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US methanol capacity

China's environmental crackdown

Primary reformer asset management

New catalyst developments



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ISSUE 359
MAY-JUNE 2019

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11 Chinese urea capacity Facing radical restructuring.



17 Primary reformer stresses Strategies to manage operating issues.

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After China



We have become so used to China dominating all global commodity markets, following its extraordinary expansion over the past two decades, that it feels slightly odd to return to a more 'normal' state of affairs. And yet, in the nitrogen industry at least, that is what finally seems to be occurring.

Chinese exports of urea fell to their lowest level for many years in 2018; just 2.4 million tonnes. When you consider that just three years earlier the figure was 13.7 million tonnes, the decline is startling. And most of those exports happened during the last four months of last year – from January to August 2018, China exported only 1 million tonnes. At the same time, China also began to import ammonia – about 1.2 million tonnes during the whole of 2018. Without Chinese support, the already over-supplied ammonia market might have been in a far worse state last year.

In 2018, for the first time in many years, net urea capacity actually fell worldwide.

The reasons for this are detailed in our article on pages 21-23 – a combination of higher coal prices forcing up production costs, natural gas shortages leading to shutdowns of gas-based capacity, higher costs of environmental regulatory compliance, and above all a sustained crackdown by central government on air and water pollution in the regions of the Yangtze River and the heavily populated northeast around Beijing. The effect has been a rapid rationalisation of urea capacity – the far-reaching shutdowns in China mean that in 2018, for the first time in many years, net urea capacity actually fell worldwide, helping to support prices going into this year. China is not just rationalising production, but also consumption, with a cap on fertilizer use from 2020 and the aim of progressively increasing nutrient use efficiency and reducing nitrogen consumption. Whatever the end result, with supply and demand much more in synch, China is likely to be much less of a factor for global nitrogen markets than it has been for most of the past two decades.

So with China suddenly becoming a much smaller player than it was before, the question becomes where the next 'big thing' will be for the nitrogen industry. The change is not just in China, either. At the same time that China – formerly the world's largest exporter of urea – is scaling back, in the two largest importers, India's push to become self-sufficient in urea production again and the steady increasing rise of US domestic capacity due to

cheap shale gas are also reducing those countries' need to buy in nitrogen fertilizers.

Consequently, the new centres of demand are shifting; to Brazil, where poor soil quality in the Cerrado region, now the subject of major agricultural development, is leading to increasing imports; to India, where fast growing food demand and new direct subsidy payments to farmers are expected to lead to increased fertilizer use; and to Africa, still badly in need of the kind of 'green revolution' that Asia and South America saw in the last half of the 20th century. IFA predicts a 33% increase in African fertilizer demand over the next five years. For sub-Saharan Africa that figure is 60%. The chief issues for African consumption are the high cost of fertilizer, exacerbated by the linked issue of poor distribution infrastructure. But new African fertilizer capacity, in Nigeria and elsewhere, and the involvement of OCP in blending plants and other ventures in the continent, may start to make fertilizer more affordable for end users. And meanwhile, as global fertilizer nitrogen demand slows; to 1% growth or thereabouts, so industrial or 'technical' uses start to become more relevant, for caprolactam, acrylonitrile and urea solutions for diesel exhaust fluid (DEF), with the industrialised and industrialising countries of east and southeast Asia particular centres of demand.

On the production side, Russia and Central Asia is another of the bright spots for new capacity – Africa, India and Central Asia between them are forecast to represent 75% of new nitrogen capacity over the next five years. Domestic demand in Russia and Central Asia is also increasing.

These developments will make for a more fragmented and diverse nitrogen market in the future – and perhaps a less volatile one? ■

Richard Hands, Editor



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Price trends

NITROGEN

US natural gas prices have defied expectations after going into winter at \$4.80/MMBtu with storage levels at a 15-year low and freezing temperatures across North America. However, by February, Henry Hub prices fell below \$3.00/MMBtu and as winter turned to spring, prices have fallen as low as \$2.50/MMBtu. This remarkable fall has been due to record levels of shale gas production. The Marcellus and Utica shales are producing 30 bcf/day of gas, with output expected to rise 350 million cfd in May. The Permian shale is also rising rapidly due to oil drilling and expected to produce 14 bcf/d in May, with pipeline bottlenecks forcing some flaring.

US ammonia applications have been down this winter due to poor weather in the Mid-West, with Winter Storm Quiana in late February and Winter Storm Ulmer in mid-March leading to heavy snowfalls and standing water, preventing ammonia applications. Some corn plantings may be abandoned for soybeans instead as a result. High water levels also hampered barge movements on the Mississippi River, but markets were nevertheless oversupplied and ammonia prices moved down. Caribbean f.o.b. prices were as low as \$200/t, levels not seen since 2017. Low gas prices and additional ammonia availability internationally from Kingisepp in Russia, which started up in March, together with PAU in Indonesia has also helped to push ammonia markets down. The return of Sorfert in Algeria from turnaround also increased supply. Meanwhile

European producers are not facing domestic natural prices of \$10.00/MMBtu as they were last year, for example, and have been able to run at high rates. All of this suggests that the market is heading for a supply cost floor, somewhere around \$190/t f.o.b. Yuzhnyy.

Conversely, in the absence of ammonia applications, US buyers tried instead to source urea, with prices spiking higher for a while, before dropping back to \$270/t US Gulf, then rising again at the end of April to \$280/t. There was a similar story for UAN, which has seen low prices reach \$280/t. This may be a relief for UAN producers such as CF Industries, following the European Commission imposing interim anti-dumping duties on UAN in April. The duties will add an extra 30-40% duty on to Russian UAN sales to the EU, as well as 16% on Trinidadian and 22% on US UAN. EU imports of UAN are close to 4 million t/a, with France the largest buyer.

European urea markets have been relatively quiet and Black Sea urea prices relatively flat at \$250/t f.o.b. or just below, although some late demand was reported in April. Further east, the new Chambal Fertilizer plant in India was commissioned in January, and is expected to reduce India's demand for imports this year. Indian buying was relatively slow in the early part of 2019, with only 500,000 tonnes bought in January, far lower than for the same month in 2018. A series of MMTC tenders in April did not do much to alter this situation, with around 400,000 tonnes secured from various sources with an Arab Gulf netback

of \$245/t f.o.b. for the largest tranche and some c.f.r. prices as low as \$250/t, although markets had been expecting up to 700,000 tonnes to be purchased. The comparative lack of Indian buying has led to the expectation of more significant tenders to come in May. This, coupled with US confirmation of Iranian sanctions from May 1st and India's policy of not sourcing Iranian urea have all helped lift market expectations, as has lack of availability from China, and indeed increased volumes of Chinese imports – up to 150,000 tonnes in the past two months, mainly from the Arab Gulf, Indonesia and Malaysia. Chinese domestic prices have been firm, lifted by higher coal prices. China has been attempting to restrict coal imports by imposing extra customs checks to try and help domestic producers, but many Chinese mines have been shut by safety inspections in the wake of a series of mining disasters. Chinese urea prices have been above \$300/t since the end of March. Arab Gulf forward prices are seen as high as \$275/t f.o.b., compared to March rates of \$230/t.

Brazil has been buying Iranian urea at a significant discount, but it is not clear whether this marks a change in purchasing patterns. Brazil has also been active on the ammonium nitrate market, with large volumes of Russian tonnes committed. Russian AN prices have also been boosted by the outage at Acron's Dorogobuzh plant, which was closed by a fire in the AN prilling tower. Export prices rose to \$190/t f.o.b. at the end of April in spite of the end of the spring planting season in Russia and Europe. ■

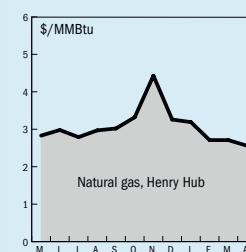
Table 1: Price indications

| Cash equivalent | mid-Apr | mid-Feb | mid-Dec | mid-Oct |
|-----------------------------------|---------|---------|---------|---------|
| Ammonia (\$/t) | | | | |
| f.o.b. Black Sea | 242-250 | 260-280 | 270-290 | 335-360 |
| f.o.b. Caribbean | 223-228 | 240 | 280-290 | 305-316 |
| f.o.b. Arab Gulf | 245-255 | 270-285 | 280-305 | 340-365 |
| c.f.r. N.W. Europe | 275-290 | 310-325 | 330-355 | 380-387 |
| Urea (\$/t) | | | | |
| f.o.b. bulk Black Sea | 224-230 | 230-240 | 270-280 | 280-300 |
| f.o.b. bulk Arab Gulf* | 247-272 | 233-255 | 280-290 | 320-340 |
| f.o.b. NOLA barge (metric tonnes) | 265 | 245 | 261 | 316 |
| f.o.b. bagged China | 300 | 260-285 | 275-290 | 320-338 |
| DAP (\$/t) | | | | |
| f.o.b. bulk US Gulf | 353-369 | 390 | 425 | 458-461 |
| UAN (€/tonne) | | | | |
| f.o.t. ex-tank Rouen, 30%N | 235 | 238 | 268-274 | 253 |

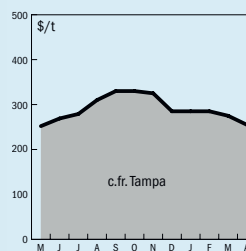
Notes: n.a. price not available at time of going to press
n.m. no market * high-end granular

END OF MONTH SPOT PRICES

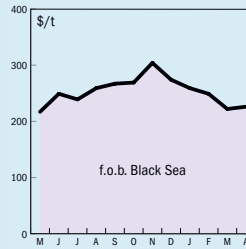
natural gas



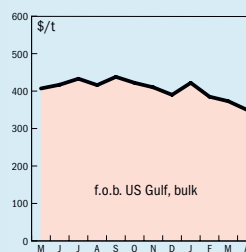
ammonia



urea



diammonium phosphate



MARKET INSIGHT

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

METHANOL

Spot methanol prices rose in all regions in March due to planned and unplanned outages in a number of regions. US spot weighted average prices for March up \$0.05/gal (\$16.50/tonne), as a fire at storage facilities in the Gulf supported prices.

In North America, official posted reference prices for April are \$1.30/gal for Methanex and \$1.29/gal for Southern Chemical, equivalent to \$432/t and \$429/t respectively. This is flat to the previous month. North American units operated at 92% capacity on average during March, and Trinidad 77%, but Venezuela's production came offline for two weeks in March, hampered by intermittent power outages, and averaged only 51% capacity. US demand into most products was flat and rather subdued in March. Demand into MMA was down slightly in March, with a small unit in Texas offline since 8 March.

European spot prices (T2 f.o.b. Rotterdam) for March were up €4 from February level at €283/t. The 2Q 2019 West European Contract Price was settled at a rollover from the previous month at €350/t f.o.b. Rotterdam T2. The ongoing suspension of duty on methanol arriving into the EU implemented by the European Commission has been extended and the duty-free allowance will now remain in place. Demand into formaldehyde was stable throughout March and acetic acid operating rates were healthy, but three units will close in April for planned maintenance.

