regaining full capacity of the hydrogen plant and the site is minimised. Further advantages are:

- Thermal cycles which have an impact on the catalyst as well as tube and construction materials are avoided, which enhances the catalyst and the plant lifetime.
- The time without hydrogen production is minimised.
- Since the steam reformer is in normal operation, the steam produced as a by-product can still be exported at full flow rate. Hence, the trip of the PSA unit has no impact on the site high or medium pressure steam network.
- The effort for the operation personnel to restart the hydrogen production is minimised since only the PSA unit has to be restarted in contrast to restarting the entire reformer section.

In case that the problems causing the PSA trip are not solved quickly, the hydrogen plant can be shut down in a controlled manner.

Procedure in case of a PSA trip

In case of a PSA trip the pressure controller (PIC) in the PSA bypass line is put on automatic mode with the current off-gas header pressure as a set point. Raw hydrogen is sent to the steam reformer burners. The surplus of raw hydrogen is sent to the flare system. For normal steam reformer and PSA operation the PSA off-gas pressure is the master controller for the PSA off-gas flow controller to the steam reformer burners. In case of a PSA trip this cascade is broken.

The composition of the raw hydrogen gas and PSA off-gas differs significantly as demonstrated in Table 1. To provide the same amount of energy to the reformer a Wobbe Index (W) measurement* and the PSA off-gas flow rate measured at the moment of the PSA trip determine the duty supplied to the reformer prior to the PSA trip. This value is used as a set point for the flow controller to adjust the PSA bypass flow rate. The reformer tube outlet temperature is still controlled by the flow rate of the balance fuel.

Table 1: **Typical raw hydrogen and PSA off-gas compositions are shown**

	Raw hydrogen	PSA off-gas
CH_4, mol-% dry	5.8	17.8
CO, mol-% dry	3.5	10.8
CO_2, mol-% dry	16.2	50.0
H_2, mol-% dry	74.2	20.6
N_2, mol-% dry	0.3	0.8
Lower heating value, kcal/Nm³	2,503	2,356
Wobbe Index, kcal/Nm³	4,003	2,368

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When restarting the PSA the raw hydrogen which was previously sent to the flare is now routed to the PSA. By producing PSA off-gas again the raw hydrogen sent to the PSA off-gas header is backed out. The load of the PSA is further increased until the entire raw hydrogen is sent to the PSA and normal operation is established where PSA off-gas and balance fuel provide the heat for the steam reforming reaction.

Required modifications for existing plants

For existing hydrogen plants the PSA bypass concept requires only minor modifications including:

- additional piping;
- instrumentation;
- modification of the DCS system.

These modifications are illustrated in Fig. 3. The black lines show the common process setup. The coloured lines present the additional piping and instrumentation. Basically the raw hydrogen pipeline upstream of the PSA is connected to the PSA off-gas pipeline upstream of the PSA off-gas surge drum to take advantage of the buffer volume of the surge drum. In this pipeline a pressure control valve and associated isolation valves are installed to maintain the required PSA off-gas pressure in the header.

The pressure in the off-gas header is measured by an existing pressure transmitter and a pressure controller (PIC in Fig. 3) has to be added which is activated in case of significant reduction in the off-gas pressure header. The PSA bypass line is equipped with a check valve to avoid any reverse flow of PSA off-gas to the raw hydrogen system.

Additional instrumentation includes a Wobbe Index measurement device which is installed in the PSA off-gas line. Table 1 shows the composition of raw hydrogen and PSA off-gas. The composition and as a result the lower heating value differ significantly so that the Wobbe Index measurement is mandatory.

The reformer burners have to be checked due to the higher adiabatic flame temperature resulting from the combustion of raw hydrogen. In rare cases a replacement of the reformer burners might be required. This can be done during a turnaround together with the installation of the required plant modifications.

Typically the required installations such as piping and instrumentation can be prepared prior to a turnaround and the integration to the process plant including the test of systems can be done during a typical turnaround interval. For new plants the PSA bypass concept can be included in the engineering and little additional effort is required.

Impact on the process

Typically the operations team will quickly analyse whether the PSA can be restarted. In case that a fast restart is not possible they will reduce the SMR load and the raw hydrogen production rate. Even shutdown of the plant might be necessary. The PSA bypass mode is only applied for a limited time (in the range of hours) to solve the issues associated with the PSA unit.

Due to the high content of hydrogen in the PSA bypass stream, the adiabatic flame temperature increases and consequently NOx emissions increase. Since the PSA bypass mode is only applied for several hours, the absolute additional amount of NOx emissions is low.

It is recommended to establish mild process conditions in the steam reformer during PSA bypass operation such as a reduced reformer outlet temperature in order to reduce the fuel consumption.

Conclusion

The PSA bypass is a valuable concept to increase the on-stream time of hydrogen plants by minimal modification of existing plants. By recycling raw hydrogen to the steam reformer burner system the plant can be kept in operation in case of a PSA trip. Recycling of raw hydrogen stabilises the pressure in the PSA off-gas header ensuring stable combustion conditions. Furthermore, the required heat for the steam reforming reaction at full capacity is provided by the raw hydrogen stream. After solving the issues leading to the PSA trip, the hydrogen production can be re-established quickly since the reformer section is already at full load. Ultimately, the impact of the PSA trip to the entire site (e.g. steam network) is minimised.

*Wobbe Index: $W = \dfrac{LHV}{\sqrt{\dfrac{\rho}{\rho_o}}}$

where: LHV = the lower heating value
ρ = the density of the fuel gas
ρ_o = is the density of dry air

Cost effective ammonia plant revamping

No matter how old or new your plant, improvements are always possible and do not necessarily have to involve large expenditure. In this article we report on some of the many ammonia plant revamp options available and report on recent case studies.

As assets get older and are subject to ever increasing competitive pressures from newer and more efficient plants, which are often located in regions with lower feedstock costs, it is vitally important that the competitiveness of existing plants is enhanced by making improvements which are both reliable and cost effective. In addition, when product prices are under pressure it is also important to focus on improving the economics of operations.

There are many drivers for ammonia plant revamps, they include:

- capacity increase;
- energy efficiency;
- reliability on-stream factor;
- feedstock change;
- emission control;
- product flexibility.

While capacity increase and energy saving are the typical drivers for a revamp to improve operating costs and profitability, there may also be other external factors such as new environmental regulations, changes in feedstock and diversified product demands. Reliability and changes in safety standards may also trigger a revamp.

As there are many stages involved in the transition from feedstock to product, there is ample opportunity to improve plant performance. To fully understand the potential revamp benefits available, an appreciation of the flowsheet is required.

- Natural gas is fed into a purification stage to remove substances which can adversely affect downstream catalysts (e.g. species containing sulphur, chloride, etc.).
- The purified feed then passes into the reforming section in which natural gas is converted into a synthesis gas (CO, CO_2, H_2). In a conventional ammonia flowsheet, two stages of reforming occur; primary reforming and secondary reforming (which also introduces N_2 into the process gas).
- The reformed process gas is then shifted to further increase the H_2 content through the conversion of CO into CO_2.
- CO_2 is then removed, usually through chemical or physical absorption, although pressure swing adsorption is sometimes used.
- A methanation stage is included to remove carbon oxides down to trace levels (carbon oxides will poison the ammonia synthesis catalyst and hamper performance).
- The process gas then enters the ammonia synthesis loop in which ammonia is formed.

The reforming section and the ammonia synthesis loop are most often the major bottlenecks of the plant as well as the most capex intensive sections of the plant to modify, along with the rotating equipment. The primary reformer represents the largest capital expenditure of any unit operation and is the largest energy consumer within the process.

Steam reforming of natural gas

The main reactions involved in the steam reforming of natural gas are as follows:

Steam reforming of methane:

$$CH_4 + H_2O \rightleftharpoons 3H_2 + CO$$

$$\Delta H \rightleftharpoons +206 \text{ kJ/mol} \qquad (1)$$

Steam reforming of C_2+:

$$CxHy + xH2O \rightarrow (x + y/2)H_2 + xCO$$

$$\Delta H = +ve \qquad (2)$$

Water gas shift:

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$

$$\Delta H \rightleftharpoons -41 \text{ kJ/mol} \qquad (3)$$

The reforming reactions (equations 1, and 2) are endothermic and therefore require considerable heat input and high temperatures to obtain an economically acceptable conversion of natural gas. Although lower pressures are desirable from an equilibrium perspective, it is more economic to operate at higher pressures.

Pre-reforming

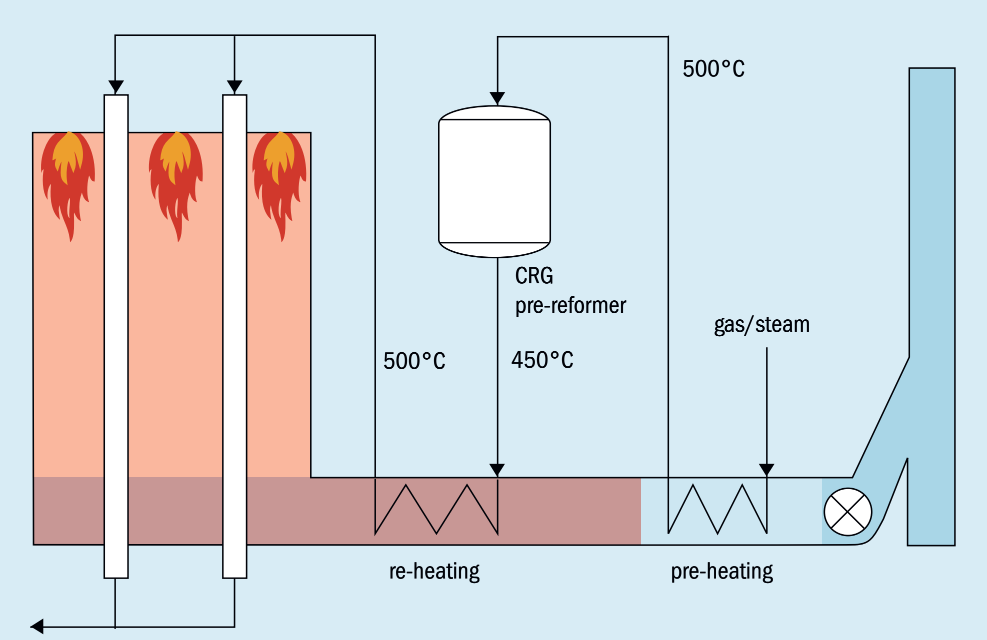
Pre-reforming is the reaction of a hydrocarbon feed with steam (equation 2) over a highly active catalyst (usually nickel based) to give a methane-rich product suitable for further downstream reforming. When considered at the design stage, a pre-reformer can result in significant capex savings but a pre-reformer can also be used to revamp existing plants (Fig. 1):

- if the primary reformer is firing limited, a pre-reformer can allow an increase in throughput without an increase in firing;
- it can allow much greater feedstock flexibility;
- overall steam ratios can be lowered.

Johnson Matthey technology enhancements

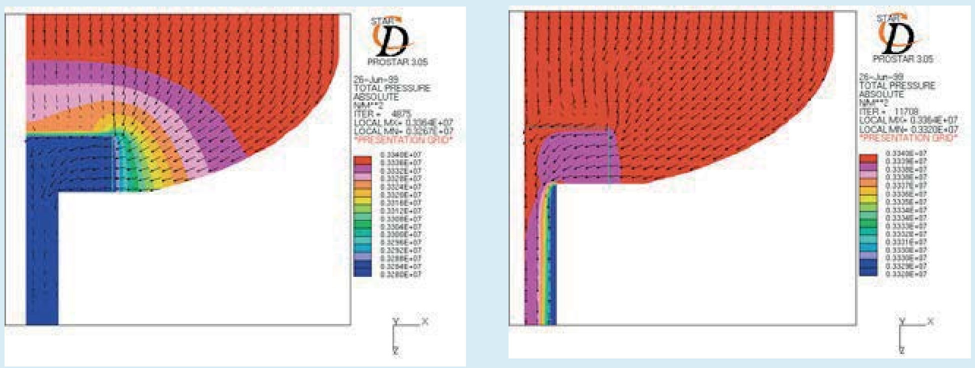
Johnson Matthey offers the complete package for ammonia plants, including technology, catalysts and services. A wide range of solutions are also available to enhance the performance of existing plants and Johnson Matthey has a proven record of successfully delivering improved performance, tailored to the requirements of individual customers.

Fig. 1: **Pre-reformer retrofit**



Source: Johnson Matthey

Fig. 2: **Reduction in pressure drop when installing STREAMLINE**



Source: Johnson Matthey

Johnson Matthey has a long history with pre-reforming, and has been producing the CRG (catalytic rich gas) range of catalysts since its development by British Gas in the 1980s. Johnson Matthey is the sole licensor of CRG technology.

Pre-reformer case study

The ammonia plant operated by Yara at Terte was built in 1968 and is of conventional Kellogg design. It has been continuously revamped over the years to improve both production rate and energy consumption. The objectives of the revamp were to:

- Increase production rate – installing a pre-reformer reduced the load on the induced draft fan, hence facilitating an increase in plant capacity.
- Decrease energy consumption – installing a pre-reformer allowed better energy integration within the primary reformer convection banks.

Minimisation of the front-end pressure was important, therefore shaped, low pressure drop, 'cloverleaf' CRG-LHCR catalyst was used.

In addition to the technology licence and catalysts for the pre-reformer, Johnson Matthey provided a number of other services including validation of the proposed design.

Commissioning of the new equipment went smoothly with minimal changes to normal plant start-up. The targets of the whole project, capacity increase and energy reduction, were reached. As a consequence of the debottlenecking, soon after the plant restart and stabilisation, a production increase of 10% was achieved on a daily basis and after further tuning after one month, a 15% increase in rate was achieved with an associated 5% reduction of energy consumption.

The wider plant

There is a great deal of opportunity to improve plant performance by considering the steam reforming stage alone, however, it is also important to consider the wider plant when looking to maximise plant efficiency. Two of the major areas for improvement when looking elsewhere in the plant are pressure drop over process equipment and heat integration. Johnson Matthey's experience with plant design and revamps has led to the development of a range of technologies to assist operations attempting to remove or reduce these issues.