In Iran, Zagros was down for 10-14 days during February for an unexpected issue but has since restarted, operating normally in March. Marjan's new 1.8 million t/a plant was inaugurated in late September and has sent around five cargoes of methanol to China since that time. The unit shut down at the end of February and is understood to have entered a restart phase during the last week of March. In Saudi Arabia, the Ar Razi was due to undergo a maintenance outage in 4Q 2018 but this has been postponed.

In India, port prices averaged \$303/t in March, up \$10 from February, due to lower import volumes from Iran during February and March. West Coast port inventory lev-

els are relatively low. Indian domestic prices started March at 23-24 Rps/kg and finished the month at the same level. At the end of the month, consumers in India and China were more confident about supply from Iran in the next few weeks, with Marjan believed to be currently in a restart phase.

Asian prices traded up by \$0.50, in the range of \$276-335/t c.f.r.; c.f.r. China prices were up \$1.50 in a range of \$276-316/t. Methanex's posted ACP for April was \$370/t, up \$10/t from March. Overall Chinese capacity utilization was stable at about 54% of nameplate capacity, or around 71% of effective capacity. Seasonal gas restrictions affected Boyuan Unichem, Qinghai Guilu and Chongqing Kabeile. Coking gas-based methanol producers in North China ran at 43% utilisation, down 5% on February, and coal-based methanol plants in Northwest China ran at rates of 63%, up 4%. The natural gas-based operating rate in China in March averaged 33%, down 1% from February. Chinese demand into MTO increased, with a recovery in olefins prices contributing to improved economics. The average MTO operating rate was 85%. Average operating rates for formaldehyde in China were up 30% at 73% in March with the end of the Lunar New Year holiday. Demand for DME in China was very bearish during the holiday week but increased in March, up by 4% at an average operating rate of 23%, although most units remained offline.

In Southeast Asia, regional supply declined significantly. BMC stopped at the end of February for a 45-50 day turnaround. Petronas's large 1.7 million t/a unit restarted in mid-March after experiencing unstable operations. Supply was tight although demand for methanol into the biodiesel sector was at a low level. MTBE demand was also low. Petronas's second MTBE line is under construction but has delayed its start-up date; it is expected to come on-stream in 3Q 2019.

In Taiwan, demand into acetic acid was stable with both units running at high rates. One acetic acid unit will undergo maintenance in April. Demand into formaldehyde was stable, with operating rates at around 70%. Demand into MTBE was healthy with the largest two MTBE units running to plan to satisfy domestic consumption. ■

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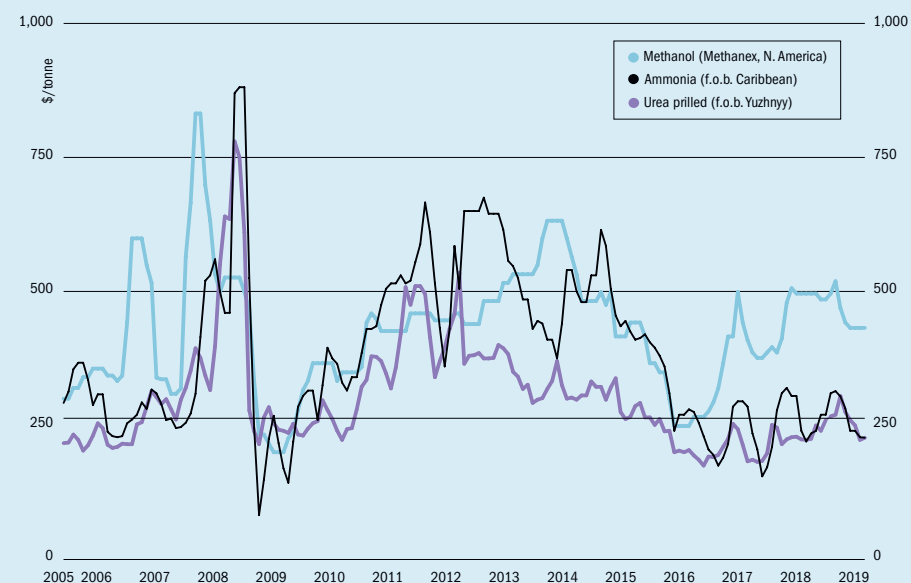
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Market outlook

Historical price trends \$/tonne



Source: BCInsight

AMMONIA

- US ammonia demand has been down significantly this year due to extremely poor weather across North America during Q1 2019. This has left a surplus of ammonia across the region.
- Ammonia markets have also been well supplied by new merchant capacity, with the start-up of Eurochem's Kingisepp ammonia plant in Russia in March following on from last year's BASF/Yara Freeport plant in Texas and PAU in Indonesia.
- Trinidadian gas restrictions are starting to ease, leading to additional availability – Trinidadian ammonia has been moving to Europe and North Africa in the absence of US demand.
- European producers have also been buoyed by lower gas prices, and the output from North African suppliers like Egypt and Algeria has been steady.
- Demand is steady but in the absence of economically forced shutdowns it may take the market some months to absorb the new supply.

UREA

- Expectations of more Indian purchasing have led to higher prices, especially since India is now officially not buying Iranian urea due to the new round of US sanctions.
- China has been focusing on domestic demand, and import volumes have been up, and export cargoes hard to come by, perhaps until at least September. High coal prices are also keeping Chinese costs high, and making the Chinese market more attractive to external suppliers. More Chinese capacity closures are likely.
- US demand for urea in the absence of ammonia applications has kept prices in North America buoyant; up to \$35/t above the same period last year. However, high river levels on the Mississippi River make shipping urea inland still difficult.
- Iranian urea is still available at heavy discounts, with evidence of some import and re-export from China, and some buying from Brazil.

METHANOL

- China remains the main importer of methanol, but the market there is becoming increasingly unpredictable due to a variety of factors, including the environmental crackdown on polluting plants, a possible move away from methanol towards ethanol blending, and the ongoing US-China trade dispute.
- In the longer term, with the forecast growth in lower-cost naphtha cracker capacity in China, MTO operating rates look set to decline, particularly in the period 2022-2024.
- In the shorter term, although winter can be time of lower demand in Europe and North America, new methanol capacity reaching the market has taken prices down \$70/t in Q1 2019 compared to 4Q 2018.
- However, as Iran represents a lot of this new capacity, sanctions are also a complicating factor, with the possibility that Iran will only be able to sell into China and India.

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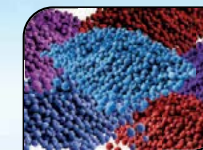
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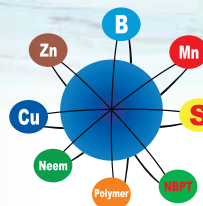
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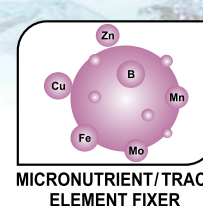
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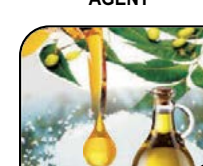
FROTH FLOTATION AGENT



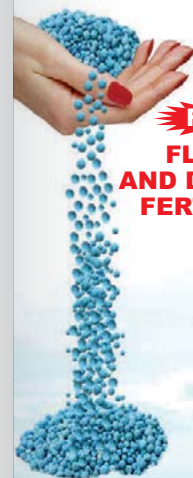
HARDENING AGENT



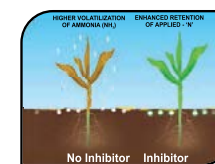
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KENYA

UN adopts resolution on sustainable nitrogen management

In its March meeting in Nairobi, the UN Environment Assembly adopted a resolution on Sustainable Nitrogen Management, and called for coherent evidence-based, global policy coordination to address the negative impacts of reactive nitrogen stemming from multiple sources. A delegation of members of the International Fertilizer Industry Association (IFA) led by Tip O'Neill, CEO of IRM, Convener of IFA's UN Outreach Group and Vice Chairman of its Public Affairs & Communications Committee, attended the Assembly, and emphasized the fertilizer industry's commitment to reducing the environmental footprint of fertilizers, while helping to close agricultural yield gaps and food security.

An improved understanding of this complex issue is vital to shape the best policy approach. IFA is already contributing to the International Nitrogen Management System (INMS), which is supported by UN Environment, and which has among its objectives a quantification of both the benefits and the adverse effects of nitrogen, which when completed in 2021 will allow for a more coherent and evidence-based policy approach.

Among its goals are increasing nutrient use efficiency (NUE) from the present 45-50% globally to a range of 50-90%, as rec-

ommended by the EU Nitrogen Expert Panel. Some cropping systems in West Europe, Brazil, the US and Japan currently already achieve around 70% NUE, but other regions, such as Sub-Saharan Africa, which are not sufficiently replenishing nutrients following harvests, actually have an overly high NUE, which indicates nutrient mining. NUE levels are low in most developing Asian countries but improvements have been observed for almost a decade in China. Efforts by the fertilizer value chain and other stakeholders to help farmers improve nutrient management performance are anticipated to produce a steady enhancement of the average global NUE.

"With the numerous uses of nitrogen in industrial transformation, energy production, and, of course, plant nutrition, IFA welcomes this timely proposal to better assess and quantify both negative and positive impacts of nitrogen, and to create a framework to explore and consider options for the improved international coordination, coherent capacity building and promotion of a better understanding of the various sources that influence the nitrogen cycle," observed Rakesh Kapur, IFA Chairman and Managing Director of IFFCO – the world's largest fertilizer cooperative based in India. ■

SWITZERLAND

Clariant joins World Business Council for Sustainable Development

Clariant says that it has become the newest member of the World Business Council for Sustainable Development (WBCSD). The company said in a press release that connecting with WBCSD's network, consisting of over 200 leading companies from all business sectors and all major economies, will enable it to continue to enhance and implement its sustainability ambitions in collaboration with likeminded partners and make a real impact on global corporate sustainability.

"We are delighted to join WBCSD and the other member companies who are part of this vital commitment to accelerate the transition to a sustainable world. Sustainability is an important pillar of our business strategy and our customers rely on us to deliver innovative solutions that address their sustainability needs. We are particularly interested in WBCSD's innovative work in relation to sustainable cities, climate and energy and the circular economy and look forward to contributing with our knowledge and innovation expertise", said Christian Kohlpaintner, a member of Clariant's Executive Committee.

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RUSSIA

Shchekinoazot chooses Topsoe ammonia technology for new plant

Shchekinoazot has selected Haldor Topsoe as licensor of ammonia technology for the construction of a new ammonia and urea plant. The plant, in Russia's Tula region, will have a capacity of 1,500 t/d of ammonia and 2,000 t/a of urea. China National Chemical Engineering Co., Ltd won the EPC contract and will construct the plant.

"This project will ensure the qualitative development of the gas industry in Russia towards a continuous increase in the feedstock processing rate and will allow switching from the consumption and export of raw materials to the production of high-tech, advanced processing products," said Anatoly Surba, General Director of JSC Shchekinoazot.

"We are very pleased to continue our long-term cooperation with Shchekinoazot. They have always set ambitious goals and strived for technology leadership, effective use of resources, and maximum productivity. We share Shchekinoazot's approach to sustainable development and environment, which helps us work effectively together on our fifth joint project," says Peter Vang Christensen, Managing Director of Haldor Topsoe's Moscow office.

EGYPT

EI Nasr awards EPC contract

thyssenkrupp says that its plant engineering business has won a major order from the Egyptian chemical and fertilizer manufacturer NCIC (EI Nasr Company for Intermediate Chemicals). The order for the engineering, procurement and construction (EPC) of a new fertilizer complex was signed in Cairo in March 2019. thyssenkrupp is realising the project in a consortium with the Egyptian company Petrojet. The order value is in the 'mid-three digit million euro range'.

"We have a particularly successful partnership with Egypt stretching back more than 160 years which offers great potential for the future. Our longstanding experience in plant construction, our strong local presence and close collaboration with our customers form the basis for our success and strong market position in the region," said Marcel Fasswald, CEO of thyssenkrupp Industrial Solutions.

"To date we have planned and built 16 of the 17 existing nitrogen fertilizer plants in the country and are delighted that another state-of-the-art plant will now be added," added Ralf Richmann, CEO Fertilizer & Syngas Technologies.

The new fertilizer complex will be built in Ain El Sokhna, around 100 km south-

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east of Cairo, close to the existing NCIC phosphate and compound fertilizer complex. It is expected to go into operation in 2022 and produce up to 440,000 t/a of ammonia, 380,000 t/a of urea and 300,000 t/a of calcium ammonium nitrate (CAN). The new plants are part of NCIC's plans to expand its current product portfolio to include high-quality nitrogen fertilizer for local and export markets.

Explosion at Egypt fertilizer factory kills ten

Ten workers were killed on March 21st when an ammonia tank exploded at a fertilizer plant at Ain Sokhna in Egypt's north-eastern Suez province, according to local media reports. The explosion reportedly occurred during operational testing of one of the ammonia storage tanks at the facility. Another five workers were said to have been injured, two of them critically, and were taken to Suez General Hospital for treatment. The site is a phosphoric acid and diammonium phosphate plant, with 360,000 t/a of DAP capacity, which is due to come into full production later in the year.

INDIA

India to become largest importer of automotive grade urea

Argus Media says in a new study that the Indian AdBlue market is forecast to grow rapidly over the next ten years. New emission standards will not only increase the number of vehicles consuming the urea solution, but also the amount of AdBlue each vehicle consumes. Strong demand and a lack of domestic automotive grade urea production will lead to India becoming the world's largest importer of AGU from 2024.

The Indian automotive market is busy preparing for the next stage of emission standards, Bharat Stage VI (BS-VI), equivalent to Euro-VI, which will be implemented on 1 April 2020. The government has been proactive in ensuring this deadline will be met with the Supreme Court ruling in October last year that no Bharat Stage IV (BS-IV) vehicle can be sold after 31 March 2020. BS-VI will encourage the use of selective catalytic reduction (SCR) systems across a range of vehicles. SCR will be used in all trucks and buses from April 2020 and all diesel cars and light-duty vehicles from April 2023. Argus says that it forecasts that AGU will import to India will surpass the US, Brazil, the United Kingdom, Japan and South Korea to become the largest AGU importer by 2024.

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DENMARK

Haldor Topsoe sells minority stake to Temasek

Haldor Topsoe Holding A/S has agreed for Temasek to purchase 30% of the shares in Haldor Topsoe AS, for an undisclosed sum. Closure of the agreement is expected later this year. Haldor Topsoe Holding A/S, which is 100% owned by the Topsoe family, will remain the long-term majority shareholder in Haldor Topsoe AS. Topsoe says that it selected Temasek in recognition of the value that the global investment company would add through its deep insights and connections in Asian growth and other emerging markets.

"We are extremely pleased to welcome Temasek as our new minority shareholder in Haldor Topsoe. As a commercial investor, Temasek's capital will further enhance our considerable growth potential organically and through potential acquisitions. In addition, Temasek is an experienced investor with significant insights and networks in Asian growth markets, including China. We look forward to truly beginning our collaboration when the agreement closes," says Jakob Haldor Topsoe, chairman of the board of directors, Haldor Topsoe Holding A/S.

Topsoe launches ClearView plant optimisation service

Haldor Topsoe has announced a technology alliance with Honeywell to expand the benefits of connected services to a broader range of chemical and refining industry clients. As part of this alliance, Topsoe has launched ClearView – a new service to maximise plant output, save energy, and improve reliability. Using Honeywell's cloud-based software platform, the ClearView service gathers operating data from the plant, uses error-detection and -correction algorithms to improve the accuracy of data, applies Haldor Topsoe's tools and experience via a 'digital twin' of the plant, and delivers performance insights straight to the plant's process engineers and managers.

Topsoe's proprietary modelling and simulation tools have been updated and refined to help customers optimise existing production and catalyst utilisation. Now, the ClearView service gives Topsoe customers continuous access to these tools to increase the profitability of their plants. As part of the service, Topsoe engineers follow plant performance and proactively guide the customers' plant engineers in optimising performance and quickly addressing opera-

tional issues based on output from the ClearView service.

UZBEKISTAN

NavoiAzot complex on course for next year

Uzbekistan president Shavkat Mirziyoyev has visited NavoiAzot to view the progress of the company's ongoing chemical projects. There are three major investments being undertaken at the site in Navoi; an ammonia-urea plant with 600,000 t/a of ammonia and 578,000 t/a of urea capacity, being built by Mitsubishi Heavy Industries and Mitsubishi Corporation, which will replace two older ammonia lines at the site; a \$217 million nitric acid plant with a capacity of 500,000 t/a, using Casale technology; and a \$500 million polyvinyl chloride, caustic soda and methanol plant, with a capacity of 300,000 t/a of methanol. The latter facility will be completed in September 2019, with the ammonia, urea and nitric acid plants scheduled for 2020 completion.

NIGERIA

OCP in talks to build ammonia plant

Morocco's OCP Group is in discussions to build a 1 million t/a ammonia plant in Nigeria at a cost of \$1.5 billion. The company said in March that it expected to finalise the deal with Nigerian authorities by the end of 2019. It previously signed a memorandum of understanding over the project in June 2018 with Nigeria's Sovereign Investment Authority.

OCP has been active in developing fertilizer projects in sub-Saharan African countries, with ongoing studies on building new facilities in both Ghana and Ethiopia to boost phosphate fertilizer production and consumption. OCP is also planning NPK blending facilities in Rwanda, Nigeria, Ivory Coast, Ethiopia and Ghana.

Dangote signs gas supply agreement

Dangote Fertilizer Limited has entered into a long-term agreement with Chevron's Nigerian subsidiary for the supply of natural gas to a new fertilizer plant that Dangote is building at Lekki. Dangote's new fertilizer complex comprises two ammonia-urea trains with a combined capacity of 3 million t/a of urea. Speaking at the signing ceremony, Dangote's Group Executive Director, Strategy, Capital Projects & Portfolio Development, Devakumar Edwin, said that the company is looking forward to hav-

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ing a long-term relationship with Chevron Nigeria Ltd as well as synergies in other upstream and wider areas of operations in the oil and gas sector. Dangote said earlier this year that it expects to commission the new facility in June 2019.

AUSTRALIA

Perdaman granted major project status

Perdaman Chemicals and Fertilizers, the developer of the 2 million t/a Karratha urea project, say that they have been awarded major project status by the Australian federal government following an assessment by the Department of Industry, Science and Technology. The decision assists Perdaman with obtaining expedited government assistance and approvals for the A\$4.5 billion project. Perdaman says that it is now looking to finalise offtake agreements with customers, finish financing arrangements and gain government approvals. A 20-year gas supply deal has already been signed with Woodside Petroleum. Pending approvals, Perdaman says that construction could begin in 1Q 2020 for completion in 2023.

UNITED STATES

Truck carrying ammonium nitrate explodes

A truck carrying a cargo of ammonium nitrate from El Dorado in Arkansas to Texarkana on the Texas-Arkansas border exploded on March 27th, killing the driver and leaving a 15 foot deep crater in the road. The explosion happened on a little-used stretch of highway west of the city of Camden, Arkansas. According to Arkansas State Police, the driver called emergency services at 6:40 am to report that his truck had rolled over and the brakes had caught fire, and he was attempting to extinguish the blaze. Three firefighters attending the incident were also injured in the explosion, although two were later released from hospital. The accident is similar to a 2014 incident in Queensland, Australia, which injured eight people, mainly attending firefighters.

EUROPEAN UNION

EC proposes anti-dumping duties on UAN

The European Commission has proposed provisional anti-dumping duties on imports of urea ammonium nitrate fertilizers (UAN) from Russia, Trinidad and Tobago and the USA, as well as compulsory registration of

UAN imports. The provisional duty applies for six months, at which time a definitive anti-dumping regulation is expected to be completed, with an anti-dumping measures able to apply for up to five years. The move has been welcomed by Fertilizers Europe, representing the European fertilizer industry. Jacob Hansen, director general of Fertilizers Europe, said; "the EU UAN industry is pleased to reach the stage where provisional anti-dumping measures are applied, expecting relief from the proven and severe injurious dumping. Due to the low dumped imports price, the European fertilizer industry was facing severe and ever-growing difficulties in the period 2017-2018. We are glad this problem was recognised by authorities and the situation is being addressed".

However, European farmers' organisation Copa said that it believes that it is global price trends that have caused UAN prices to lower rather than dumping, and the chair of the Copa Working Party on Cereals Jean-François Isambert said in a statement that the proposed duties would add about €2 billion to the costs of fertilizer in the EU and that farmers will therefore end up paying more for what is already an increasingly expensive input.

NETHERLANDS

Stamicarbon showcases innovation agenda

Maire Tecnimont's innovation and license subsidiary Stamicarbon held a Future Day event at the Jaarbeurs Media Plaza in Utrecht in early April. At the event, managing director Pejman Djavdan announced the company's innovation agenda to drive sustainable solutions in agriculture, confirming its full commitment towards innovation and technology development for the coming years. This investment will cover incremental and strategic innovation, research and development to further enhance its technological angle.

Stamicarbon's innovation ambitions are focused on three areas:

- Specialty fertilizers (including controlled release fertilizers, seed cores and micronutrients)
- Renewable production of fertilizer (using wind or solar energy to produce fertilizer)
- Digitalisation (optimising plant operations by harnessing the power of real-time data).

Attended by more than 130 employees and 40 guests from industry organisations,

related companies, and innovation partners, the Future Day was designed to inspire, spark discussion and plant seeds for collaboration. Topics addressed included:

- How to feed the world's growing population (expected to reach 9.7 billion in 2050)
- How to make fertilizers more enriching and sustainable
- Digitalisation, drones and robotics
- Vertical farming
- Future food sources (including insects and alternative proteins).