Inlet distributors and outlet collectors

Upon entering a vessel containing a catalyst bed, it is vital to obtain a uniform distribution of the process gas prior to catalyst bed entry to avoid issues associated with flow maldistribution, including increased pressure drop, reduced catalyst efficiency and localised overheating. Correct and efficient flow distribution can easily be obtained through the use of well-designed inlet distributors. Johnson Matthey has extensive experience in the design of inlet distributors to complement the performance of the catalyst bed, achieving optimal results and reducing the potential for issues during operation.

Alongside inlet distributors, a correctly designed gas collector at the base of the vessel will help reduce pressure drop within the vessel and increase process efficiency. As with inlet distributors, Johnson Matthey has extensive experience of collector design.

In both cases Johnson Matthey uses state of the art computational fluid dynamics (CFD) techniques to analyse flow patterns within existing vessels (Fig. 2) and uses the information to provide bespoke designs specifically tailored to the needs of the customer. The designs may be offered separately, or as an integral part of a STREAMLINE™ retrofit.

STREAMLINE

As part of a technology review, Johnson Matthey conducted a significant study into the contributions to the pressure drop experienced over a vessel, including the inlet nozzle, inlet distributor, hold down material, catalyst, support system, outlet collector and exit nozzle. Extensive modelling using CFD was used to confirm the pressure drops in specific areas. The results demonstrated that the pressure drop contributions across the inlet distributor and outlet collector were less than 0.01 bar each, and that the contributions across the inlet nozzle and hold down media were negligible. It was shown that a significant portion of the vessel pressure drop was over the support material and the exit nozzle, demonstrating the need for an optimised support material.

STREAMLINE is designed to reduce pressure drop in fixed bed vessels, and is suitable for use in many different converters. STREAMLINE uses a novel support material to significantly reduce the pressure drop in the annulus around the collector, where the bulk of the flow is radial and high velocities lead to high pressure drops. STREAMLINE low pressure drop support material meets all the critical criteria for the ideal support, including high voidage as a function of its shape, high strength, large particle size and low silica content.

The STREAMLINE service from Johnson Matthey comprises:

- a complete study to identify accurately all of the sources of vessel pressure drop in a converter;
- a proven solution based on a proven support medium; and
- installation and discharge assistance.

More than 20 installations are operating in large plants worldwide, with typical single vessel pressure drop savings of 0.4 bar. A reduction in the front-end pressure drop of an ammonia plant allows a reduction in compressor power requirements for an increase in throughput at a constant suction pressure.

LTS case study

One ammonia plant in Asia Pacific has saved over $250,000 per annum (based on a gas price of $3/million Btu) in energy costs by installing a system comprising KATALCO™ 83-3 and STREAMLINE in their low temperature shift vessel.

Johnson Matthey completed a detailed study of the low temperature shift vessel installation. This included detailed CFD modelling of the internal arrangement at the converter exit. Modelling of the existing arrangement confirmed the measured pressure drop of 1.25 bar. The CFD work also showed that minor modifications to the exit nozzle and the installation of the STREAMLINE system would reduce the pressure drop by 0.9 bar to only 0.35 bar.

The reduction in pressure drop was confirmed by subsequent plant performance.

KBR ammonia capacity upgrade technologies

KBR has a long history in the design, engineering and construction of ammonia plants and has a dedicated ammonia revamp technology team to increase the capacity and energy efficiency of existing plants. Ammonia plant capacity can be increased beyond conventional techniques using proven KBR technologies. Interaction with the plant owner in order to define the best optimal and economical combination of capacity/energy retrofit options is essential to define a successful revamp project.

Commercially proven KBR technologies to upgrade ammonia plants include:

- KBR Reforming Exchanger System: KRES™;
- all refractory secondary reformer;
- floating head water tube boiler;
- radial flow shift reactors;
- add-on true cold wall converter;
- unitised chiller.

Reforming – KRES™

KRES™ has been successfully implemented in commercial operations in ammonia plants for Methanex (Canada) since 1994. The KRES™ unit can be either added to the current plant configuration or replace the complex fired steam methane reformer thus facilitating the use of a unique process configuration and relatively simple heat exchanger design.

The KBR KRES exchanger is optimally integrated into the ammonia flowsheet to provide a steam balanced plant. The key principles behind integration of KRES™ are:

- utilise the high grade waste heat exit secondary reformer for generating 30% additional synthesis gas rather than passing to generate HP steam, which is a lower grade carrier of energy thus boosting the capacity of the plant;
- maximise recovery of lower grade heat elsewhere in the plant to minimise reduction in production of HP steam due to incorporation of KRES™;
- pressure drop through the front-end is not increased since the flow is in parallel to the primary reformer;
- waste heat boiler duty is reduced as part of the heat from the secondary reformer effluent which is used to reform gas in KRES™. By doing this, steam generation is reduced to have a balanced plant.

Retrofit experience with KRES™ includes a plant capacity increase from 1,680 t/d to 2,140 t/d at PCS Nitrogen, Lima Ohio (2015) and a plant capacity increase from 1,600 t/d to 2,000 t/d at CFCL-1 Rajasthan, India (2009).

All refractory secondary reformer

The KBR secondary reformer design incorporates several special features which have provided superior performance in the operating units. The design incorporates a special mixing and combustion chamber (elongated) where the oxygen in the air combusts part of the process gas from the primary reformer leading to high temperature. KBR's proprietary combustion chamber design avoids the use of a conventional metallic burner in the secondary reformer. The KBR combustion chamber design, made of all refractory, makes the secondary reformer robust and improves reliability as it does not require periodic inspection and maintenance as in the case of metallic burners.

Floating head water tube boiler

The legacy Kellogg waste heat boiler (with bayonet design) is protected by a water jacket on the outside and a single layer of refractory on the inside. The metal shell is designed for about 204°C (400°F). The refractory layer also has a metal liner. Operational issues with this design, such as warping of the metal liner and nails on the outside of bayonets creating hot spots, have been reported in the past.

The new KBR floating-head boiler has a special dual-layer refractory that requires no metal liner. The design incorporates a water jacket on the shell and on the transfer line from the secondary reformer to assure against overheating in the event of a refractory failure. It uses a proprietary inlet gas distribution design. External bypasses are used to adjust the process temperatures. High-level heat recovery downstream of the reformer is achieved in this proprietary, natural-circulation, floating-head type waste heat boiler. This is a well proven, mechanically robust design that provides superior reliable performance.

KBR used to have three waste heat boilers in the legacy design. In the current design, all three exchangers are replaced by one floating head exchanger. The new exchanger is on a new foundation and can be installed while the plant is in operation. This exchanger design has been in operation successfully in over 30 ammonia plants.

Recent retrofit experience includes two plants in the USA, one designed for a capacity increase from 1,450 t/d to 1,675 t/d (expected to be in operation in 2019) and the other designed for a capacity increase

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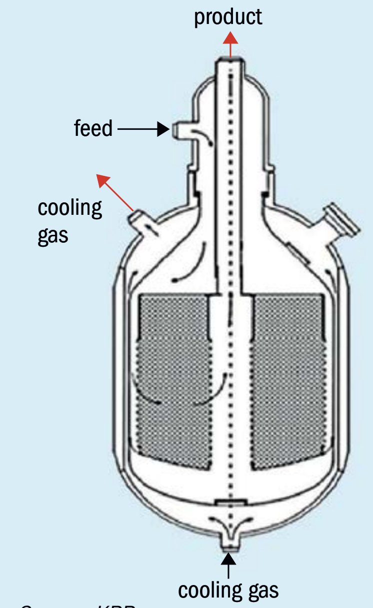
Fig. 3: **KBR cold wall add-on converter**

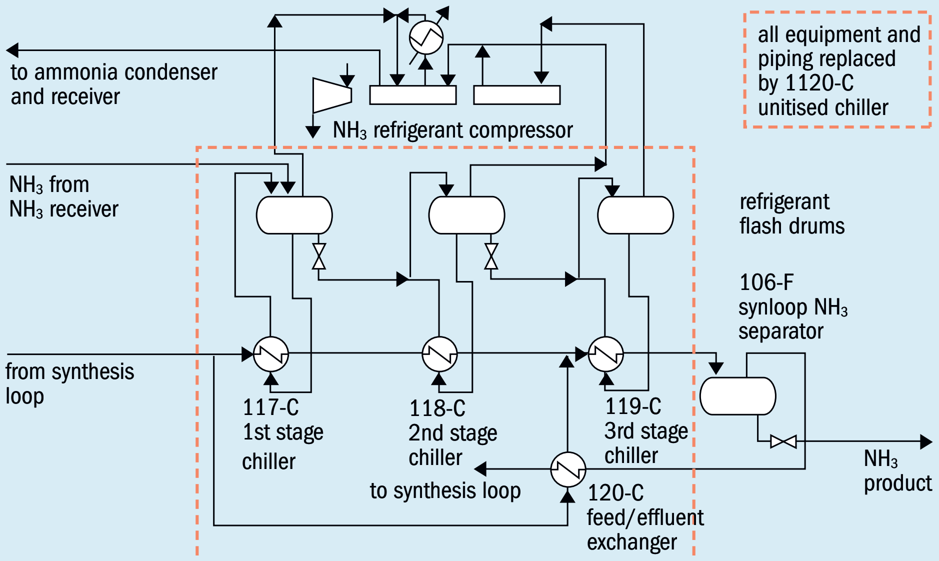


Source: KBR

Fig. 4: **Pressure shell after hydro test in the fabrication shop**

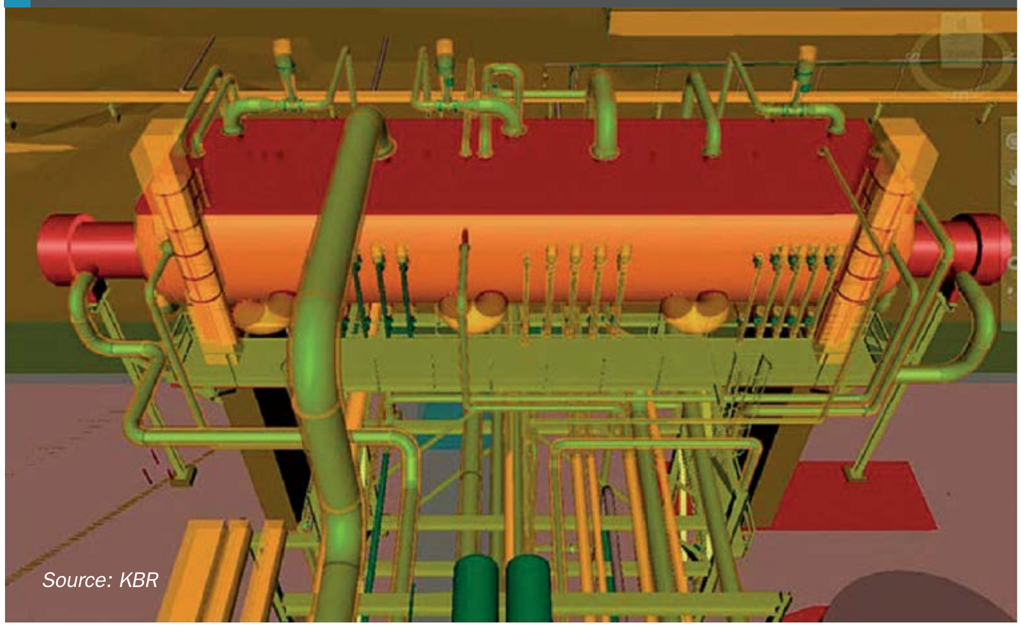
PHOTO: KBR

Fig. 5: **Legacy MWK refrigeration system**



Source: KBR

Fig. 6: **Unitised chiller – retrofit option**



Source: KBR

from 1,300 t/d to 1,727 t/d (expected to be in operation in 2020).

Radial flow shift reactors

Legacy Kellogg plants have shift reactors with an axial flow design. It has been found that pressure drop becomes critical for these reactors over the operational life of the plant. The pressure drop issue can be handled by replacing the reactor internals with a radial flow design.

Recent retrofit experience includes a plant in the USA, designed for a capacity increase from 1,300 t/d to 1,727 t/d (expected to be in operation in 2020).

Add-on true cold wall converter

One of the keys to debottlenecking the synthesis loop is to increase the converter exit ammonia concentration. Modifying the converter internals is the first economical option to consider. For further capacity increase KBR has a true cold wall one-bed radial flow add-on converter (Fig. 3) to further increase ammonia concentration.

The synthesis section in ammonia plants has seen quite a few improvements over the years, many of which have been applied to revamps. Plants with wet loops have been converted to dry loops by introducing molecular sieves. The benefits of molecular sieves include reduced synthesis loop pressure drop and reduced chance of moisture carryover to the ammonia converter.

Fig. 4 shows the pressure shell of KBR cold wall add-on converter hydro test in the fabrication shop.

KBR has found that economics favour

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47 48 49 50 51 52 53 54 55 56 57 58 59 60

the add-on converter after an internal upgrade has been done. The cold wall design avoids all the known reliability issues with the "hot wall" design.

Recent retrofit experience includes capacity increases at CFCL-1, Rajasthan, India, from 1,600 t/d to 2,000 t/d (2017) and CFCL-2, Rajasthan, India, from 1,600 t/d to 2,000 t/d (2018).

Unitised chiller

In the legacy Kellogg design, each synthesis loop chiller was a standalone exchanger attached to the corresponding elevated flash drum. In later years, flash drums were built as one vessel with partitions and exchangers were combined. In a natural progression of the design, the chillers and the flash drums were integrated to improve efficiency. This unitised chiller has been a standard KBR offering for new projects since the late 1980s.

The unitised chiller is a specially designed, multi-stream heat exchanger that cools the effluent from the ammonia synthesis converter with recycle gas and with boiling ammonia refrigerant at several temperatures. In doing so, the unitised chiller combines several heat exchangers, drums, and expensive high-pressure piping and fittings into a single item of equipment. This design saves pressure drop in the synthesis loop and reduces capital cost.

As converter effluent is cooled from both sides, closer temperature approaches are taken that shift compression load to the high pressure end thus reducing compressor power. KBR has used the unitized chiller in numerous ammonia plants since 1980s. There are over 30 ammonia plants currently in operation with unitised chillers (mostly 4 stages). The most recent (with three stages) was implemented as a part of revamp project for a confidential client in the US.