"Stamicarbon is determined to be part of the solution. We believe we can best use our 70 years of knowledge and experience to help develop smarter fertilizers and significantly improve the production of fertilizer," Djavdan said.

Futurist and trend watcher Richard van Hooijdonk kicked off the program by sharing a glimpse of the future of agriculture, including biotechnology; genetically modifying crops to produce greater yields; drones, offering advanced forms of crop monitoring; artificial intelligence: sensors and climate data helping to make predictions on optimal harvesting; and vertical and urban farming – bringing food production closer to citizens, reducing transportation costs and CO₂ emissions.

Saskia van den Muijsenberg, director of biomimicryNL, introduced 'biomimicry', a term derived from the Greek words bios 'life' and mimesis 'imitate', so literally 'imitate life'. Mrs van den Muijsenberg tries to catalyse innovation by helping companies to discover other development strategies in nature and to develop them further and translate them to real business opportunities. She gave insights in how nature can inspire people to design sustainable technologies.

Bas Godschalk of Insects-for-all talked about the 'food of the future'. Insects can play a key role in meeting the growing demand for sustainable protein. Production of insects requires only 40% of the energy that is needed to produce other kinds of proteins, so there are opportunities to introduce these technologies and enrich diets. During the event, participants were dared to taste several foods made using insects.

Other speakers included Taylor Pursell of Pursell Agri-Tech, who explained the innovative controlled release fertilizer technology already in operation in the USA, and Rob Faessen, who explained Stamicarbon's developments in digitalising and optimising urea plants.



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MALAYSIA

Design study for methanol plant

Air Liquide will partner Samsung Engineering on a front-end engineering and design (FEED) study of a methanol production plant for Sarawak Petchem, a state-owned oil and gas firm established and owned by the State Government of Sarawak state in Malaysia. Air Liquide will be the technology licensor while Samsung Engineering will design the project's utility systems and balance of plant. Following the FEED study, and subject to a final investment decision by Sarawak Petchem, the contract will be converted to an engineering, procurement, construction and commissioning contract at the end of 2019. The methanol plant, which will be located in Bintulu, Sarawak State, will come into operation in 2023. It will produce 5,000 t/d of methanol based on Air Liquide's Lurgi *MegaMethanol* technology.

David Maloney, Air Liquide Engineering and Construction chairman & CEO, said: "we are proud to have established this partnership which further enhances our position as a leading technology provider for methanol plants".

UNITED STATES

Methanex in warning over third methanol plant

Methanex faces a revolt by its largest shareholder, London-based M&G Investment Management Ltd, over the construction of a third methanol plant at Methanex's Geismar site in Louisiana. In a public letter to the company, M&G warned Methanex that the planned \$1 billion investment would be too risky without a partner, arguing: "we are supportive of the plant in concept, however, we strongly believe that without the participation of a strategic partner such a project would represent unacceptable financial risk to the company given the cyclical nature of its cashflows."

Methanex has relocated two plants from its Chilean facility at Punta Arenas, where it faces gas shortages, to the Geismar site, and each as a capacity of 1 million t/a of methanol. However, the proposed third plant would be a much larger investment, with 5,000 t/a (1.7 million t/a) of methanol capacity, and would be a new build rather than a relocation. Local and state officials have signed off on tax breaks for the project. M&G owns 16.5% of the Canadian firm, and has also talked about nominating its own representative to Methanex's board.

The board of Methanex has said that it prefers to pursue the expansion with a partner, but believes that the investment is a sound one and will not rule out proceeding on it without one. Front end engineering and design work is ongoing, and a final investment decision is expected by the middle of 2019.

Linde to build new hydrogen plant

Another development in St James Parish, Louisiana is a new \$250 million hydrogen plant which Linde has said it will build by 2021. Linde says that it expects to break ground on the new plant by the end of 2019, with assistance from Louisiana's Industrial Tax Exemption Program, began early last year between Louisiana Economic Development and Praxair, which subsequently merged with Germany's Linde. The new plant will increase US hydrogen output by 10%, according to the company.

Yuhuang plant to begin production next year

Yuhuang Chemical Industries (YCI) says that its new \$1.85 billion YCI Methanol One plant will begin commercial production in mid-2020. Construction work at the 1,300 acre site in St James Parish, Louisiana began in January 2017, and is ongoing. Major equipment items have



The YCI Methanol One site.

PHOTO: YCI METHANOL ONE

been delivered and will be erected during 1H 2019. The plant, one of the largest greenfield investments by a Chinese company, will be a 5,000 t/d (1.7 million t/a) methanol plant. YCI is owned by

Shandong Yuhuang Chemical, although in August 2018 Koch Industries bought into the project in return for exclusive offtake rights.

TRINIDAD & TOBAGO

Major equipment items delivered

Mammoet says that it has completed delivery of all heavy lift items for construction of the new Caribbean Gas Chemical Ltd (CGCL) methanol and DME plant in Trinidad and Tobago's Union Industrial Estate, La Brea, on the south side of the island. Mitsubishi Heavy Industries contracted Mammoet to transport and install 120 pressure vessels and modules for the construction. Over the course of one year, the major cargo was received in a total of 22 shipments. Mammoet's scope included port handling activities, inland transport coordination and the customs clearance process inclusive of the 120 modularised vessel cargoes. The main reformer vessel clocked in at 1,240 short tons (1,130 metric tonnes). Following its completion, the facility is expected to produce 1.0 million t/a of methanol and 20,000 t/a of dimethyl ether per year.

AUSTRALIA

Waste to energy plant for Australia

Scrap metal recycling company Sims Metal Management says that it aims to enter the waste-to-energy gasification industry, unveiling plans at an investor conference to build a series of plants around the world capable of turning the residue left when

cars are shredded into gas. The company has large car shredding plants which recycle around 80% of the materials from end of life vehicles, including ferrous and non-ferrous metals, but which also produce large volumes of so-called automotive shredder residue (ASR), including glass, plastic, rubber and other materials. Sims' aim is to turn this ASR from a waste product that goes to landfill to a co-product and energy source by gasifying it. The company noted that incineration produced up to 30% waste (compared to the input tonnage) in terms of ash, while gasification generated only 18% slag as waste. The calorific value of ASR is about 16 MJ per kg according to Sims. The company aims to spend \$158 million to install and operate seven waste to energy plants, with the first one to be built in Australia, co-located with one of its existing processing facilities.

UNITED KINGDOM

Biomass gasification plant begins operation

The Bioenergy Infrastructure Group (BIG) says that it has begun operating a new 21.5 MW gasified biomass power station in Cheshire following the completion of testing. The Ince Bio Power plant produces syngas from partial oxidation of waste wood. BIG says the power station will process up to 170,000 t/a of waste annually and cut greenhouse gas emissions by 65,000 tonnes CO₂e each year.

The company's chief commercial officer, Neil Bennett, said: "We are delighted that Ince is now fully operational and will continue to generate clean, base-load, renewable energy for the people of the north west of England. This is not only a significant milestone for Ince but also an important moment in the development of gasification facilities in the UK, which are a sustainable alternative to incineration."

BIG already operates multiple biomass and energy-from-waste plants in the UK and has several more under development or construction. Four of the facilities were bought from the Green Investment Group in 2017.

New contractor for waste gasification plant

A new contractor has been appointed to oversee final commissioning of the delayed £200 million (\$154 million) Energy Works scheme in Hull. Black & Veatch has been appointed as the

new engineering, procurement and construction (EPC) contractor after the previous contract, with MW High Tech Projects UK Ltd had contract terminated following "significant delays". The waste gasification plant, which will process 240,000 t/a of residual household waste from local authorities across the UK, will use fluidised bed gasification to generate syngas for a 24 MW power plant, sufficient to power 40,000 residences. It was originally scheduled to begin operations in April 2018. No timescale has been given for the new completion date.

Hamish McPherson, chief executive of BIG, said: "Black & Veatch has demonstrated both technical capability and organisational commitment to the renewable energy industry, including as a lead contractor at our Ince Bio Power project in Cheshire, and we are delighted to have brought them on board in Hull. This represents very good news not only for this facility but for the city of Hull. We have regenerated a brownfield site, will be enabling other local businesses to reduce their carbon footprint, and will be providing clean energy to the local grid."

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Methanex Corp.'s largest shareholder plans to nominate four directors to the company's board on the grounds that new leadership is needed to oversee the development of a methanol plant in Louisiana. M&G Investment Management Ltd., which owns a 16.5% stake in Vancouver-based Methanex, said in a letter to shareholders Monday that it has raised concerns with management about the risks of building the plant without a partner. M&G said it plans to nominate the directors at the company's shareholder meeting in April because it doesn't believe Methanex takes seriously its concerns that building the plant alone could stress its balance sheet and make it harder to pay dividends and repurchase shares.

"We are concerned that there is not sufficient oversight from the independent directors within the board room to maintain financial discipline in what is a relatively indebted company in a cyclical business," M&G said.

Methanex said in a statement that it already put forth its slate of 11 directors for the annual general meeting on April 25. Ten of those are independent and four of them have joined since 2016. "Methanex is committed to acting in the best interest of all shareholders and gives due consideration to constructive recommendations for strategies or actions that have the potential to create value," the company

said in the statement. "Through an ongoing private dialogue with M&G over the last two years, it is clear M&G has developed a short-term focus on share buybacks."

M&G's nominees include: **Paul Dobson**, acting chief executive officer of Hydro One Ltd; **Lawrence Cunningham**, a law professor at George Washington University; **Patrice Merrin**, the former CEO of Luscar Ltd; and **Kevin Rodgers**, a former global head of foreign exchange trading at Deutsche Bank AG.

Consultancy and events company CRU Group has announced the appointment of **David Trafford** as chief executive officer.

"David brings real breadth of experience in the commodities that we specialise in, and understands the nature of roles at every level of the business. I am delighted to see him appointed this year, as we celebrate our 50th anniversary," said Robert Perlman, chairman, CRU.

David is an international natural resources executive with over 30 years' experience in the mining, metals and investment banking sectors. Arriving in 2015, David joined as CEO of CRU Consulting to lead the global expansion of the business unit and to substantially increase sales.

"It is an honour and a privilege to be asked to run CRU Group, a business with an unparalleled heritage and reputation in commodity research, built over 50 years by dedicated professionals and supported by



David Trafford.

loyal customers," said David Trafford, chief executive officer, CRU.

The Saudi International Petrochemical Company (Sipchem) has appointed **Abdullah Saif Al-Saadoon** as its new CEO, replacing former chief Ahmad Al-Ohali. The company's board of directors approved Al-Ohali's resignation on 24 March after he was appointed by Saudi King Salman bin Abdulaziz Al Saud as Governor of the General Authority for Military Industries as Minister. Al-Saadoon joined Sipchem in 2001 after a period with fellow domestic producer SABIC, with his most recent position before CEO as president for operations and manufacturing.