The unitised chiller replaces 117-C; 118-C; 119-C and 120-C exchangers along with the associated drums (Fig. 5). Exchangers 118-C, 119-C and 120-C were due to be replaced anyway for increased capacity, so a decision was made to use a three stage unitised chiller and save energy.

Expected energy savings for this project is about 2,240 kW total for the synthesis compressor and refrigeration compressor. The power savings avoided making any changes to the refrigeration compressor turbine for the upgraded capacity operation. Fig. 6 shows the unitised chiller retrofit option.

The capacity of the plant will be increased from 1,300 t/d to 1,725 t/d and is expected to be in operation in 2020.

KPI revamp to offload the primary reformer

A comprehensive study of a large ammonia plant was carried out by process technology and consulting company KPI for capacity and energy improvements. The ammonia plant had been stretched to its operating limits at about 1,800 short t/d with the following constraints in the reforming section, including the process air compressor:

- process air compressor near its maximum design speed (~103.6%);
- low process air temperature (~130°F/72°C below normal design);
- low secondary exit temperature (~75°F/42°C below normal design);
- higher methane slip from the secondary reformer (+0.45% over normal);
- higher S/C ratio in Primary (~3.4) to lower the methane slip;
- ID/FD fan dampers fully open;
- low mixed feed preheat temp (~40°F/22°C below normal design);
- lower superheat steam temperature (~85°F/47°C below normal design);
- very high heat flux (~133% over normal);
- higher feed preheat temperature (~95°F/53°C over normal);
- excessive combustion air leakage from the rotary APH (~15%);
- limited convection HT surface with no extra space to add any more coils.

Additional limits in the balance of the plant included:

- both syngas & ammonia compressors at 100% & 102.8% speeds;
- high inerts in make-up gas due to high methane and CO_2 slippages;
- inefficient synloop with high inerts and high H/N ratio.

The main premise of the revamp approach was based on the following requirements:

- no modifications of the major compressors;
- no additional turnaround time than normal;
- minimum 110% of ammonia production without sacrificing energy efficiency or operating reliability;
- least capital with an attractive payback.

The revamp study of such a highly bottlenecked plant with these requirements posed an unusually greater challenge especially without any expensive compressor upgrades.

Based on the identified plant bottlenecks along with the premise and approach of the revamp together with an initial screening of various options, upgrading the process air capacity was identified as key to upgrade the reforming capacity with minimum changes.

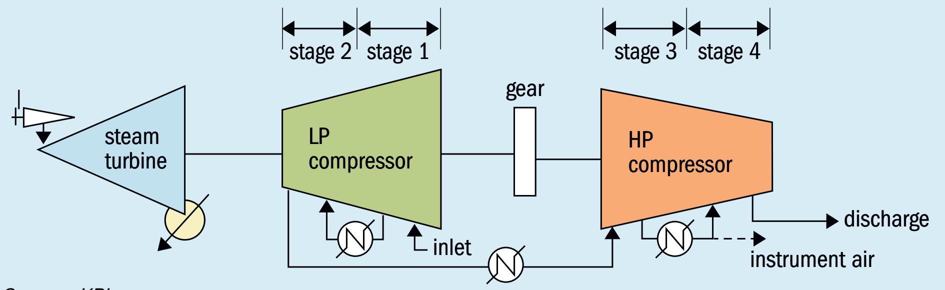
Further review of the plant capacity upgrade options identified a new approach to avoid any modifications of the major compressors for a reasonable increase in the plant capacity with an improved energy efficiency for an attractive payback. To fully realise the benefit of increased reforming capacity, the synloop capacity also needed an upgrade to balance and maximise the ammonia production.

Process air compressor

The existing process air compressor for the ammonia plant is a multistage centrifugal machine driven by a steam turbine. It is configured in two casings with four stages of compression each separated by an intercooler as shown in Fig. 7. The low pressure (LP) compressor is driven by a condensing turbine using superheated MP steam, and the high pressure (HP) compressor is driven through a speed increasing gear coupled to the LP machine.

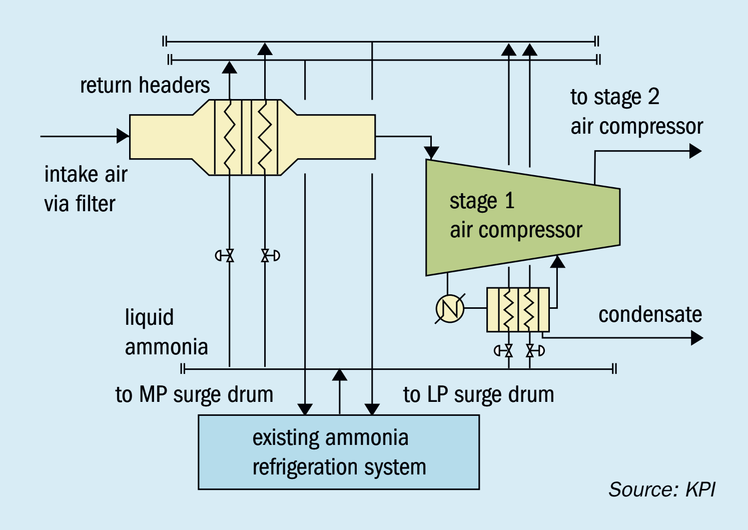
A newly patented approach utilising the multistage integrated chilling (MIC) or multistage chilling (MS) scheme along with heat integrated split (HIS) flow of process air was proposed to upgrade the existing process air compressor system to provide a cost-effective option to increase the pro-

Fig. 7: **Process air compressor – typical train arrangement**



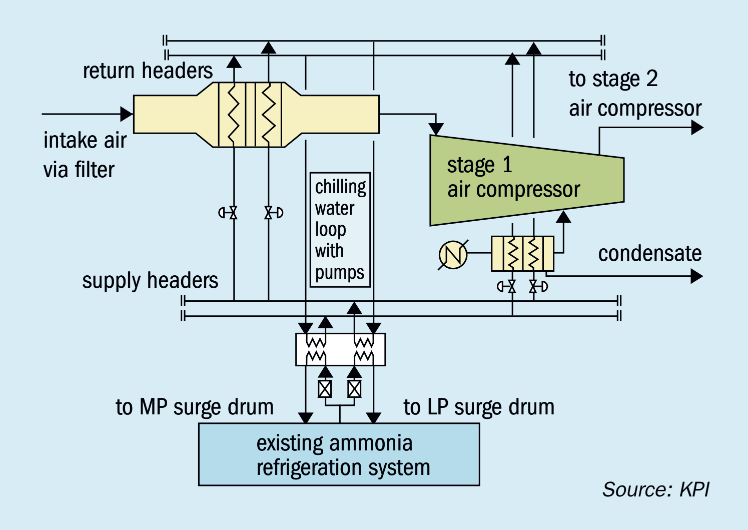
Source: KPI

Fig. 8: **Multistage integrated chilling – typical direct**



Source: KPI

Fig. 9: **Multistage integrated chilling – typical indirect**



Source: KPI

cess air compressor capacity by up to 20% without any additional power or the use of an external refrigeration system.

MIC is a staged thermal coupling of the ammonia compressor with the process air compressor (PAC) to maximise its capacity. The capacity limitation of the PAC is evaluated with a rigorous re-rating model for the chilling requirement in each stage to maximise its capacity. The ammonia stream is suitably staged to balance with the existing ammonia compressor system. The MIC scheme can use a direct or an indirect mode of chilling as shown in Figs 8 and 9.

The MS scheme is similar to the MIC scheme except that it will use an external refrigeration package. Depending on plant specific constraints, a hybrid system may be used with a portion of the chilling duty supplied by an external refrigeration package. In any case, the PAC capacity is maximised by evaluating the limitation in each stage with the rigorous re-rating model.

Sparing ammonia refrigeration

Any combination of the following options can be used to create some spare ammonia refrigeration capacity through the existing ammonia compressor unless it already has some extra capacity. The spare ammonia refrigeration capacity is then used with the process air compressor to upgrade its capacity.

- reducing the total inerts in the make-up gas;
- increase the purge rate to fully utilise the purge recovery unit;
- marginal reduction CW supply temperature, if possible;
- adding a single bed converter.

Depending on the ammonia plant specific constraints, a combination of the above measures can be adopted. In most situations, additional ammonia capacity provides the most incentive for quicker payback. In that situation, adding a single bed converter in series may provide a viable option to also raise the synloop capacity to reasonably balance with the increased reforming capacity to maximise the ammonia production along with the improved energy efficiency.

Heat integrated split flow scheme for process air

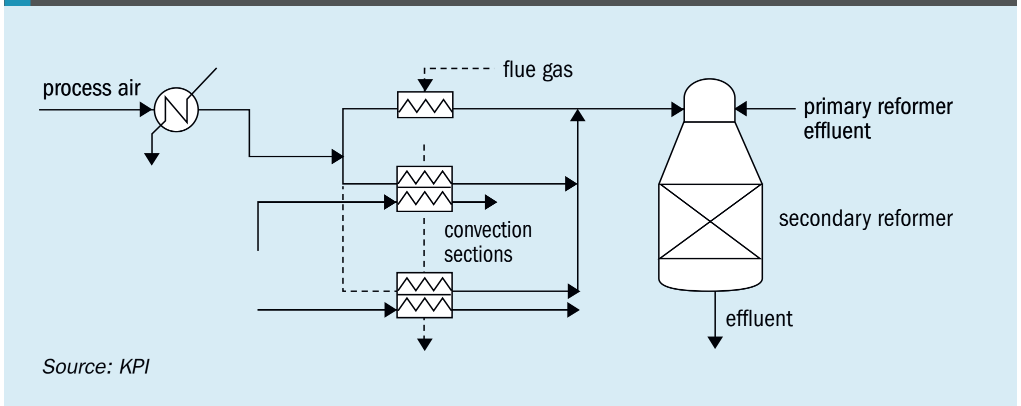
The higher mass flow of process air available needs to be suitably handled to provide sufficient preheating with a minimum pressure drop to maximise reforming capacity and ammonia production. However, the existing process air preheat coil becomes further limiting to accomplish any of this as no additional heat transfer surface can be added in the space-constrained convection section. To overcome this limitation, a heat integrated split (HIS) flow scheme is used as shown in Fig. 10.

The HIS scheme takes advantage of the redundant surface area of two other service coils in the space-constrained convection section which becomes available only with the new service conditions of the revamp case with MIC scheme. With minor modifications of the top one or two rows of those convection coils, part of the process air flow can be preheated in a split flow for additional process air preheat with reduced pressure drop. Further, process air is partly preheated externally using HP steam which also helps to reduce the process load on the existing process coil. Based on the revamp case steam balance, some extra HP steam becomes available as compressors driver steam demand is reduced with MIC scheme. The HIS scheme with a combination of split flow and an external steam exchanger increases the degree of process air preheat with minimum impact on pressure drop for higher process air flow.

Case study results

Using the MIC scheme along with the HIS flow scheme, the process air mass flow rate could be increased to 114% along with higher head of 108% (of base operating case) without any modifications to the PAC or its steam turbine. This resulted in debottlenecking the primary reformer with minimum changes to push additional throughput resulting in 112% ammonia production.

Fig. 10: **Process air preheating – air split flow scheme**



Source: KPI

ZoneFlow™ reactor based revamps

In 2Q 2018, ZoneFlow™ Reactor Technologies LLC (ZFRT) will be commissioning a commercial level pilot plant to demonstrate the performance of its proprietary, radically innovative, structured catalyst solutions for steam reforming, pre-reforming and post-reforming. ZoneFlow (ZF) reactors provide higher heat transfer, lower pressure drop, higher geometric surface area, more uniform flow and heat distribution, and long-term structural integrity compared to the current state-of-the-art pellet catalyst. The use of ZF reactors enables significant capital and operating cost reduction in steam reforming for both new plants and revamps.

ZF reactors are advanced engineered catalyst systems based on unique 'annular' foil casing structure (see Fig. 11) offering major advantages over conventional 'pellet' steam reforming catalysts:

- Lower pressure drop (dP) – the ZF uses dP mainly to enhance the turbulence near the tube wall, avoiding to a large extent the "unutilised" dP in overcoming flow and diffusion resistance typical of random pellet packed column.
- Superior heat transfer – ZF annular structure directs the gas flow to impinge the hot surface of the tube wall which significantly enhances heat transfer and also lowers the tube skin temperatures, thus also permitting process intensification and reliable operation at lower steam-to-carbon (S/C) ratios.
- Ultimate strength against thermal cycling and "wall-proximal" flow based on flexible annular metallic structure.

The following four cases are used to highlight ZF application potential for front-end ammonia plant (see Fig. 12) debottlenecking and revamps.

Case study: Stressed primary reformer make-over

ZF technology can be used to overcome several bottlenecks of the primary reformer:

- primary reformers suffering from below nameplate capacity limitations on the process (catalyst tube) side due to either pressure drop or tube temperatures or both, possibly caused by catalyst breakage from thermal cycling and reduced catalyst activity/effectiveness;
- need for higher S/C ratios to limit outlet temperatures in conjunction with the above which puts further constraints on achievable throughput;

Fig. 11: **ZF reactor elements**

- reformer capacity curtailed in order to operate to maintain tube wall temperature (TWT) limits and also to avoid hot spots with the ultimate objective of conserving tube life.

ZF replacement can overcome the governing bottlenecks and further optimise reformer conditions with slightly lower S/C ratio, slightly higher outlet temperature with lower approach to equilibrium and lower than original pressure drop, without exceeding the original tube design temperature and/or bridgewall temperature.

Case study: Simple debottlenecking of primary reformer

ZF technology can provide the following benefits to the primary reformer:

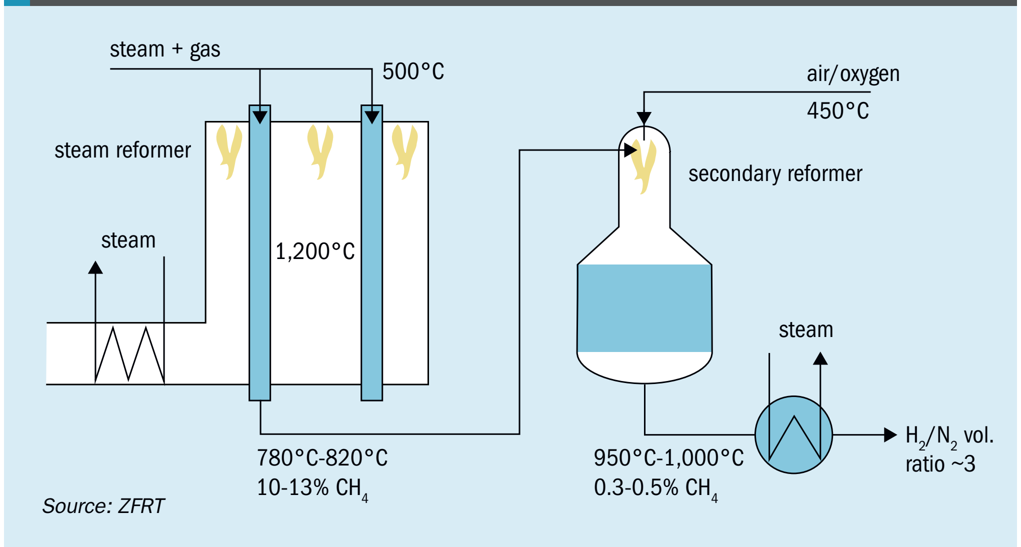
- incremental reforming capacity without exceeding maximum TWT or bridgewall temperature;
- optimised operation and reforming severity in terms of T out and S/C;
- marginal utilisation of available design margins on burners and fans;
- dP slightly lower than design even with increased capacity;
- slightly higher average heat flux without exceeding tube design or bridgewall temperature;
- better temperature uniformity leading to extended tube life and improved reliability;
- better catalyst robustness, performance and "life cycle" costs based on longer operating life;
- better catalyst performance and "life cycle" costs.

Case study: ZoneFlow™ convective pre-reforming (ZF-CPR)

The ZF-CPR is an ultra-low pressure drop structured catalytic reactor with high surface area/low cross section for non-adiabatic convective pre-reforming (CPR). It can be inserted horizontally into the existing mixed feed preheat (MFPH) coil in the convection section with some level of modifications and/or reconfiguration of portions of adjacent coils, depending upon the level of capacity increase. It accomplishes in-situ non-adiabatic pre-reforming (including conventional reheat) providing 8-15% additional reforming capacity by transferring convective heat to radiant duty. ZF-CPR reactors operate at higher reforming temperatures and higher reaction rates than conventional adiabatic pre-reforming reactors.

Convective pre-reforming fully exploits ZF's core advantages of heat transfer and pressure drop and when combined with

Fig. 12: **Typical steam reforming front-end of an ammonia plant**



Source: ZFRT

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ZF in the radiant section, the net pressure drop increase is marginal. Additional advantages of ZF-CPR include:

- no concerns over horizontal loading catalyst settling, run attrition and related feed by-passing;
- minimised modifications and related downtime (can be executed within a typical turnaround depending upon case-specific factors)
- shifts steam loads to utilities and offsites, thus also lowering core-plant carbon footprint.

Case study: ZF-PR in heat exchange / post reforming with secondary reformer

For achieving ammonia plant revamp capacity expansions of more than 15% (up to 30%) an effective and proven solution is to install heat exchange post reformer integrated with the secondary reformer effluent. However, the usual challenges are the size scalability and protection from potential metal-dusting. Since the post reforming is heat-transfer limited, application of an enhanced heat transfer ZF-PR structured catalyst system can effectively reduce the surface area requirements and thus size of the post reformer and thereby the installed cost of this expensive piece of equipment. This in turn also allows larger capacities within the heat exchange reformer scalability limits.

ZF-PR is a pressure drop optimised enhanced heat transfer structured catalyst design that can be ideally applied to smaller ID heat exchange tubes, while also providing extended operating life. Benefits include:

- allows up to 30% incremental reformed gas without increasing primary reformer radiant duty;
- can achieve further additional capacity when combined with ZF-CPR retrofit;
- modular add-on with minimised modifications and related downtime.

As the post reformer syngas contribution is devoid of N_2, the process air flow to the secondary reformer needs to be proportionately increased for eventually bringing the H_2/N_2 ratio in the make-up syngas to the desired level of ~3.0. Accordingly, the secondary reformer exit temperature increases due to more process air flow, which in turn is good for achieving a higher mixed temperature at the bottom of the post-reformer for better temperature approach and feed conversion.

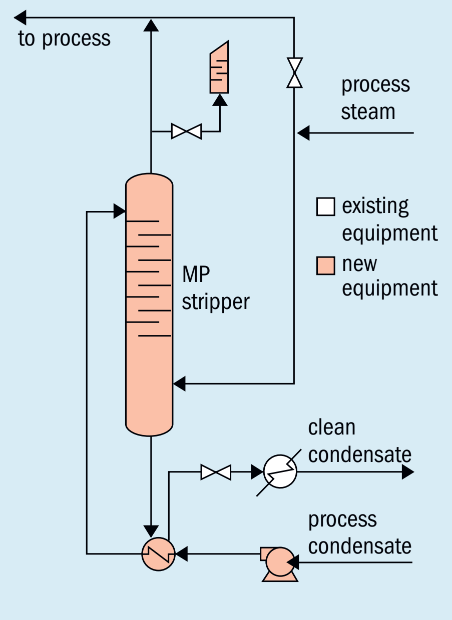
Casale ammonia plant modernisation

With a large number of revamping projects successfully carried out over the last decades, Casale is the world leader in ammonia plant revamping. Most projects have included key modifications to reformers, machinery, ammonia converters and other equipment. Casale's unique ammonia plant revamp strategy has always focused on the development and application of new, advanced technologies to obtain the best possible improvements in plant performance at the lowest cost. Performance improvement normally comprises an increase in capacity, a reduction in energy consumption, or a combination of the two. But it can also be a reduction of pollutant emissions or the stabilisation of production in the hottest season.

Casale's approach for ammonia plant revamping depends on the final target. Normally, if the aim is a moderate capacity increase or energy saving, the process line is not modified and the focus is on each plant section, to find bottlenecks and increase the efficiency through advanced technologies. On the contrary, in the case of more ambitious targets, such as large capacity increase, the process line can be drastically transformed. There are also other types of revamping projects which require specific strategies, as described in the following paragraphs.

The focus here will be on Casale's revamping options for reducing emissions from ammonia plants.

Fig. 13: **MP stripper process**



Source: Casale

Typically, in an ammonia plant there are two sources of gaseous emissions that can be controlled or reduced: process condensate stripper overhead and NOx from primary reformer. Several revamp options are possible.

Process condensate stripping improvement

With a medium pressure stripper process, a fraction of the medium pressure process steam is used to strip the process condensate. A typical process flow diagram is shown in Fig. 13. In this case the existing stripping section can be completely dismantled.

New items include the stripping columns, condensate feed-effluent exchanger and condensate pump(s).

Advantages of this option are:

- zero emissions: stripped stream is recycled into the process;
- LP steam saving.

Disadvantages of this option are:

- higher cost (completely new MP section);
- process steam temperature decreased by about 30°C.

This type of intervention has been implemented in 2012 in a plant in the US.

LP stripper with liquid recycle into the process and gas to the primary reformer

With this option (Fig. 14) the existing low pressure stripper is maintained. A new overhead cooler using cooling water is installed to condense stripper effluents at about 60°C. A portion of the condensate, concentrated in contaminants, is injected into the process upstream of the mixed feed coil. Non condensable gases, minimised thanks to a lower condensing temperature, can be either used as fuel after compression through an ejector with natural gas or injected in the tunnels of the primary reformer (acting as NSCR). A condensate feed-effluent exchanger can be optionally installed to reduce the steam requirement.

New items include: the overhead condenser, recycle pump, process injection pump and ejector.

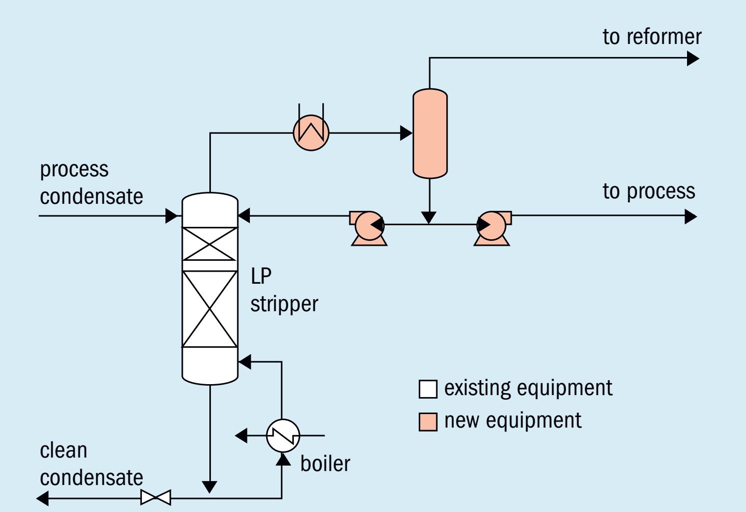
Advantages of this option are:

- existing stripping section is maintained;
- no valuable utilities are used (e.g. MP/HP steam)

Disadvantages of this option are:

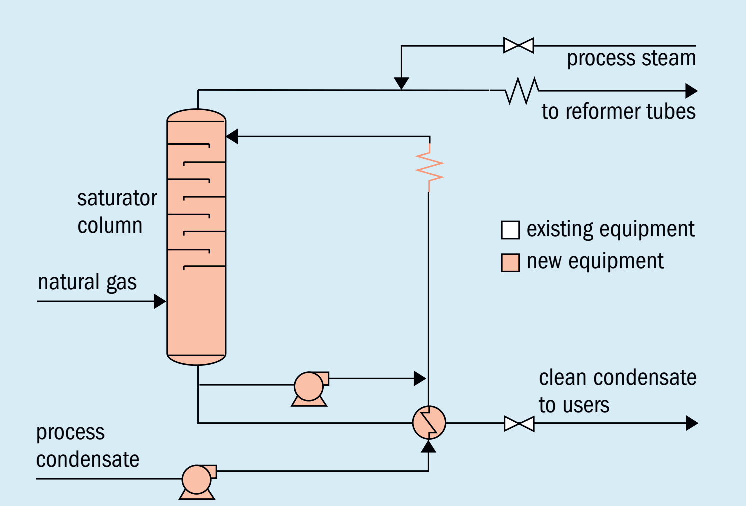
- LP consumption increase by about 30%.
- Part of the contaminants are not recycled into the process but used as fuel or flared.

Fig. 14: **LP stripper with liquid recycle**



Source: Casale

Fig. 15: **Natural gas saturator**



Source: Casale

A similar system has been successfully installed by Casale in 2010 in an ammonia plant in Bulgaria.

Natural gas saturator

Through the addition of this new section (Fig. 15) it is possible to achieve both cleaning of the process condensate (final ammonia concentration below 5 ppm wt) and recovery of about 25% of the total process steam from the condensate (energy saving).

After desulphurisation, natural gas feed enters at the bottom of the new saturator column and is used to strip process condensate in lieu of the existing LP stripper.

The new gas saturator/process stripper is a tray type column running with forced circulation of condensate. Condensate collected in front-end separators is pumped and exchanges heat with stripped condensate and finally heated in new convection section coils together with circulating condensate.

New items include: stripping columns, the condensate feed-effluent exchanger, condensate pump(s) and reformer coil(s). Advantages of this option are:

- zero emissions: stripped stream is recycled into the process;
- LP and MP steam saving

Disadvantages of this option are:

- higher cost (completely new MP section);
- need for reformer modification.

A similar unit has been implemented in the revamping of a plant in Romania.

NOx control

There are two main strategies that can be adopted in an ammonia plant to reach the required pollutant emission level: combustion modification and post treatment.

Combustion modification

By reducing the amount of oxygen that is available to react with the nitrogen, NOx is reduced. This is achieved through the use of oxygen trim controls. To minimise the O_2 levels, a combustion analyser is used to adjust the fuel and air mixture. This method can reduce the level of NOx produced by up to 10%, but it may significantly increase the emissions of carbon monoxide (CO).

Flue gas recirculation (FGR) is a method of NOx reduction that lowers the temperature of the flame, and therefore reduces thermal NOx. A portion of the exhaust gas is re-circulated into the combustion process, cooling the area. This process may be either external or induced, depending on the method used to move the exhaust gas.

Staged combustion is an effective technique for lowering NOx. Staging means that some of the fuel or oxidiser, or both, is added downstream of the main combustion zone. While the overall stoichiometry can be the same as in conventional burners, the combustion process is staged over some distance while heat is simultaneously being released from the flame.

Staging can only be effectuated using particular burner designs, best known as low NOx or ultra low NOx burners, which are usually characterised by longer flames, which help the reduction of NOx emissions. These longer flames in fact typically have a lower peak flame temperature and more uniform heat flux distribution than non-staged flames. The temperature is decreased due to the extended flame and surface area, and the lower temperature reduces the amount of thermal NOx. CO levels may be elevated when using low NOx burners. It is important to monitor CO and true NOx levels to better control low NOx burners.

Post-treatment

Post-treatment acts directly on the flue gas stream removing NOx from the exhaust gas after they have been formed in the combustion chamber. One of the advantages of post-treatment is that multiple exhaust streams can be treated simultaneously, thus achieving economies of scale.

The selective catalytic reduction (SCR) of NOx is a catalyst-based technology for the reduction of NOx concentration into gaseous streams. It is an efficient, versatile and widespread solution available today. The SCR process is based on the selective catalytic reduction of nitrogen oxides with ammonia. The reduction of the nitrogen oxides takes place by injecting an ammonia source as reducing agent into the flue gas stream. Subsequently, the mixture of ammonia and exhaust gas passes through the catalyst. The reductant then reacts with the NOx in the emissions and forms H_2O and N_2 (ambient nitrogen). This process may take place at anywhere between 260°C and 650°C depending on the catalyst used. SCR may reduce NOx emissions by up to 90%.

Selective non-catalytic reduction (SNCR) is a process that involves a reductant, usually urea or ammonia, being added to the top of the furnace and going through a very long reaction at approximately 760-870°C. This method is more difficult to apply to boilers due to the specific temperature needs, but it can reduce NOx emissions by 70%.

Toposoe revamp options

Topsoe is a well-known catalyst and process technology supplier, who specialises in providing complete revamp solutions to help customers improve their existing plant efficiency to match modern high-efficiency demands, boost capacity, reduce emissions, health and safety risks, optimise plant operation, train operators and improve plant reliability.