Calendar 2019

JUNE

4-5

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

11-13

IFA 87th Annual Conference, MONTREAL, Canada
Contact: IFA Conference Service, 49 Avenue d'Iéna, 75116 Paris, France.
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

19-20

Syngas Nitrogen Russia and CIS, MOSCOW, Russia
Contact: Milana Stavnya, Programme producer, Vostock Capital
Tel: +7 (499) 505 1 505
Email: MStavnaya@vostockcapital.com

JULY

16-19

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

SEPTEMBER

8-12

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

8-13

Ammonium Nitrate/Nitric Acid Conference, VIENNA, Austria
Contact: Hans Reuvers, BASF
Karl Hohenwarter, Borealis
Email: johannes.reuvers@basf.com
karl.hohenwarter@borealisgroup.com
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22-24

TFI World Fertilizer Conference, CHICAGO, Illinois, USA
Contact: Valerie Sutton
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Email: vsutton@tfi.org

OCTOBER

27-29

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Plant Manager+

Problem No. 54 High efficiency trays for the urea reactor

The main reasons for the installation of high efficiency trays (HET) in a urea reactor are as follows: 1) to improve the redistribution of unreacted carbon dioxide inside the liquid phase rich in free ammonia, 2) to reduce the back mixing

phenomena due to the density increase of carbamate and urea solution from the bottom to the top of the reactor and 3) to reduce channelling which has a negative effect on the solution residence time.

Prabhat Srivastava from Tata Chemical Limited, India, starts the round table discussion: Casale supplies high efficiency reactor trays for increasing conversion efficiency. I have read a short article about another type of high efficiency trays named SuperCups. Does anyone know anything about these high efficiency SuperCups developed by Saipem? Do you know of any references where they are being used?

Mark Brouwer from UreaKnowHow.com, The Netherlands, shares his experiences and asks a question: Each licensor has developed its own high efficiency tray design. Good mixing between the gas and liquid phases is important and I believe a dedicated design is a better choice than a standard tray design. How much improvement such a tray can bring depends on how far one operates from equilibrium and the performance of the old trays. What is important is to do the performance test under the same conditions. So if the performance guarantee is defined as CO₂ conversion one should keep the N/C ratio the same.

Prabhat Srivastava asks for clarification: When you say "how far one operates from equilibrium and the performance of the old trays", do you mean the gap between design CO₂ conversion and actual conversion at design operating parameters.

Mark Brouwer replies: Yes, for example, higher than design plant loads or more inerts than design are factors which increase this gap. Please be aware that a licensor has to choose a certain reactor volume to limit investment costs for the reactor and thus accepts a certain distance from equilibrium in the design.

Girish Prakash from Tata Chemicals limited, India, put a new direction to the discussion: Apart from the savings accrued, are there any technical factors which need to be kept in mind when considering tray replacement? I mean, for example, factors like the liner thickness, because generally a tray replacement job will take place after 10-12 years of operation and during this time the liner thickness will have decreased substantially.

Vasile Stan from Azomures, Romania, shares his experiences with high efficiency trays and makes a suggestion: Casale have installed their high efficiency trays in many companies, ask for a reference list and get in contact with few of them, you will see they are good.

Easa Norozi from Khorasan Petrochemical Company, Iran contributes to the discussion with his experiences: As we know, the purpose of trays is to promote good interaction between gases in

the reactor. In this case the product yield can be increased and plant process control will be easier. For these reasons the high efficiency trays can help to achieve the above goals. We installed Casale high efficiency trays ten years ago. They are good for increasing the capacity from 1,500 t/d up to 1,700 t/d without any change in N/C ratio and for good process control.

Tarun Batra from National Fertilizer Limited, India, provides his observations regarding high efficiency trays: Our urea reactor was equipped with Casale high efficiency trays during the revamp of our urea plant. The performance of the reactor improved in terms of CO₂ conversion with the high efficiency trays.

Jawad Aslam from Fauji Fertilizer Limited, Pakistan, also shares his experience: I would like to share our experience with regard to high conversion in the urea reactor. We installed five additional trays in 2008 and as a result the conversion increased by 0.5% only. However, in 2012 we were able to increase the urea reactor efficiency by 4% as a result of the following changes:

1. the internal rib supports of the trays were replaced by full ribs;
2. the re-lining of 2.75 lining courses (5th, 6th & 7th);
3. increasing the size of the reactor outlet line from 6" to 8".

Prabhat Srivastava shares his experiences and raises a question: In my opinion points 1 and 2 are the mechanical part, whereas changing the size of the line size can only increase reactor efficiency if the line size was limiting flow.

Prem Baboo from National Fertilizers Ltd, India, provides more information: The installation of five additional high efficiency trays increased urea production and reduced steam consumption. The financial benefits are determined by the urea sales and energy prices. It has been demonstrated that the installation of high efficiency reactor trays in an existing urea plant is very profitable. The payout time for the investment is in the order of few months. The CO₂ conversion increased by about 1.0-1.5 %.

Mohit Uberoi from Zuari Agrochemicals Limited, India shares the result of the high efficiency trays in his plant: We have Casale high efficiency trays in our urea plant. It has led to an increase in our production capacity and has also decreased the steam consumption in the decomposers.

Mark Brouwer from UreaKnowHow.com, together with a group of independent engineers, has prepared a revamp guide on high efficiency trays to provide information to end users about the various designs of high efficiency trays and the main points of importance.

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PHOTO: METHANEX

The return of US methanol capacity

The US has seen a huge upturn in domestic methanol production, as cheap natural gas lures back capacity that had drifted overseas, and offering the possibility of the country becoming a net exporter in just a few years.

The US methanol industry has been on something of a rollercoaster ride over the past three decades. During the 1990s, capacity surged on the back of fuel demand for methanol derivative methyl tert-butyl ether (MTBE) due to an oxygenated fuel standard, at the same time that gas industry deregulation led to a fall in domestic gas prices. However, this boom quickly turned to bust as the US power industry moved towards gas-based power production, driving up domestic gas prices as gas reservoirs became depleted, while health and safety concerns over MTBE suddenly axed the source of demand that had caused the boom in the first place. US methanol capacity decamped overseas, mainly to Trinidad, where gas prices were lower but access to the US market was easy, and to a lesser extent to Venezuela and Chile. The US methanol industry contracted from 18 plants producing 6.6 million t/a in 1998 to just four plants producing 1.0 million t/a in 2005.

However, over the past decade the wheel has turned once more, as cheap US

shale gas has once again turned the feedstock equation on its head, while rising domestic demand for formaldehyde and acetic acid, methyl methacrylate and other methanol-based chemicals has supported millions of tonnes per year of imports which have been ripe for replacement by domestic capacity.

Re-starts and relocations

The first phase of this US methanol renaissance began with a series of re-starts of idled and mothballed plants. In fact the first of these was not in the continental United States, but just north of the border in southeastern Alberta, Canada where Canadian gas prices were likewise falling due to the country's intimate cross-border connection to the US gas market. Methanex re-started its mothballed 470,000 t/a Medicine Hat methanol plant in 2011 after nine years of lying idle due to high gas prices, beginning the current trend of resurgence in North American methanol production.

The next re-start was at Eastman's Beaumont, Texas methanol plant in 2013, bought by Egyptian/Dutch fertilizer manufacturer OCI, revamped to a capacity of 900,000 t/a and reconfigured to include an ammonia side-stream. The same year LyondellBasell also restarted its 800,000 t/a Channelview methanol plant near Houston, Texas, which had been idle since March 2003 and which had previously come close to being sold off. Methanex, meanwhile, facing gas supply curtailments at its Chilean methanol hub, relocated two of the plants from Punta Arenas to Geismar, Louisiana. The relocation of the two 1.0 million t/a units cost C\$1.4 billion and was completed by the end of 2015, when the second unit came on-stream.

New capacity

This activity had added 4.2 million t/a of North American methanol capacity in just four years, restoring, in the case of the US, two thirds of the capacity that had closed down or left since 1998. However, restarting or relocating existing plants is a relatively cheap and easy option where it is available. The next question was whether the market would bear the cost of building new capacity in the United States and Canada.

The answer appeared on the face of it to be 'yes', as there followed a whirlwind of new plant announcements by both existing and new producers. Gas prices continued to be low by international standards, averaging around \$3.00/MMBtu, and there were still imports to be displaced. However, while the presence of the huge US Gulf of Mexico oil, gas and refining industry gives project developers access to many skilled specialised fabrication and construction contractors, building plants in the US is not cheap, especially as regards labour and material costs and the maze of permitting that must be negotiated. The price of building a new US plant can be as much as 40% higher than a similar plant in a lower cost region. Volatile, unregulated feedstock as well as product prices can also give financiers pause for thought. There were fears for a while that shale gas prices were "too low" and not high enough to justify continuing investment in production; important since shale gas wells have a very short lifespan compared to conventional drilling. These fears over gas pricing were not borne out, though – indeed, experience made the gas industry progressively more efficient at extraction, and margins continued to be sufficient to keep prices low. Cheap gas

and favourable local tax regimens give US plants lower operating costs, which compensate for the higher capital expenditure.

These factors meant that project development for the new greenfield plants was not as fast as it had been for the re-starts and relocations, and with the exception of Celanese, which built a new 1.3 million t/a methanol plant at its Clear Lake, Texas facility in conjunction with Mitsui, which started up in 2015, it is only now that these new projects are starting to come on-stream. The Clear Lake project was something of a 'slam dunk' because Celanese was already a major purchaser of methanol to feed acetic acid and acetyl production at Clear Lake, and so it was an existing site with a guaranteed offtake for the methanol produced, calming financiers' jitters considerably. The companies have since decided on an expansion of methanol capacity with an additional 1.7 million t/a plant, but have yet to release a firm timetable for this.

The next major project was the 1.75 million t/a 50:50 joint venture between OCI Natgasoline and Consolidated Energy Limited (CEL) in Beaumont, Texas, now the largest US methanol plant, which started up in June 2018. Originally proposed as a methanol to gasoline (MTG) facility using the ExxonMobil process, the MTG part was shelved early on during project development and the plant built solely as a methanol facility. Project partner CEL is owned by Helm (25%) and Proman (75%), and it is also the 100% owner of Methanol Holdings Trinidad Ltd (MHTL), which runs most of Trinidad's methanol plants. Via MHTL the companies thus have access to a major international methanol trading and marketing operation.

CEL is also a major partner in the Big Lake methanol project, at Lake Charles, Louisiana. This \$1.6 billion, 1.4 million t/a plant is being developed by G2X Energy, which is majority owned by CEL, partnered by methanol marketer Southern Chemical. Construction began in 2016, and the plant is due for completion this year.

Small scale producers

Not all methanol developments in the US have been on the scale of these mega-projects, however. Houston-based G2X Energy built a 185 t/d methanol plant at Pampa, Texas in 2015, partnered by Southern Chemical, which remains a minority shareholder in G2X – although as noted above, CEL took a majority stake in the company in 2016. Again the original G2X plan was to move downstream to MTG production, but as with Natgasoline this plan has apparently been put on the back burner for now.