Topsoe's toolbox for revamping the reforming section includes: Topsoe's oxygen fired SynCOR™ technology, which can operate at low steam to carbon ratios; the prereformer that can handle feedstock changes as well as heavy and difficult feedstocks; and heat exchange reformer (HTER) that can be installed to increase the reforming capacity (typically by 20-25%) of existing units.

Steam balance optimisation

In almost all ammonia plants excess steam export from the plant is unavoidable and, in many cases, the auxiliary boiler is sized for start-up and upset conditions, but operates at reduced or even minimum load under normal operating conditions. This can result in a plant operating with excess steam that is vented to atmosphere, wasting valuable energy. Haldor Topsoe's heat exchange reforming can be introduced into the ammonia plant by installing the HTER after the secondary reformer, operating in parallel to the existing primary reformer.

Besides capacity increase, the HTER can be utilised to optimise the steam balance of the whole complex. In the block flow diagram in Fig. 16 natural gas is used for the feed and fuel for the ammonia plant and as fuel for the auxiliary boiler. By installing the HTER, excess steam export can be eliminated and savings can be made in natural gas fuel consumption. Increasing the plant efficiency of the reforming section will also be of benefit when revamping the rotating equipment in the plant as less steam will be consumed in the steam turbines.

Table 1 shows the impact on fuel costs in a case study for a 2,200 t/d ammonia plant. The base case is similar to the block diagram in Fig. 16 where the ammonia process plant and auxiliary boiler is fired with natural gas. The feed and fuel cost was calculated to be around $96 million/year. This was compared to a plant where an HTER had been introduced, thereby saving approx. $3 million/year in fuel costs in the process plant. If in addition to installing the HTER the fuel in the auxiliary boiler is replaced with a cheaper alternative fuel (assumption: costing half the price of natural gas), the fuel and feed gas costs can be reduced even further to around $89 million/year.

Table 1: **Components modelled in simulation**

Process layout	Base case	With HTER and same auxiliary boiler	With HTER and new auxiliary boiler
NG feed, Gcal/h	487	487	487
NG fuel, Gcal/h	173	138	138
Auxiliary boiler fuel, Gcal/h	57	72	72
Feed + fuel cost, million $/year	96.4	93.7	88.8
Excess steam, t/h	30	0	0

Assumptions: Gas price = $16/Gcal, alternative fuel cost = $8/Gcal, operational hours = 8,400/year
Source: Topsoe

Energy reduction with SK-501 Flex™

Topsoe recently introduced a new high temperature shift (HTS) catalyst to the market, SK-501 Flex™, which has opened up possibilities for operating the front end of the ammonia plant with completely different conditions than was previously possible. The new catalyst provides greater operational flexibility because it permits operation at lower S/C ratios to provide energy savings or increase plant capacity, without Fischer-Tropsch byproduct formation. In addition, the new HTS catalyst eliminates the use of chromium (VI) which improves the overall safety for operation personnel and is more environmentally friendly.

In the case study shown in Table 2, the base case is a conventional ammonia plant with a S/C ratio of 2.8 which is compared to the same plant except the existing HTS catalyst has been replaced with the new SK-501 Flex™ HTS catalyst and the S/C ratio has been reduced to 2.5. As a result of making these changes the feed consumption increases by 2% due to the equilibrium conditions in the reformer and the lower S/C ratio, but the fuel consumption is reduced by 7%. Overall, the savings of natural gas feed + fuel as a result of installing the new catalyst is 1%. Other benefits include a lower pressure drop in the front-end of the plant due to the reduced flow. Steam generation will be slightly affected but will be compensated for by savings in compression energy due to the lower pressure drop in the front of the plant. The payback time for this catalyst replacement was estimated to be less than one year.

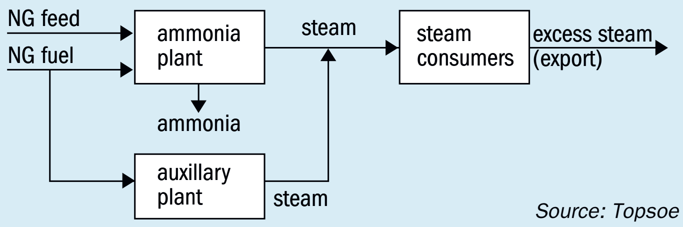
Boosting capacity of ammonia synthesis loop

Many plants face limitations and bottlenecks in the ammonia synthesis loop. One way of increasing the capacity of the back end of the plant is to install a make-up gas converter, an add-on unit that can be easily implemented in existing plants (see Fig. 17). It provides savings in circulation energy and does not require any changes to the main synthesis loop.

Case study: Boosting ammonia capacity by 35%

In this case study an ammonia producer in the Caribbean region with a 1,360 t/d ammonia plant wanted to boost the plant

Fig. 16: **Steam generation in an ammonia plant**



Source: Topsoe

Table 2: **Benefit of SK-501 Flex™ in existing plant**

S/C	2.8	2.5	Difference
Feed	100%	102%	+2%
Fuel	100%	93%	-7%
Feed + fuel	100%	99%	-1%
Production	100%	100%	0

Source: Topsoe

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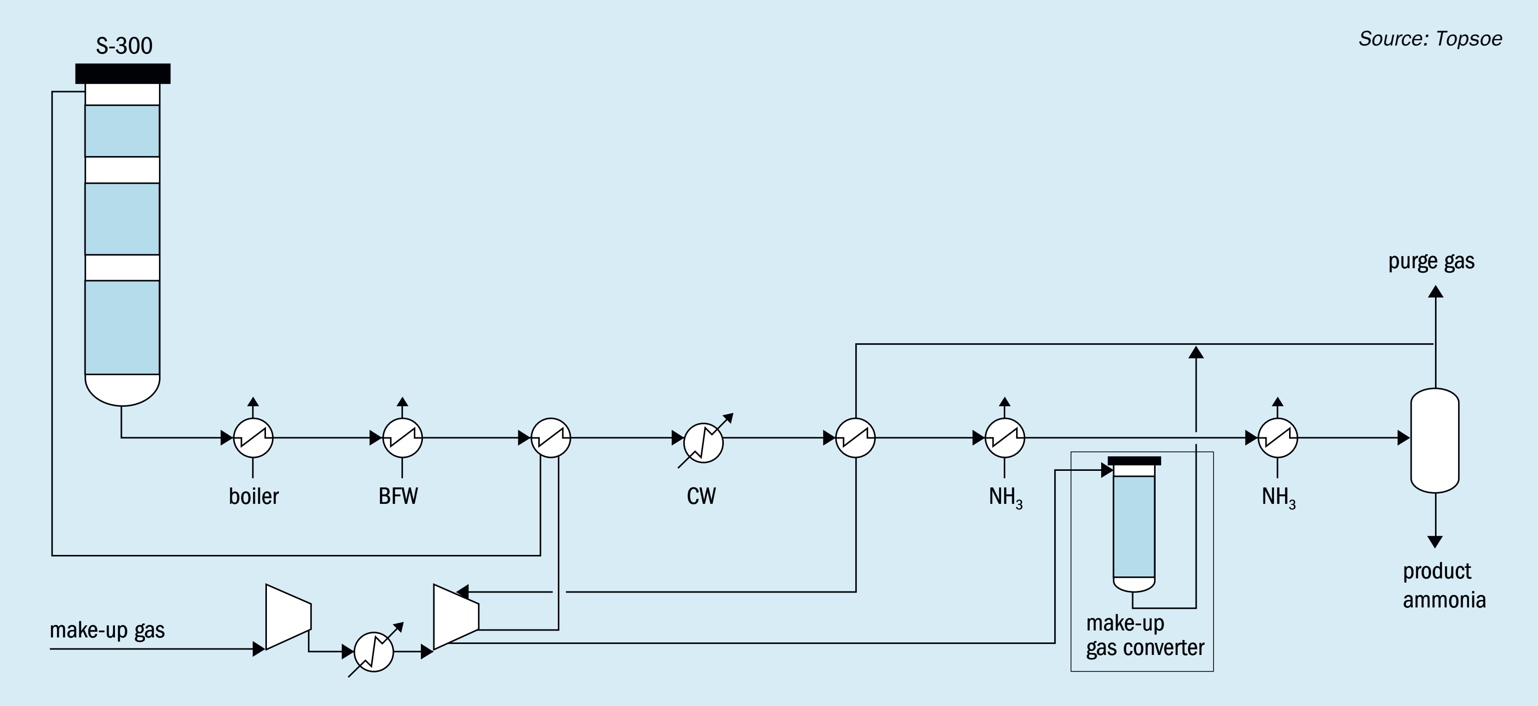
Fig. 17: **Topsoe synthesis loop with make-up gas converter**



capacity by as much as 35%. This was made possible by introducing the Topsoe make-up gas converter. The converter was successfully put into operation in 2015 and is operating well. A key feature of this revamp was that the loop pressure was reduced by more than 25 kg/cm² while at the same time achieving a 35% capacity increase. The reduction in loop pressure and increase of capacity is achieved with only 20% increase in catalyst volume, and minor modifications in the main loop. In order to make enough syngas to produce 35% more ammonia some changes were also required to the front end. The make-up gas converter increased the ammonia production by close to 500 t/d and the payback time for the make-up gas converter unit was less than one year.

Table 3: **IMAP Ammonia+™**

Process layout	Base case	Co-production IMAP Ammonia+™
No. of reforming units	1	1
Synthesis loop design	ammonia loop	once-through methanol and ammonia loop
No. of syngas compressors	1	1
Plant capacity (NH_3/MeOH), t/d	1,500	1,300/200
Investment cost, $	base	31 million

Source: Topsoe

Product diversification via co-production

The price of ammonia and methanol has fluctuated widely over the years. Having the ability to co-produce methanol in an ammonia plant provides flexibility to maximise profit as market conditions change and prices fluctuate. Local market demands e.g close proximity to methanol consumers such as UFC-85 plants, may also make it attractive to produce methanol in an ammonia plant.

Topsoe IMAP™ co-production technology

Toposoe's IMAP™ (integrated methanol and ammonia process) technology covers different variants of the co-production scheme but the focus here will be on the special scheme to revamp an existing ammonia plant to add the flexibility to produce relatively small amounts of methanol (typically between 15 and 35% of the original nameplate capacity of the ammonia plant). This can be done in a fairly simple way and at a very low investment cost compared to building a similar size grassroots methanol plant. The majority of the process units such as the reforming section, synthesis gas compressor and utilities can be shared, the air separation unit normally used in methanol plants is no longer required and the plant can have common operators etc.

Table 3, illustrates this further where the base case is an existing 1,500 t/d ammonia plant that is converted into an IMAP plant co-producing methanol. In this case it is assumed that 200 t/d methanol will be produced. The existing reforming units and syngas compressor are used, the only additions are a new once-through methanol synthesis unit along with the distillation and a high pressure methanator. The investment cost for the 200 t/d methanol plant in this case is $31 million which is much lower than the cost for constructing a new separate 200 t/d methanol unit.

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Methanol converters under continual development

In a competitive market, methanol producers need access to both leading edge production techniques, and technology solutions. In this article we focus on recent improvements and ongoing developments to enhance the efficiency and performance of steam raising methanol converters.

Methanol production methods have evolved considerably over many decades, and the need for efficient and cost-effective approaches to its production remains important for the chemical industry. For large scale plants in particular, technology that minimises cost and maximises efficiency and yield are especially important.

The Lurgi WCR

Air Liquide Engineering & Construction offers optimised Lurgi Methanol processes for a wide range of set-ups and conditions. These range from a natural gas-based state-of-the-art 5,000 t/d Lurgi MegaMethanol™ process, with the efficient and cost-effective use of combined reforming and combined gas cooled/water cooled reactors, to designs tailored for high CO syngas, oxygen-based reforming setups and feed gases with high CO_2 content.

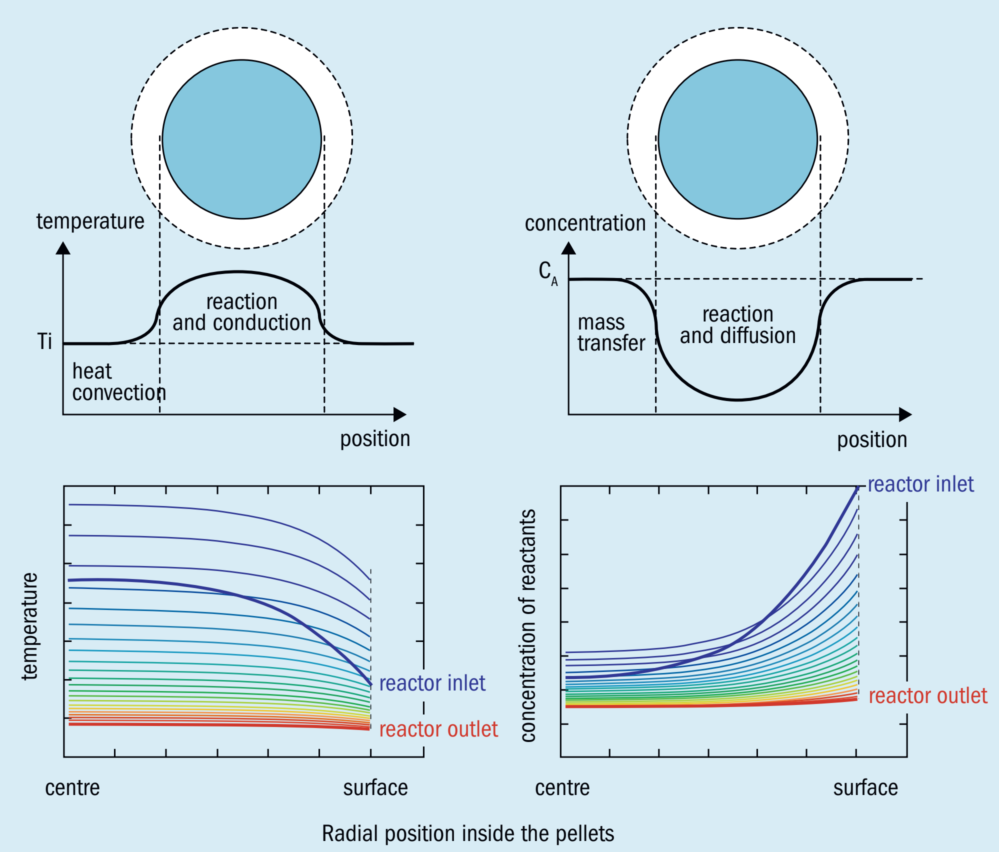
Since 1969, Air Liquide Engineering & Construction has licensed approximately 60 Lurgi methanol plants, delivering more than 47 million tonnes per year of methanol production. The design and development of Air Liquide Engineering & Construction's methanol plants is closely tied to Clariant's catalyst production and development.