Meanwhile, US Methanol is a company that has bought two smaller second hand methanol plants, one in Rio de Janeiro, Brazil, the other in Slovenia, and which is transporting them to the heart of the Marcellus and Utica shale deposits in West Virginia. The first plant, dubbed 'Liberty One', with a capacity of 200,000 t/a, has been relocated and was due to start up in mid-2018, but has been delayed pending arrival of a new compressor train and construction of an oxygen plant by Praxair, and is now due for completion in 4Q 2019. The second, 160,000 t/a plant, 'Liberty Two', is intended to follow a few years down the line.

Primus Green Energy is a Houston-based company which has developed a



Construction at US Methanol's Liberty One site in West Virginia.

PHOTO: US METHANOL

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small, modular methanol plant concept intended to be used for small scale applications such as waste gasification or stranded shale gas wells. It is aiming to deliver its first, 160 t/d (50,000 t/a) plant to the Marcellus shale region near New Martinsville, West Virginia for production beginning in 2020.

Enter China

US domestic methanol demand has increased about 20% since 2011, to 7.8 million t/a in 2018. This figure is about a 3% increase year on year – a mature level of growth, but still quite respectable. However, with the completion of Big Lake and Liberty One, US methanol capacity is set to reach that level by the end of 2019. Future plant developments therefore have to be predicated not on meeting US domestic demand, but instead on exporting US methanol overseas – a third step change in cost structure.

The biggest market for methanol in the world, and also the fastest growing by far, is China. China has embraced methanol initially as a fuel blending component, and as a way of producing dimethyl ether (DME) for blending into LPG in order to try and reduce China's dependence on oil imports by using domestic coal to make methanol-based fuels. But in recent years this has expanded into making polyolefins using methanol – so-called methanol to olefins (MTO) production. Chinese MTO production has mushroomed, and while most of it is based on integrated upstream methanol production, a good proportion has been based on merchant methanol bought on the open market. This in turn has made China the largest importer of methanol in the world, and the logical destination for any methanol plant based on selling into the international market.

Consequently a number of Chinese companies have moved into the US to develop methanol capacity, aiming to arbitrage cheap US gas prices to sell methanol to Chinese MTO producers. The first of these was Northwest Innovation Works (NWIW), backed by Shanghai Bi Ke Clean Energy Technology, which originally planned three 1.7 million t/a methanol plants in the Pacific Northwest – now down to two projects, at Kalama in Washington State and Port St Helens, just over the river in Oregon. The permitting process has been a fraught one, however, with the Kalama environmental impact report thrown out and needing to be re-submitted, and delays to a gas pipeline spur meaning that no con-

Table 1: New and recent US methanol plants

| Company | Site | Capacity | On-stream date |
|---------------------------|----------------------|------------------|----------------|
| Natgasoline | Beaumont, TX | 1,800,000 t/a | 2Q 2018 |
| Big Lake 1 | Lake Charles, LA | 1,400,000 t/a | 3Q 2019 |
| US Methanol | Charleston, WV | 200,000 t/a | 4Q 2019 |
| Primus Green Energy | New Martinsville, WV | 50,000 t/a | 2020 |
| Yuhuang | Lake Charles, LA | 1,600,000 t/a | 3Q 2020 |
| Methanex | Geismar, LA | 1,800,000 t/a | 2023? |
| NWIW | Kalama, WA | 1,800,000 t/a | 2023? |
| Celanese/Mitsui | Clear Lake, TX | 1,700,000 t/a | 2023? |
| IGP Methanol | Myrtle Grove, LA | 2x 1,800,000 t/a | 2023? |
| US Methanol | T.B.A. | 160,000 t/a | ? |
| Lake Charles Clean Energy | Lake Charles, LA | 1,000,000 t/a | ? |

Source: MMSA, BCInsight

struction is likely before 2H 2020 at the earliest, while Port St Helens has faced a negative decision on changes to land use.

While these projects remain locked in legal battles, however, Yuhuang has received permits to build its proposed 1.6 million t/a methanol plant at Lake Charles, Louisiana. Ground was broken in 2015, and the \$1.9 billion plant is now scheduled to be up and running by 3Q 2020.

IGP Methanol, operating in partnership with China Cosco Shipping Energy Transportation Co., Ltd, and Jinguotou (Dalian) Development Co., Ltd (JGT), has taken the hint and also selected Louisiana for its own major complex, slated to be built at Myrtle Grove, Louisiana, comprising two 1.8 million t/a methanol plants for export to China, where they will be used for MTO production at Jinguotou's complex at the port of Jinzhou. A further two trains have been discussed for the longer-term future, according to IGP.

Methanex is also seeking to get in on the action, with the proposal to build a new, third plant at the company's Geismar, Louisiana complex. This plant would also be 1.8 million t/a in size, and also aimed at exporting methanol to Asia, but the company has faced an internal revolt from major shareholder M&G Investments, which says that the project is too risky without an external partner.

North of the border, there have been some more speculative projects, including one by Calgary-based Nautical Energy which would entail building a three-stage methanol complex in Alberta that would total 3 million t/a capacity when finished. There has also been a proposal for Victoria, British Columbia to use carbon dioxide from a natural

gas power plant at Pine River, operated by Spectra Energy, together with electricity from BC Hydro's proposed new Site C dam, to produce methanol to blend as a fuel in the province of British Columbia. Both of these projects are very uncertain, however.

A net exporter

Table 1 shows, there are a number of new methanol plants recently completed or under construction, which should add 5 million t/a of methanol capacity over the period 2018-2020, taking US capacity to 9.4 million t/a, well ahead of any projected demand. The US is thus on course to be a net exporter of methanol from the end of 2019 or start of 2020. Of the next wave of projects currently under development, US Methanol, Methanex and Celanese/Mitsui seem the most likely, with NWIW still needing to overcome its permit problems, and financing for IGP still uncertain. The Lake Charles Clean Energy Project has been around for some years and aimed to use gasified petroleum coke from local refineries to produce methanol, but at a project cost of \$3.8 billion, and with a lot of other methanol capacity going up in the Gulf Coast, it looks very doubtful now. There are also many other projects under discussion – Valero, Southern Louisiana Methanol (aka 'ZEEP'), Gulf Coast Energy, Zeogas and many others, but there are no firm plans for any of them as of time of writing.

Even so, what seems clear is that the US is set to become a major exporter of methanol over the coming years, and the global methanol market is going to have to get used to North America being not a consumer, but a competitor. ■



PHOTO: ISTOCKPHOTO.COM/CHUANFENG WONG

The impact of China's environmental crackdown and rising domestic feedstock prices has been to decimate the country's urea capacity. Exports are falling year by year – could China become a net importer again?

China is the world's largest producer and consumer of urea, and the balance between the two and the consequent volume of imports or exports that the country experiences has long been one of the key factors driving global urea markets. China has long pursued a policy of self-sufficiency in domestic nitrogen production, but in spite of this capacity growth lagged behind rapidly increasing demand during the 1980s, and China was a large net importer of urea during this era. There was a concerted government push to build new urea capacity during the 1990s and China's urea production rose rapidly, finally catching up with demand in 1998. Even so, rapidly increasing demand for urea meant that even China's breakneck capacity building during the 1990s and early 2000s only just kept pace with demand, and while

there were significant exports in some years, domestic consumers sometimes ran short, and the Chinese government had to introduce high export taxes to encourage producers to sell on the (subsidised) domestic market rather than the more lucrative international market.

By 2005, China had 48 million t/a of urea capacity and was producing flat out, at around 90% utilisation rate. At the time, China's industrialisation was in its greatest growth period, averaging 15% growth per year. There was abundant coal available for new project developments and ample capital for investment. Chinese urea capacity nearly doubled over the subsequent decade, to reach 86 million t/a in 2015. Unfortunately, domestic demand, which had been increasing rapidly, began to plateau and mature, and had only

reached 60 million t/a by that time. Even so, China was already over-applying urea to try and get the most from its relatively small area of arable land, and this was bringing attendant problems in terms of nutrient leaching into watercourses, as well as smog and air pollution from new plants. The result of this huge overhand of capacity was that in spite of utilisation rates dropping to 85%, China became a major net exporter of urea, peaking in 2015 at 13.7 million tonnes.

During the 2010s, following the financial crisis, the Chinese government has tried to move China from being a purely industrial economy to a consumer-driven economy, while at the same time starting to tackle the massive structural overcapacity that had developed in virtually all industries, and from 2015, also starting to make progress with cleaning up the country's environment.

The 'New Era'

By 2016, China had already begun a series of new environmental initiatives, including four rounds of environmental inspections which lasted to September 2017. This

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led to a wave of temporary shutdowns of polluting industrial plants, and the worst polluters who had emissions problems identified were not able to reopen until they met tighter environmental standards. At the same time, the “2+26 Cities Air Control Plan” was launched, which led to winter shutdowns of industry in the vicinity of Beijing, Tianjin, and 26 other cities in the worst affected areas, to balance out the additional coal burning for power generation and domestic heating that occurred from October to March.

China’s new direction was given an official stamp from the very top in October 2017 at the 19th National Congress of the Chinese Communist Party (CPC), where president Xi Jinping gave a speech announcing what he described as the beginning of a ‘New Era’ for China. The speech marked the beginning of Xi’s second five year term as president of China, and Party Congresses are held only every five years – it was thus a major occasion and Xi took the opportunity of it to lay out a 14 point programme which the Communist Party promptly enshrined in its constitution as ‘Xi Jinping Thought on Socialism with Chinese Characteristics for a New Era’ (or simply ‘Xi Jinping Thought’). Only two other leaders have had their policy statements adopted as official adjuncts to the Chinese constitution; Mao Zedong and Deng Xiaoping. As such it marked a watershed moment in Chinese politics, in which president Xi set out a vision of building a “beautiful China” via a “national policy for energy conservation and environmental protection”, and regarding improvements to the environment as being on a par with economic development.

The speech came at a time when China was engaged in one of the largest environmental crackdowns in the country’s history, following an 18 month nationwide tour by government inspectors during which more than 80,000 factories were fined or temporarily closed for environmental violations, and more than 12,000 government officials were disciplined for failing to properly enforce environmental regulations. This crackdown was given fresh impetus by Xi’s policy announcement, and a series of new laws followed to drive home the message, including a new environmental tax from January 2018 which replaced the previous ‘pollutant discharge fee’. The new law set a standard rate of environmental tax for all companies, instead of charging different rates in different provinces.

Yangtze River shutdowns

The Yangtze river has been one of the focal points for the environmental cleanup, via a government document issued in June 2017 called the “Guidance to Enhance Industry Green Developments in The Yangtze River Economic Belt”, an attempt to reverse the effects of industrial development along the river and promote sound environmental policy. While the details of implementation are left to local provincial governments, there are a total of 47 key projects for relocation or transformation of hazardous chemical manufacturing companies which must be finished by the end of 2020. Strict standards in energy consumption and environmental protection are being imposed on newly built projects. High-pollution industries such as coking, tanning and electroplating are being strictly controlled, and companies with older and less efficient production capacity not in line with national industrial policy are forbidden to relocate to the upper and middle reaches of the Yangtze River. Wastewater discharges and phosphogypsum disposal are typically the main environmental problems for phosphates producers.