At the heart of the Lurgi Methanol process lies the water cooled reactor (WCR). In 1970, this technology had a capacity of less than 500 t/d. Now, WCR throughput can exceed 3,000 t/d in a single reactor, and deliver 5,000 t/d or more in combination with the gas cooled reactor in world-scale plants.

The Lurgi WCR is a well-established, high-performance, high yield methanol reactor that is extremely flexible. It offers a range of benefits:

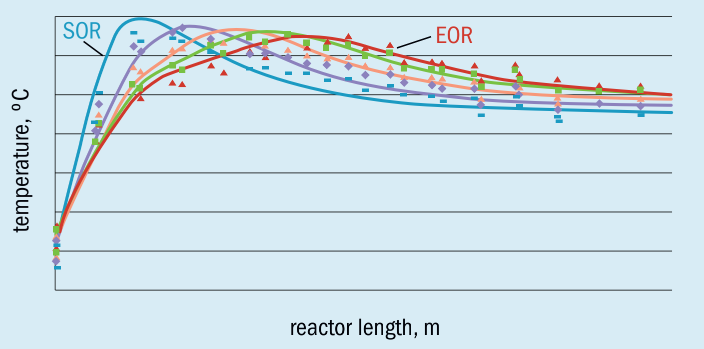
- With a very high heat transfer per unit volume, the WCR can accommodate highly reactive gases with high CO content with the consequence that the recycle ratio can be reduced to a minimum.
- Air Liquide Engineering & Construction designs its methanol synthesis loops with minimised flow rates, which in turn leads to reduced duty requirements, minimised opex and catalyst volumes, and corresponding capex savings on catalyst, equipment and piping.
- The cooling surface is uniformly distributed around the catalyst, ensuring quasi-isothermal operation and reliable

Fig. 1: **Temperature and reactant concentration profiles in the catalyst pellets**



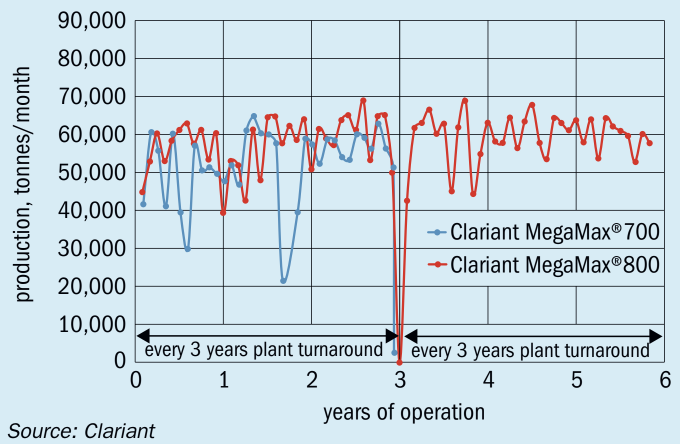
Source: Air Liquide

Fig. 2: **Evolution of temperature profile in the WCR between start-of-run (SOR) and end-of-run (EOR) (data points from operation and model in full curves)**



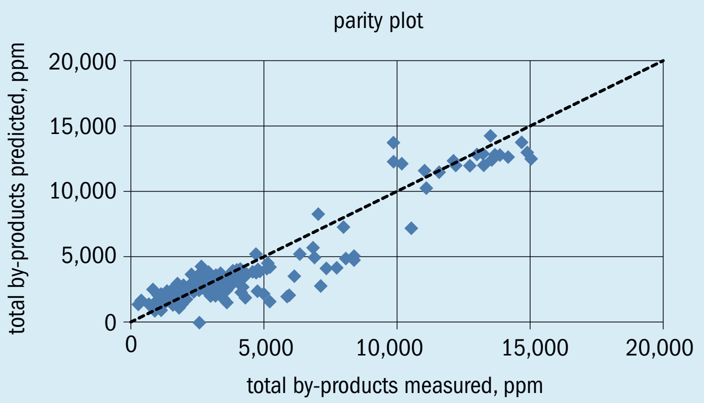
Source: Air Liquide

Fig. 3: **Operating data from a Lurgi methanol plant based on a WCR with 2,000 t/d nameplate capacity**



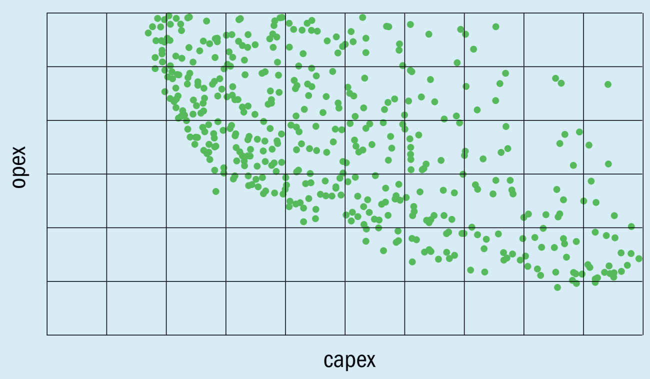
Source: Clariant

Fig. 4: **By-product formation model, developed using more than 500 data points across a range of process setups and fed gases**



Source: Air Liquide

Fig. 5: **Rapid evaluation of single-stage WCR concepts to select optimal opex and capex for a small-scale MeOH unit (depending on market conditions and customer requirements)**



Source: Air Liquide

temperature control. This in turn minimises the risk of hot spots and maximises catalyst life.

- In an operator comparison of two methanol plants[1], the inherently stable temperature control of the Lurgi WCR was found to result in simpler and easier operation of the reactor.
- The superior heat removal capability provides flexibility in the cooling temperature, which can be set at high levels to produce valuable high-pressure steam. Conversely, when the customer cannot valorise high pressure steam, the cooling temperature can be decreased to reduce the stress on the catalyst and maximise catalyst life time.
- The combined development of Clariant's catalysts and Air Liquide Engineering & Construction's WCR set-up ensures maximum synergistic effects for both the WCR and Clariant's high-performance MegaMax catalyst series.

Air Liquide Engineering & Construction and Clariant have developed and validated advanced methanol synthesis models. These enable the best use of the WCR itself and optimise the integration of the reactor in the synthesis loop. This enables the highest yields to be extracted and excellent performance from the latest generation of WCRs.

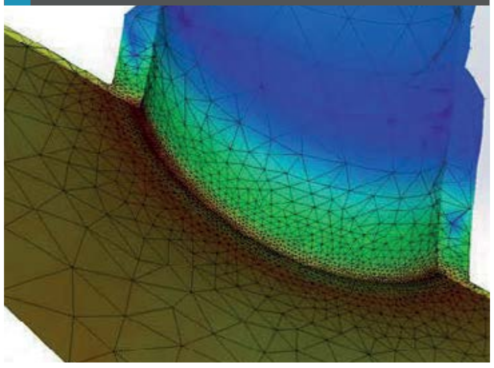
In a joint effort, Air Liquide and Clariant developed detailed heterogeneous kinetic models, in which the reaction is simulated not only in the reactor but also inside the catalyst pellet (Fig. 1). This allows the capabilities of the latest Clariant catalyst generations to be better leveraged in improved WCR designs.

Building on the new kinetic model, with years of operational data from Air Liquide Engineering & Construction's WCRs, a predictive catalyst de-activation model was developed for the WCR, which allows better forecasts and extends catalyst lifetimes (Figs 2 and 3).

Based on lab and commercial plant data a by-product formation model was developed to simulate the formation of individual components (such as ketones and higher alcohols) across a range of process setups and feed gases (Fig. 4). The WCR can be designed to minimise the production of by-products that are difficult to separate from methanol.

With its deep understanding of methanol kinetics, catalyst properties and by-product formation afforded by its recently developed advanced methanol synthesis models, together with 50 years of experience in designing steam raising methanol converters, Air Liquide Engineering & Construction can rapidly design an optimal WCR and integrate it into an optimised methanol plant. In a recent case study for a small capacity methanol unit with a single WCR, for example, Air Liquide Engineering & Construction was able to screen more than 10,000 cases and settle rapidly on the optimal solution (see Fig. 5).

Fig. 6: **A finite element analysis of a part of the WCR structure**



SOURCE: AIR LIQUIDE

Fig. 7: **Schematic of the Lurgi WCR**

Source: Air Liquide

PHOTO: AIR LIQUIDE

Fig. 8: Air Liquide's Lurgi WCR

The result is an updated, leading-edge WCR that can be easily tailored to specific project needs. The new Lurgi WCR is designed to deliver the highest performance, methanol yields and reliability at the lowest catalyst volumes. The WCR is integrated in an optimised methanol synthesis loop, with the lowest recycle ratios and production cost. The formation of by-products in the WCR is clearly understood, and the WCR is designed to minimise levels of specific by-products such as paraffin waxes, thereby reducing the duty on the downstream distillation process. Feed gases with substantially more CO_2 than CO can generate less heat and provide stringent kinetic and equilibrium conversion constraints. Following its most recent developments, Air Liquide Engineering & Construction can optimise the WCR design for such gases and supply solutions for the conversion of CO_2 to methanol.

Air Liquide has also invested substantial effort into improving the mechanical design of the WCR itself (see Figs 6-8). Based on detailed understanding of the temperatures and flows in the WCR, Air Liquide Engineering & Construction has optimised the mechanical design in-house to deliver a reactor with the lowest weight and cost. Air Liquide Engineering & Construction's involvement in detailed engineering and equipment supply for methanol plants ensures that the feedback from manufacturing is included in the reactor design. Improvements in materials available in the market are also considered to ensure the most cost-effective design and to accelerate reactor delivery times.

Since the fourth quarter of 2017, Air Liquide Engineering & Construction has started the execution of three new projects involving methanol plants with WCRs only.

Casale's Isothermal Methanol Converter (IMC)

Over the past decade, China has become a major producer of methanol from coal. At the same time, the general trend in the methanol market as a whole, which is dominated by natural gas-based production, has been towards world-scale methanol plants of capacities that are beyond the capacity limits of traditional plant schemes and, therefore, require innovative process developments.

Casale has utilised its considerable experience in designing traditional natural gas-based methanol plants, together with its solid process knowledge and robust engineering capabilities to develop solutions to meet the special challenges raised by world scale methanol and coal-based plants. The main outcome of this multidisciplinary work is the IMC (Isothermal Methanol Converter) technology. More than one IMC layout has been developed in response to market trends and specific client needs. The IMC technology portfolio includes gas-gas and steam-raising variants, and for both types axial and axial-radial catalyst bed configurations are available. The IMC converter has been successfully applied in both natural gas based plants and coal based plants, with capacities ranging from 300 t/d to 7,000 t/d. Its flexible design makes it possible to reach very high production rates in single vessel units, up to 10,000 t/d, and it is well suited to the very demanding conditions of coal based plants located in China.

IMC steam-raising converter

The make-up gas of coal-based methanol plants normally has a low inert content and is rich in carbon making it possible to achieve high production rates with low recycle ratios and low catalyst volumes. In fact, as the gas is very reactive, it can easily create problems with catalyst overheating and hot spots in the converter.

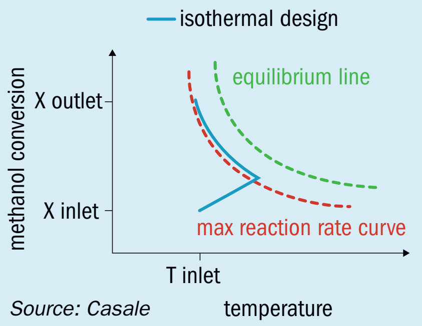
In the case of gasification plants, the amount of carbon monoxide and carbon dioxide present in the synthesis gas is very significant. High concentrations of carbon oxides imply that the converter must be provided with a heat sink to control the reaction temperature. This heat sink is normally boiling water generating medium-pressure steam at around 25-30 bar. This pressure is selected because its corresponding temperature level matches the operating temperature in the catalyst bed well, and the steam produced can be utilised in the plant in turbines. Steam production usually ranges from 1.1 to 1.3 t/t methanol, depending on the temperature of the boiler feed water.

The Casale converter combines the functions of a reactor with those of a plate heat exchanger and is characterised by the fact that the catalyst bed is cooled by plates immersed in the catalyst, containing boiling water as cooling fluid (Fig. 9). The feed water enters through a distributor at the bottom of the plates. It then flows inside the plates from the bottom to the top. The water/steam mixture is collected at the top of the converter.

Fig. 9: **IMC reactor with heat exchange plates vertically immersed in the catalyst mass**

Source: Casale

Fig. 10: **Isothermal converter conversion profile vs temperature in catalyst mass**



Source: Casale

Fig. 11: **3D model for IMC reactor**

Source: Casale

In both coal-based and combined reforming methanol plants, the synthesis gas contains significant concentrations of carbon monoxide and carbon dioxide. In coal-based plants these may be as high as 15 vol-% CO and 5 vol-% CO_2 at the reactor inlet. With such high concentrations of carbon oxides and with the low inert gas content, the heat exchange rate must be carefully controlled to obtain the best possible reaction conditions through the catalyst bed (Fig. 10).

This necessitates careful design of the reactor internals to keep the temperature profile inside the catalyst under control and, above all, to minimise the temperature spread (the difference between the highest temperature in the hottest part of the catalyst and the gas temperature at the closest cooling plate), so as to reduce by product formation as much as possible.

Part of the steam raised in the IMC is used, after superheating, to power the steam turbine drive of the synthesis gas compressor; the remainder is fed into the plant's steam system for use in the methanol distillation section and other applications.

The steam-raising reactor is also applicable to world-scale methanol plants, based on combined reforming of natural gas; and the IMC used in the Kaveh world-scale methanol project in Iran combines a steam-raising bed and a gas-cooled bed in a single pressure vessel.

The steam-raising converter is the most innovative, optimised and adaptable reactor in Casale's methanol converter portfolio (Fig. 11).

The converter is provided with circulating pumps to drive the BFW through the plates and with a steam drum to separate the steam from liquid water.

The converter includes only one isothermal bed, traversed by the process gas in an axial or axial-radial path. All the reaction gas passes into the reactor through the top inlet connection. The gas enters the catalyst zone at about 210-215°C. The catalyst temperature is kept under control by means of counter-current or cross-flow heat exchange with the BFW in the plates, which partly vaporises as it flows upwards. The reacted gas exits the converter through the bottom nozzles at about 225-250°C, depending on the age of the catalyst, the converter layout and the pressure of the generated steam. The BFW-steam mixture exits from nozzles placed on the converter top.

Reactor control is designed to allow stable and efficient operation in all possible operating conditions. Two main parameters are controlled in particular.

- the inlet temperature to the catalyst bed is automatically controlled by an external by-pass of the converter feed-effluent gas-gas exchanger
- the BFW boiling temperature is controlled by setting the pressure of the steam drum.

Casale has expended a great deal of effort on this target, involving process, mechanical, fluid dynamics, materials, and corrosion specialists in optimising the design of the reactor internals.

The most significant design features of the IMC are:

- heat removal inside the catalyst is performed by heat exchange plates;
- the heat exchange elements are specially designed for this particular service and the critical environment in which they have to operate (catalyst loading and unloading, thermal expansion, mechanical stress, corrosion stress);
- all of the internal parts are designed to allow them to be replaced easily in future, without touching the pressure vessel;
- easy access is provided to the catalyst bed and to all critical points;
- the bed in each vessel is filled with one continuous layer of catalyst;
- catalyst loading and unloading procedures are familiar and easy.

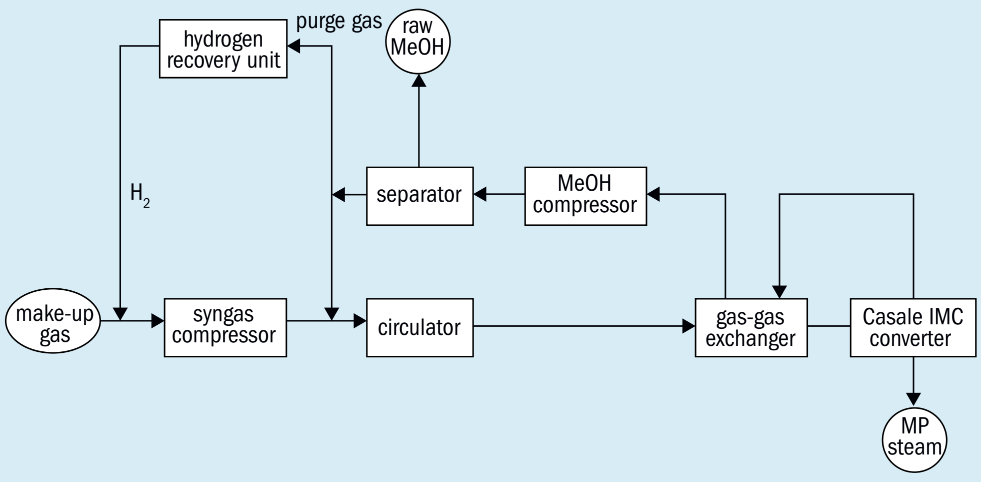
Depending on what best fits the requirements of the synthesis loop optimisation, the catalyst bed of the IMC converter can be designed for an axial or axial-radial gas path. Where it can be used, the axial-radial approach is preferred as it avoids the extra capital cost of installing multiple axial reactors.

The main characteristics of the axial catalyst bed are:

- pressure drop is wholly due to the resistance to flow of the catalyst. It rises as the catalyst ages;
- the maximum allowable pressure drop across the catalyst bed is 3 bar, so the catalyst bed height is automatically limited;
- the entire catalyst charge is in the gas path and therefore utilised.

The main characteristics of the axial-radial catalyst bed are:

Fig. 12: **Synthesis loop block flow diagram**



Source: Casale

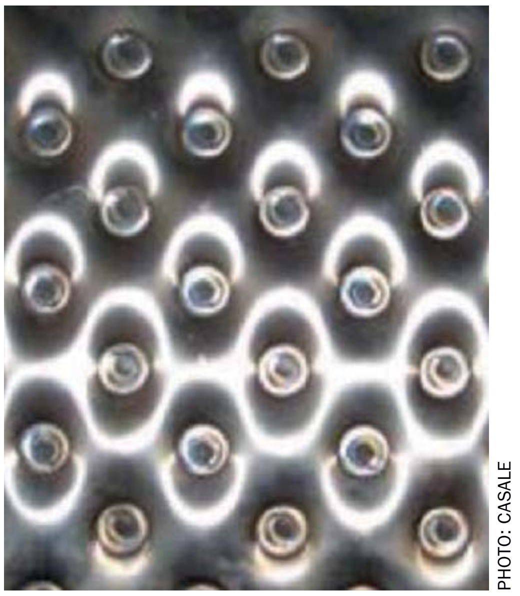


Fig. 13: Dimple plate

- pressure drop is mainly due to the perforated wall at the catalyst bed outlet and remains essentially constant through the life of the catalyst;
- the catalyst bed height has no effect on pressure drop, so there is no limit on bed height.
- the entire catalyst charge is in the gas path and therefore utilised.

Casale has successfully used axial-flow catalyst beds in coal-based methanol plants of up to 2,000 t/d capacity, reaching an agreeable compromise between pressure drop and vessel size.

For higher capacities from 2,500 t/d up to 10,000 t/d, a single, plate-cooled reactor with axial-radial layout is typically used. This minimises pressure drop but also allows a larger quantity of catalyst to be installed without raising the catalyst bed height above the limit set by the catalyst manufacturer. As long as the converter does not exceed transportation size limits, the main advantage of Casale's axial radial technology is the possibility of installing one single reactor instead of more than one axial converters in parallel.

The IMC converter allows the methanol synthesis loop to be simplified (see Fig. 12). It consists of a synthesis converter, a gas-gas heat exchanger which preheats the process gas entering the converter, condensers (air cooler and water cooler) to cool down the gas to the methanol condensation temperature, a separator to separate the liquid raw methanol from the unreacted gas, a purge recovery unit to recover hydrogen from the purge gas so as to correct the SN, and the synthesis gas circulator and make-up gas compressor.

With the IMC converter the synthesis loop pressure drop, circulation and exchanger duties are all minimised, as is the energy consumption of both the circulator and the cooling section. Consequently specific equipment sizes in the loop are limited, enabling very large capacities in a single train.

Advanced mechanical design

Casale's continuous development programme and experience accumulated over years of operation of its IMC plate-cooled converters has led to several mechanical improvements to the IMC.

Exchanger plates

The exchanger plates are responsible for cooling down the process gas and keeping the temperature of the catalyst within the required range.

The dimpled design (Fig. 13), though common in many low pressure applications, has been optimised by Casale, keeping the manufacturing sequence of inflating the plate sections after the two sheets have been welded together.

Compared to standard configurations, the mechanical characteristics, design pressure and plate strength of the Casale plate design are considerably increased and BFW distribution inside the exchanger plates is optimised thanks to the welding pattern.

The material of construction has also been carefully selected with one having superior mechanical characteristics, allowing the thickness and weight of the exchanger plates to be reduced. The thinner sheets are less susceptible to welding stresses and minor deformation after laser welding. The selected material is also very resistant to possible corrosion from BFW contaminants.

Before going into production of the dimple plates, Casale conducted detailed investigations and testing, backed up by laboratory analysis, in collaboration with RTM Breda on exchanger plates from each supplier. Construction procedures have been optimised, welding quality improved, and overall tolerances reduced.

Internals design and tests

In the last years, Casale has continued working on IMC internals design with the aim of upgrading the converter:

Internal piping has been optimised with the help of finite element analysis to design a simple elastic structure able to support the internals and absorb deformation due to thermal expansion.

Tolerances on the exchanger plates were reduced, making it possible to reduce the gaps between them, which maximised the IMC exchange surface and the reactor performances as well.

The design of the internals has been simplified to facilitate installation, minimise field welding. and shorten the installation schedule.

Connections to the plate bundles (exchanger plate assemblies) have been optimised to provide maximum flexibility during operation to avoid stress accumulation brought on by thermal expansion of the internals and the catalyst as the reactor is brought up to the operating temperature, which could adversely affect reliability.

According to client needs, Casale always verifies the status of its internals after years of operation, performing laboratory analysis whenever possible, and studies new ways to upgrade existing and new plant.

Chinese coal-based methanol plant experience

Currently, 12 Casale synthesis loops with IMC steam-raising converters are running in China. On the basis of capex-opex parametric analysis and, especially, on operating experience acquired in these Chinese projects, Casale has selected the best compromise between the capital cost of the synthesis loop and that of the distillation section. Casale has identified a design for the IMC and synthesis loop that minimises equipment size and running cost but, at the same time, reduces the concentration of higher alcohols in crude methanol and, thus, the column dimensions and capital costs in the distillation section. The peak temperature in the catalyst and, consequently, the formation of unwanted by-products can, of course, be reduced by increasing the recycle ratio and specific heat exchange surface in the IMC and increasing the CO_2 content in the make-up gas, but the additional capital and operating costs that these measures entail in the synthesis loop have to be compared carefully with the corresponding savings that are likely to result in the distillation section.

Some operating data from Chinese plants are given below.

Xinneng Energy Ltd – Xin'ao Group

The Xinneng Energy methanol plant started up in July 2009. The design capacity of the methanol loop is 2,035 t/d of crude methanol, using synthesis gas from coal gasification. Peak capacities above 110% of nominal load were easily attained immediately after start-up. A successful performance test was held during 2009. The client conducted an additional internal performance test at 98.5% load (2,005 t/d) in March 2010; the production rate during the test run was limited by a lack of synthesis gas. After start-up following a routine change of catalyst in 2012 a stable production rate of 110% of nominal load was reached. By-products in crude methanol are below the guaranteed value.

At 100% load the saturated steam production was in line with the design value and the loop operating pressure was more than 10 bar below design value, showing that converter and catalyst were working very efficiently. During catalyst aging synthesis loop performance has not changed significantly. At the design loop operating pressure 10% of extra capacity has been reached.

Xuzhou Coal Mining Group Corporation

Casale designed the methanol synthesis loop section and distillation section for Xuzhou Coal Mining Group Corporation's methanol plant which has a design capacity of 2,000 t/d of refined methanol.

The plant has been running since starting up in May 2013. A performance test at 100% load was signed in June 2013, just after catalyst reduction. A higher quantity of steam is generated in the IMC reactor at 100% load. Loop operating pressure is about 5 bar below design value, demonstrating that converter and catalyst are working very efficiently. With the help of Casale technicians, after the performance test the synthesis loop was tested at higher capacity and smoothly reached 113% of load.

Jinmei reactor

Casale designed a 4,000 t/d methanol synthesis loop for Shanxi Jinmei Huayu Coal Chemical Industry Co., Ltd. This large coal-based plant is equipped with only one steam-raising IMC reactor and will be one of the largest coal-based plants featuring a single converter. Thanks to the use of the IMC design the plant will have a high efficiency with low circulating power, simple operation and maintenance. Start-up is expected during 2018.

The Jinmei reactor is a low-alloy vessel of 4.2 m diameter designed for 90 bar(g) at 340°C. The axial-radial design was selected to limit pressure drop without recourse to installing multiple converters: inner and outer perforated walls contain the catalyst and are designed to equally distribute the synthesis gas over the bed height. Synthesis gas passes through the bed radially and exits from the central pipe.

The plate exchanger maintains control of the temperature inside the bed. Exchanger plates were arranged in a radial configuration in two concentric circles to ensure the necessary cooling for the reactants. Boiler feed water is supplied to each exchanger plate by a separate inlet collector and leaves through a common outlet collector together with an internal piping net. The Internal piping layout is studied and optimised to absorb differential thermal expansion between the internals and the vessel, in both axial and radial directions.

Johnson Matthey's new RSRC distributor design

Johnson Matthey offers a variety of converter designs for methanol synthesis including: the tube cooled converter, radial flow steam raising converter and axial flow steam raising converter. Recent developments have led to an improved design of the central distributor in the radial flow steam raising converter (RSRC).

The radial flow steam raising converter is designed with catalyst on the outside of the tubes and steam inside the tubes. In Johnson Matthey's DAVY™ design, fresh feed gas enters at the bottom of the reactor and into a central perforated-wall distributor pipe. The gas then flows radially out through the catalyst bed. Water from a steam drum enters at the bottom of the vessel, and flows upwards through the tubes where it is partially vaporised, removing the heat generated by the reaction before returning to the steam drum. The reaction temperature is controlled by varying the steam pressure inside tubes embedded in the catalyst bed.

Original design

The Johnson Matthey radial flow steam raising converter was first brought into service in 2005, using a vendor designed central distributor, rather than the default Johnson Matthey design.

All of the other vendors for subsequent RSRCs adopted the default Johnson Matthey distributor design of approximately 100,000 holes each of 2 mm diameter drilled through a 25 mm thick plate, which is rolled into a cylinder and welded.

Fig. 14 shows one of the central distributor sections and Fig. 15 shows two sections of the central distributor joined together.

The timing of a new charge of catalyst for the RSRC at a customer site provided an ideal opportunity to commercialise a new distributor design: a V-wire design that would address the drawbacks of the original thick plate design (see Table 1).

New design

To address the problems of the original design, Johnson Matthey developed a new distributor design, based on the use of V-wire construction used in many other technologies.

Fig. 16 shows a cut-away drawing of the new distributor.

C-channel

In the new design, the C-channel is bent into circular hoops: as strong as a thick plate, but lighter. Larger holes are less likely to block, and easier to clean.

Any debris that is pushed through the holes will collect in the C-channel and be difficult to remove, but that was considered to be an acceptable compromise for the combination of strength and lightness of the C-channel construction.

The larger holes are arranged so that the vertical spacing matches the C-channel dimensions, but with a larger circumferential spacing. The total area of the holes is about 2.5% of the distributor surface – the same as for 2 mm holes on a 12 mm pitch in the thick plate design. In the new design there are fewer holes, each larger in diameter and punched (not drilled) through the thinner material that makes up the C-channel. This saves a lot of time and effort to create the holes.

PHOTOS: JOHNSON MATTHEY

Fig. 14: One of the central distributor sections.