The move has affected China’s phosphate industry more than its nitrogen industry, as the former is concentrated in the provinces along the Yangtze river; Sichuan, Guizhou, Hubei and Anhui. Even so, around 900,000 t/a of urea production is affected by the legislation, with Hebei Yuanlong and Shijiazhuang Zhenyuan due to relocate before October 2019.

Rising costs

The net effect of these crackdowns has been to raise the cost of urea production. Most of China’s ammonia production is based on coal gasification, and Chinese government attempts to rein in coal mining overcapacity and push electricity generation towards less carbon intensive sources like natural gas and renewables have driven up both coal and natural gas prices, and hence the cost of ammonia feedstock – this has been exacerbated by shutdowns of ammonia and urea capacity for similar breaches of environmental regulations that the phosphate industry has faced.

On coal, the government’s aim is to reduce coal’s share of China’s energy mix to 65% by 2017 and 58% by 2020 as part of its commitments under the Paris climate agreement. Chinese coal produc-

tion peaked in 2013 and 700 million t/a of capacity closed between 2016 and 2018. The government’s target is for 800 million t/a of closures during the current Five Year Plan (2016-2020). While there has been some new, more modern and efficient capacity being opened, the effect was to push coal prices up dramatically in 2016 and by a significant amount in 2017 (there was actually a small net increase in Chinese coal capacity in 2017). Particularly affected have been urea plants with older, less advanced gasification systems which require more expensive anthracite coal to operate, and most of those that can have switched to cheaper bituminous coal. Chinese anthracite coal prices doubled from mid-2016 to the end of 2017, and although they relaxed slightly during 2018, they remain at historically high levels.

On the natural gas side, things have also become difficult for urea producers who are based on gas-based production. China hopes to replace large tranches of coal-based power production with renewables and nuclear but also natural gas-based production. China is a net gas importer and in spite of increasing unconventional gas production from shale gas, tight gas, coalbed methane and sour gas, the country is a large importer of LNG as well as pipeline gas. Although LNG prices are considerably down from their peak of \$14/MMBtu a few years ago, at \$6.50-8.00/MMBtu, they are still considerably higher than domestic Chinese gas prices. This means that Chinese urea producers cannot rely upon LNG imports to operate cost efficiently.

New environmental regulations of course also impose additional costs of compliance, and at the same time China is facing increases in energy costs and also in labour costs, the latter due to a rapidly ageing workforce – a demographic consequence of several decades of the ‘one child’ policy which is now filtering through into fewer new workers entering the economy at the same time that older workers are retiring.

All of this has had an adverse effect on the cost structure of the Chinese urea industry. Chinese natural gas and anthracite based plants are now at the top of the urea cost curve, and even the bituminous coal plants are near the top, making it competitive internally within China but less so on the international market, with a break even cost of \$240/t f.o.b.

Prospects for demand

The Chinese government has set a target that there be zero growth in nitrogen fertilizer demand in China from 2020, and consumption has actually been falling over the past four years. On the other hand, consumption from industrial uses continues to rise. While fertilizer demand represented 76% of Chinese urea consumption in 2018, urea formaldehyde and other resins for fibreboard production represented 15%, melamine production, again mainly for resins another 7%, and other uses such as urea solutions for diesel exhaust scrubbing (AdBlue/DEF) are also rising rapidly. In the short term, however, these are unlikely to balance reductions in fertilizer use. Chinese urea consumption fell from 61 million tonnes in 2015 to an estimated 52 million t/a in 2018. With fertilizer consumption likely to remain fairly constant going forward, incremental increases in industrial demand for urea could see this rise to 53.5 million t/a by 2022. Nevertheless, overall Chinese domestic urea demand is largely stagnant and not able to come to the rescue of overcapacity.

Capacity closures

All of this makes for a very challenging environment for China’s urea producers, especially for older plants, using less efficient coal gasification technology which often requires anthracite coal, and which produce more pollution. Last year Integer Research calculated that around 30% of Chinese urea capacity up to 23 million t/a – is more than 20 years old and faces closure. Peak urea production in China was 68 million t/a in 2015. This fell to 65.7 million t/a in 2016, and just 54.3 million t/a in 2017.

How much of capacity is idled, how much permanently closed, and how much simply operating at lower production rates is more difficult to assess. Further reductions in effective capacity have come from the government’s emission permission licenses, introduced in late 2017, which set an annual ceiling for emissions, and which can force a closure for part of the year once the plant’s limit is reached. Winter closures in the 2+26 cities area affects around 20 million t/a of urea capacity, and forces its closure from September to May. It is estimated that urea production in the affected region may be down by one third, taking 6 million t/a of the market. Still other plants have stopped producing ammonia and instead

are importing ammonia to produce urea (or, more frequently, diammonium phosphate). This has led to a surge in Chinese ammonia imports, to 500,000 t/a in 2017 and 1 million t/a in 2018.

Overall, best estimates are that around 12-13 million t/a of Chinese urea capacity was permanently closed from 2015-2017, taking capacity to 74 million t/a. Another 2.6 million t/a closed in 2018 according to CRU estimates, with 7.6 million t/a of capacity idled. Taken together with the winter air pollution restrictions and normal operational outages, Chinese urea production fell to an estimated 54 million tonnes in 2018, only 2 million tonnes above domestic demand, even though higher urea prices during 2018 (no doubt in no small part due to the programme of closures) helped buoy the Chinese market.

There have also been some new plants, often replacing older, less efficient capacity at the same site. During 2018, Ningxia Petrochemical added 800,000 t/a of new urea capacity, Hualu Hengsheng 1.0 million t/a and Xinganmeng Boyuan 520,000 t/a. Another 6.9 million t/a of new capacity is expected to come on-stream during 2019 and 2020, and another 4.4 million t/a is under development and could be added out to 2023, most of it in the coalfields of Inner Mongolia. Even so, the forecast is for overall Chinese urea capacity to continue to fall over this period as more older, less efficient and less economic capacity closes. Chinese information service BAIINFO forecasts Chinese urea capacity to fall to 65 million t/a by 2020, although actual production is nevertheless likely to rise as relocations are completed and more plants meet the new pollution requirements.

Exports

As noted above, a few years ago China was the world’s largest urea exporter, with 13.7 million tonnes shipped overseas in 2015. The rapid programme of closures has however seen this fall rapidly; to 8.9 million tonnes in 2016, 4.7 million tonnes in 2017, and just 2.4 million tonnes in 2018. Even so, production ran so close to demand in 2018 that in order to meet that 2.4 million tonnes stocks of urea at

Chinese ports were drawn down heavily, falling by almost 1 million tonnes. Inventories at producers are also reported to be lower. At the same time, imports have risen, from virtually nothing in 2015 to 200,000 tonnes in 2018. And this is a net import figure – one complicating factor with the import/export balance has been shipments of urea from Iran. Since the US placed economic sanctions on Iran in October 2018 over the country’s alleged breaches of its nuclear agreements, significant volumes of Iranian urea have been making their way to China, where they are quietly re-bagged and re-exported.

Chinese urea consumption fell from 61 million tonnes in 2015 to an estimated 52 million t/a in 2018.

Fertecon recently estimated that around 400,000 t/a of the export figures for 2018 could represent re-exports of Iranian urea.

There are signs that Chinese exports are increasing again now; export figures for Q4 2018 and Q1 2019 were higher than the comparable figures for the previous year. Overall, it is estimated that Chinese urea exports will reach about 3.0 million t/a for 2019, and the expectation is that 2018 will be the low point for now – as noted above, the impact of new, more efficient capacity will be to increase production by up to 4 million t/a by 2023. Some of this will be absorbed by additional domestic demand, but overall Chinese exports may rise to 3.7 million t/a over that period – a shadow of their previous figure, perhaps, but probably a more sustainable long term level.

US-China trade dispute

Finally, one other potential complication has been the ongoing trade dispute between the US and China, which has seen numerous types of good facing additional tariffs. One of the key commodities affected has been deliveries of US LNG – China placed a 10% tariff on imports of US LNG in September, which has helped push up Chinese domestic gas prices and force gas-based urea producers to idle capacity. The dispute has not otherwise notably affected urea markets so far, and at time of writing there were encouraging noises coming from both sides about “productive” talks about ending the impasse. However, president Trump’s mercurial nature makes for greater uncertainty about the final outcome. ■

The merchant ammonia market

PHOTO: MARTIME CONNECTOR



Ammonia shipping is usually via LPG tanker.

New capacity has is being developed in Russia, Indonesia and the Middle East, while the US continues to build plants aimed at import substitution, reducing demand there.

While most ammonia goes to captive, downstream uses, particularly urea and nitric acid/ammonium nitrate production, some ammonia is traded across borders. These volumes are relatively small compared to ammonia production as a whole, as ammonia is relatively difficult to handle. Nevertheless, there is a significant merchant ammonia market, representing about 10% of ammonia production; the merchant ammonia market stood at 19.0 million t/a in 2017.

Demand

Demand for merchant ammonia is broadly split into fertilizer-based demand and industrial or so-called 'technical' demand. Fertilizer demand is the largest slice, representing 64% of merchant ammonia demand. Fertilizer-based merchant ammonia demand is often for ammonium phosphate production – phosphate is the larger, bulkier raw material, so mono- and di-ammonium phosphate (MAP/DAP) capacity is often based around phosphate production: around 45% of the merchant ammonia market goes towards phosphate production.

Some fertilizer merchant ammonia demand is also based around urea or ammonium nitrate production; where feed-

stock prices make it too expensive to produce ammonia domestically, but there is written down nitrogen capacity which can still be utilised. This is the case in parts of southern Africa, for example, which import ammonia from South Africa. About 15% of merchant ammonia production goes to downstream nitrogen production.

Finally, technical demand for ammonia also represents a significant factor in merchant ammonia markets – around 36% of merchant ammonia goes to industrial uses, including caprolactam, acrylonitrile, adipic acid, isocyanates (for polyurethane production), and low density (explosive grade) ammonium nitrate. Large technical importers include South Korea, Taiwan, and, increasingly, China.

Changing patterns of demand

The largest importers, historically, have been the United States and India. However, US imports of ammonia are on a steady downward trend as more domestic capacity is built. This has been a consequence of the shale gas boom which has reversed the previous trend for US ammonia capacity to drift overseas to Trinidad. In 2012, at the peak of its import demand, the US bought 7.8 million t/a of ammonia from overseas.