Fig. 15: Two sections of the central distributor jointed together

Table 1: Drawbacks of the thick plate distributor

Manufacturing	Operation
● Drills wear out fast ● Expensive to fabricate ● Long fabrication time ● Weld seam gives a strip where there are no holes, leading to non-ideal gas flow patterns ● Sections are easy to assemble out-of-sequence, which can create a "lean" in the assembled distributor	● 2 mm holes block easily with loose debris ❍ Increased pressure drop ❍ Non-ideal flow distribution ● 2 mm holes can be "peened" shut by repeated impact from construction debris or broken ladder rungs ❍ High pressure drop ❍ Failure of internal section joints ● Difficult to clear blocked holes

Source: Johnson Matthey

Joints between sections

The distributor is designed in multiple sections, each approximately 1.5 to 2 m tall. This allows very gentle loading of the KATALCO™ 51-9 catalyst, but the sections must be joined together. There are three obvious choices for joining the distributor sections: overlapping spigot joints, internal flanges and external flanges (see Fig. 17).

To decide on where to use spigot joints and where to use internal flanges Johnson Matthey considered the pressure profile inside the distributor pipe.

Pressure profile

In case of a relatively smooth surface on the inside of the central distributor, there are three competing effects:

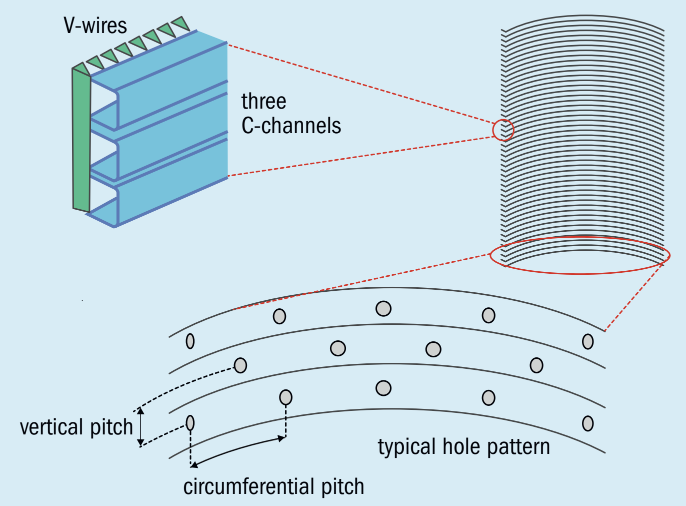
- Change in elevation – small impact
- Friction – small impact
- Pressure recovery due to drop in velocity – largest impact

The non-friction effects are described by the Bernoulli equation:

$$\underbrace{P}_{\text{pressure energy}} + \underbrace{\tfrac{1}{2}\rho v^2}_{\text{velocity energy}} + \underbrace{\rho g h}_{\text{elevation energy}} = \text{constant}$$

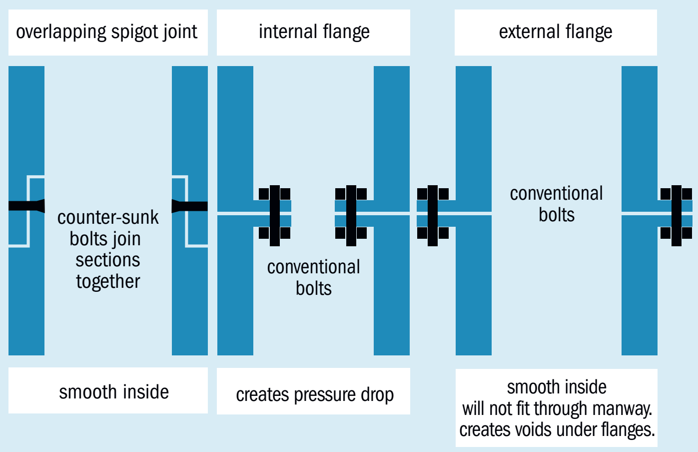
At the entry to the distributor the velocity is at its maximum, and the "velocity energy" term is high. At the top of the distributor the velocity is zero and therefore the "velocity energy" term is zero. The "elevation energy" change is small, so (almost) all of the reduction in "velocity energy"

Fig. 16: Cut-away drawing of the new distributor



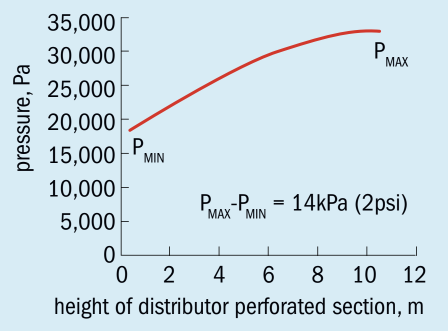
Source: Johnson Matthey

Fig. 17: Options for joining distributor sections



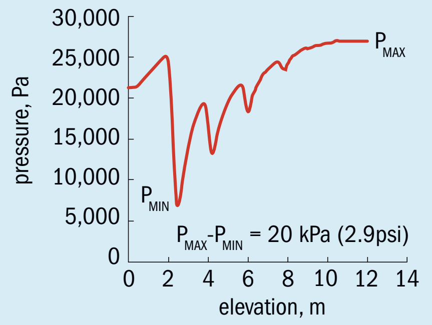
Source: Johnson Matthey

Fig. 18: **Pressure at centre of distributor with smooth internal surface**



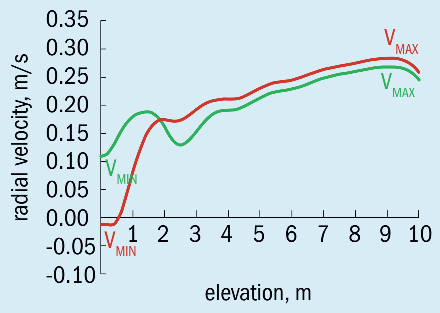
Source: Johnson Matthey

Fig. 19: **Pressure at centre of distributor with internal flanged points**



Source: Johnson Matthey

Fig. 20: **Velocity near the start of the catalyst bed with mix of spigot joints and internal flanges**



Source: Johnson Matthey

Table 2: **Initial investigation options for future design improvements**

Hole pattern No.1	Hole pattern No. 2	Number of sections	Section joints
Adjust the hole pattern to take full advantage of the 200 mm diffusion annulus of ceramic balls that surround the central distributor.	Use different hole patterns for each section of the distributor to reduce (P_{MAX} - P_{MIN}) as much as possible.	Use fewer sections. The lower weight of the C-channel constriction allows longer sections, and it turns out that KATALCO 51-9 is a strong catalyst and we don't have to be so gentle after all	Use unique joints so it is impossible to install the sections in the wrong order on site. Include adjustment to keep distributor perfectly vertical.

Source: Johnson Matthey

is offset by an increase in the pressure energy (the effect can be seen in Fig. 18).

If all of the joints use internal flanges there is a large initial pressure drop (see Fig. 19). The initial pressure drop is approximately 20 kPa in Fig. 19, which is slightly larger than the 15k Pa pressure drop across the perforations in the distributor. This means that the pressure inside the bottom section of the distributor is lower than the pressure in the catalyst bed associated with the adjacent section. This leads to a recirculation flow, with some gas flowing from the catalyst bed back into the bottom section of the distributor. This is very undesirable.

If a mix of spigot joints near the bottom and internal flanges for the upper sections is used, the overall (P_{MAX} - P_{MIN}) is reduced, which leads to a better gas distribution through the catalyst bed than using spigot joints for every section, and significantly better than when using internal flanges for every joint. But the true test is the effect on the gas distribution. Fig. 20 compares the velocity profile for two cases:

- Internal flanges for all distributor sections (red line);
- Spigot joint between sections one and two, the rest use internal flanges (green line).

Fig. 20 shows the undesirable recirculation effect as a negative velocity for the red line. Replacement of the first joint (between sections one and two) with a spigot joint results in a significant improvement in the velocity variation.

Further through the catalyst bed the flow variation becomes even smaller.

The new design can be summarised as follows:

- vendor standard V-wire construction;
- C-channel used for strength with lightness;
- Spigot joints used for lower sections, internal flanges for upper sections to reduce (P_{MAX} - P_{MIN}) and improve the gas distribution through the catalyst bed.

Future designs

Valuable information was gained with the development of the new distributor. Johnson Matthey is now in a development cycle to use CFD models to evaluate some design options for an even better design (see Table 2).

Hole pattern No. 1

Fig. 21 shows a photograph of the outer edge of the central distributor and the 200 mm annular layer of inert balls that helps to diffuse the gas leaving the central distributor. With 2 mm holes you do not need

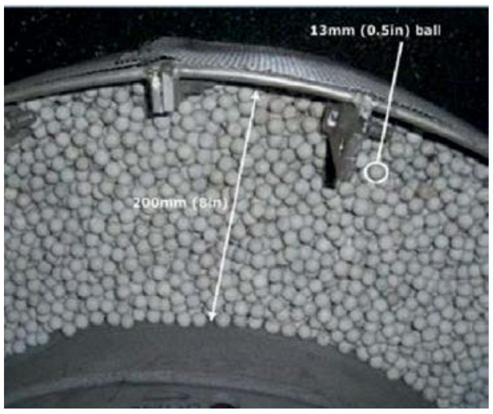


PHOTO: JOHNSON MATTHEY

Fig. 21: Annular layer of inert balls between distributor and catalyst

the layer to be 200 mm deep – a much smaller layer is sufficient, but we use 200 mm to make it easy to load the inert balls without them spilling into the catalyst bed. With the new distributor, with fewer holes, we can take advantage of the full 200 mm deep layer to diffuse and mix the gas jets associated with each larger hole.

The vertical hole pitch can be varied by:

- only having holes in only some of the C-channels – the vertical pitch can be increased to twice or even three times the C-channel dimension;
- varying the circumferential hole pitch – increasing it or decreasing it;
- a combination of both changes.

CFD models will be used to see how the gas jets disperse through the annular layer of inert balls to find the vertical and circumferential hole pitch that gives a small variation in the gas interface velocity at the start of the catalyst bed.

Hole pattern No. 2

As seen in Fig. 18 and Fig. 20, variation in the pressure at the centreline of the distributor will cause flow variation in the catalyst bed. One way to reduce the ratio of maximum velocity/minimum velocity (V_{MAX}/V_{MIN}) is to adjust the hole pattern to have fewer holes in the top sections of the distributor.

CFD models will be used to see how much improvement in V_{MAX}/V_{MIN} is possible based on different vertical and circumferential hole pitch in each section of the distributor.

Number of sections

The C-channel design combines high strength with low weight, making it possible to manufacture longer sections without increasing the weight of each section. Experience has shown that the weight of each section can be increased without making installation on-site significantly more difficult.

The increasing familiarity of operators and specialist contractors with loading KATALCO 51-9 catalyst into the RSRC using canvas hoses ensures that it can still be treated gently with a much larger height of each distributor section. KATALCO 51-9 has a high crush strength, and the gentle treatment is to minimise the formation of dust and fines, not to avoid damage to the catalyst.

The combination of these factors gives confidence that each distributor section can be made much longer than in the original design. Longer sections mean that fewer sections are required, speeding up the time to load the catalyst into the converter.

The optimum number of sections will still be influenced by the variation in hole pitch to reduce the variation in V_{MAX}/V_{MIN} ratio.

Section joints

At the vendor's workshop the order of the sections is determined with the bolt hole positions in each section, adjusted to ensure that the distributor is vertical, with no "lean" to one side. On-site the sections are easy to install in any order – and using the wrong order usually results in the distributor leaning over when installation is complete.

To avoid this, Johnson Matthey will be considering:

- unique section joints to ensure the sections are installed in the correct order – for example by using a different number of bolts in each joint (e.g. 6, 7, 8, 9);
- another option is to have the height of each section different, so the installation team know to install the shortest section first and the longest section last.

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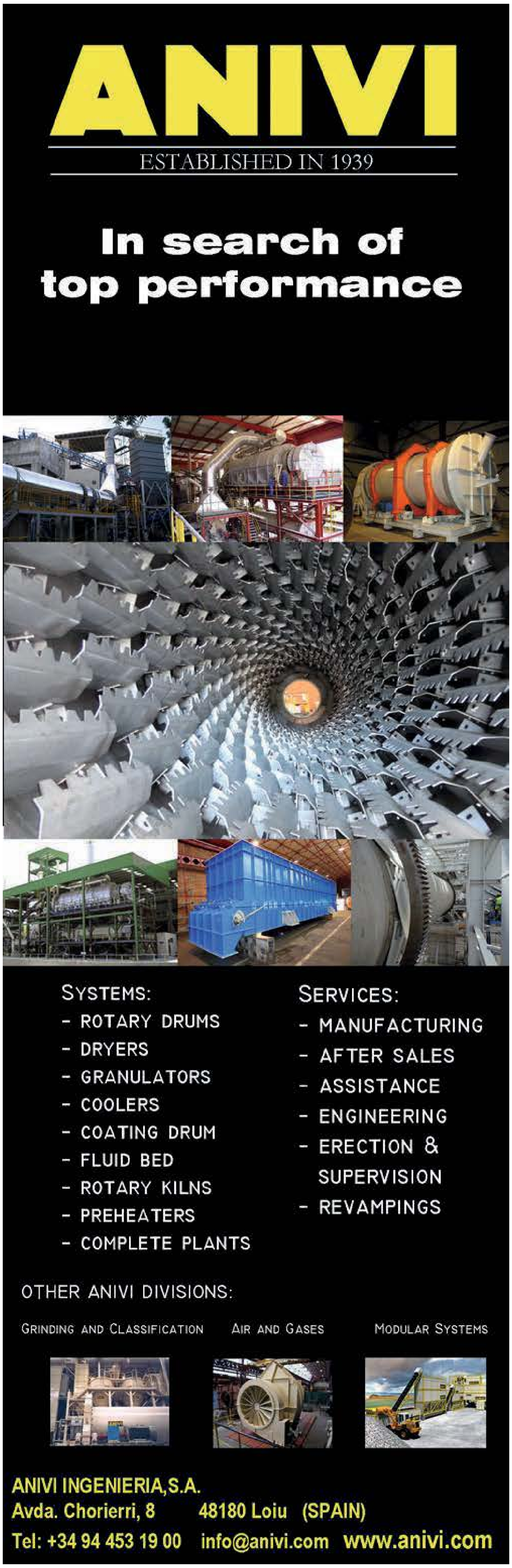

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