By 2017 this had fallen to 3.7 million t/a, and this trend looks set to continue. In April 2018, BASF and Yara opened their new joint venture 750,000 t/a ammonia plant at Freeport, Texas, based on hydrogen-rich off-gas from other plants in the vicinity. US ammonia production rose to 12.5 million t/a in 2018, and imports dropped to 2.6 million t/a according to the USDA. There were also 430,000 t/a of US exports. After Freeport there had been something of a hiatus in new US project announcements aside from a few small-scale project developments, and a number of previously announced projects still looking for finance, but then in October 2018 Cronus awarded TKIS the contract to build a new 760,000 t/a ammonia plant at Tuscola, Illinois. Construction is due to begin this year for completion in 2022.

In India, meanwhile, there are half a dozen new urea projects with ammonia plants attached, but no standalone ammonia capacity planned, and India's ammonia imports (2.3 million t/a in 2018) are unlikely to be affected.

New demand is however likely to come from two major sources; Morocco and China. Morocco imported 1.8 million t/a of ammonia in 2018, up 800,000 t/a in just two years as new phosphate capacity comes onstream at the Jorf Lasfar phosphate hub. Morocco's OCP is expanding its MAP and DAP capacity to try and monetise its huge phosphate rock reserves, and has no domestic natural gas reserves to feed ammonia production, consequently having to rely upon imports. IFA forecasts that Moroccan ammonia demand could reach 2.7 million t/a by 2022. In China, as we discuss elsewhere in this issue, new environmental legislation is challenging domestic nitrogen production. Chinese ammonia imports rose to 720,000 t/a in 2017 and 1.0 million t/a in 2018, and this trend is likely to continue as long ammonia prices on the international market are lower than Chinese domestic production costs – last year CRU put the break-even cost at about \$350/t. Chinese ammonia imports have been particularly for industrial uses, including its burgeoning caprolactam industry.

Production

Ammonia capacity aimed at the merchant market is usually based on low feedstock costs in coastal locations for easy access to international shipping. For this reason little merchant ammonia capacity is based on coal-based production (South Africa is something of an exception), but instead

cheap, stranded or associated natural gas production. As such, the siting and building of merchant ammonia capacity is intimately connected with natural gas pricing.

The largest exporters of ammonia have been Trinidad and Russia over the past few years, with Canada, Algeria, Indonesia and the Gulf countries (Saudi Arabia, Qatar and Iran) some way behind. Trinidad used to predominantly supply the US market, but Trinidad has been hit by both rising domestic US production and gas supply curtailments which have kept the island to below 75% utilisation rates. Trinidad's exports have averaged around 4.0-4.5 million t/a for the past few years.

Ukraine was also once counted as one of the major exporters, but Ukrainian export tonnages have fallen markedly, due to the conflict in the east of the country, and rising gas prices which have forced the virtual shutdown of the Odessa Port Plant (OPZ).

New capacity

As well as the Kingsport ammonia plant mentioned above, last year also saw the start-up of the 660,000 t/a Panca Amara Utama

(PAU) ammonia plant in Indonesia, which loaded its first cargo in July 2018, although it didn't reach design capacity until December. The next large addition to merchant ammonia capacity is due to come in June 2019 from the start-up of the 890,000 t/a Eurochem Kingisepp facility in northwest Russia.

Further down the line, Algeria could see additional export capacity from Fertil (about 300,000 t/a) in 2021 or 2022, Salalah Methanol in Oman (330,000 t/a by 2021), while as noted above, Cronus in the US could reduce US ammonia import demand by 760,000 t/a from 2022.

Trade patterns

Shipping costs are also important to the merchant ammonia market. For this reason much (about 80%) ammonia trade is inter-regional; across the Mediterranean, Black or Baltic Seas to Europe, for example, across the Caribbean Sea to the US, from the Middle East to India, or across the Pacific to East Asia. In terms of longer distance trade, the ammonia market is usually assumed to be split into two major hemispheres, with the Suez Canal in Egypt acting as the dividing line.

However, changes in the supply and demand balance are changing some of the established trade patterns. As US imports fall, so Trinidadian ammonia is displaced elsewhere; to Europe, Morocco and even the Far East. Meanwhile, industrial demand remains strong in China, South Korea and Taiwan and – in spite of the start-up of the PAU plant in Indonesia – there is a deficit in ammonia markets in the region, which is drawing more supply from Russia and Trinidad. With markets west of Suez in relative surplus, cargoes are moving east of Suez more frequently.

Iranian sanctions

Iran is a major exporter of ammonia, and so the resumption of US sanctions on Iran has the potential to complicate matters somewhat – paying for ammonia cargoes is far more difficult with US banks refusing to handle payments to Iran. Most Iranian ammonia goes to India – around three quarters of Iran's exports. While China may be willing to accept ammonia imports from Iran, India's willingness to do so under the new sanctions regimen remains an open question. ■



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This year's Nitrogen+Syngas conference was held from March 4th-7th in Berlin.

Nitrogen+Syngas 2019

PHOTO: FRETSCHE / SHUTTERSTOCK.COM

The Nitrogen+Syngas conference continues to be one of the most well-attended meetings in the syngas and downstream nitrogen technology calendar. In this, the conference's 32nd year, it attracted over 770 delegates to the slightly austere Estrel Centre on the southeast side of Berlin. A brief overview of some of the papers presented follows.

CRU's Josie Armstrong introduced the conference, describing the nitrogen investment environment – one of capacity additions outpacing demand in the past couple of years, balanced last year by Chinese capacity closures. Nitrogen producers face falling prices and squeezed margins, and consequently many are being forced to redefine their strategies to secure growth. New investment is coming in areas such as premium and speciality fertilizers, faster growing markets such as Brazil and Africa, and in better vertical integration.

Market papers

Laura Cross, CRU's head of nitrogen analysis, took up some of these themes in her market overview, focusing on several of the key developments affecting nitrogen markets. China's capacity rationalisation, as discussed elsewhere in this issue, could see in Laura's view another 12 million t/a of urea capacity closed over the period 2019-2023, mostly older, anthracite coal-based capacity. Winter gas shortages and air pollution restrictions affect another 20 million t/a of capacity for around half the year. Even the emergence of China as a re-export route for Iranian urea will not overcome this rapid fall in Chinese exports.

India is set to import 1.7 million t/a of urea less by 2023 due to new plant start-ups, but the likely completion dates of many of the new Indian projects will be pushed back beyond that date, and gas supply for some of the new plants still remains uncertain. Meanwhile, overall new capacity addi-

tions in 2020-21 worldwide will be less than new demand, leading to price tightening. However, many geopolitical uncertainties remain, from the US-China trade dispute, Iranian nuclear sanctions and India's elections.

Holger Weiss of German credit bank KfW looked at some of the ways in which plant financing has changed in the past ten years. Regulation has increased since the financial crash, making lenders more risk averse. A capital intensive industry with volatile feedstock prices, and potential environmental and reputational challenges is not necessarily seen as a good risk. However, mitigation strategies can overcome banks' reluctance, via offtake and feedstock supply contracts, hedged gas prices or other price risk mitigation (e.g. tying gas prices to product prices, as occurs in Trinidad). Environmental and social due diligence is also a must these days, to head off land and labour issues, questions of biodiversity etc, especially if a project can adhere to the IFC's performance standards on the subject.

Ammonia in the new energy economy

Three papers looked at the prospects for 'green' ammonia. Kazutaka Hiraoka of JGC presented the results of a cost study conducted as part of Japan's Basic Hydrogen strategy. Japan is committed to reducing CO2 emissions by 25% by 2030 (compared to 2013) and is looking for low carbon fuels for power generation. As part of this, it is seriously considering large scale ammonia import as a hydrogen carrier, or even burning ammonia produced by renewable electricity (or conventional means plus carbon capture and storage) as a fuel. By 2030 Japan could be importing 1.9 million t/a of ammonia to make 300,000 t/a of hydrogen.

thyssenkrupp Industrial Solutions presented 'off the shelf' modular designs for 50 t/d and 300 t/d ammonia plants based on TKIS' own alkaline water electrolysis technology. Capital costs are already comparable to conventional small ammonia plants, and are improving. Operating costs obviously depend on the cost of renewable electricity, but this too continues to fall.

Finally, the Technical University of Braunschweig considered some of the potential catalyst poisoning issues by oxygen or water in an electrolysis-based ammonia plant.

Advanced process control

Another of Tuesday's sessions focused on the ongoing digitalisation of the industry.

Michael Fjording of Haldor Topsoe highlighted his company's new *ClearView* service concept, developed in conjunction with Honeywell, which uses live plant data to provide visualisation tools to help operators better understand and manage their plants, as well as pro-active communication from Topsoe's experts who are also monitoring the data with suggestions or support.

Saipem likewise had their *XSiGht* digital framework which focuses on predictive maintenance using machine learning techniques to provide more effective troubleshooting and tackle potential plant problems before they occur, while Siemens looked at advanced process control using a 'digital twin' of an existing plant to identify areas for improvement in process control and suggest optimisation strategies.

Other process control papers included using Raman spectroscopy for on-line urea process control and analysis, jointly presented by Casale and Endress+Hauser – Kaiser Optical Systems.

Commissioning case studies

Two papers closed out the first day of the conference looking at recent plant commissioning experiences. The first, with the PAU ammonia plant in Indonesia, was presented by Annie Jing of KBR. The 700,000 t/a unit on Sulawesi is the first plant to use KBR's *Purifier Plus* process scheme, combining the *KRES* reformer exchange system with the Braun Purifier. Magnetite passivation and continuous filtration helped prevent foaming in the amine CO₂ removal system during commissioning, but commissioning was delayed by issues with the cryogenic nitrogen plant and compressor lubrication systems. Neste Engineering Solutions also reported on the start-up of the SOCAR urea plant in Azerbaijan.

Ammonia technology

Among the ammonia technology papers, Klemens Wawrzinek of Linde reviewed the current status of the Linde Ammonia Concept (LAC). After a few lean years with no references LAC is back, with recent installations at Jubail in Saudi Arabia, JR Simplot in Wyoming, KuibyshevAzot at Togliatti in Russia, and, at Salalah in Oman, an ammonia synthesis adjunct to the existing Salalah Methanol Company plant is being constructed, using hydrogen rich purge gas from the methanol unit, due for completion in 2020. Linde has developed a modular concept for plant construction for 150 t/d

and 300 t/d plant, and also illustrated modularisation of a larger reformer construction to minimise site work.

Methanol co-production

Co-production of methanol and ammonia occupied three papers on the morning of Wednesday 6th. Esbe Sorensen of Haldor Topsoe described the large-scale *SynCOR* Methanol process – there is more on this and other Topsoe co-production technologies on pages 28-30 of this issue. John Pach of Johnson Matthey illustrated a variety of options for ammonia and methanol co-production, depending on the balance of products desired, as well as other downstream co-production options such as formaldehyde, urea formaldehyde concentrate, mono ethylene glycol (via a tie-in with Eastman), and methylamines and derivatives.

Finally, Vaois Kitsos of TKIS introduced a co-production option using TKIS' Ude ammonia technology combined with *AdWin-Methanol*, developed by GasConTec, and capable of large scale production from 3,000 to 10,000 t/d. So-called *AdWinCombined* integrates the two processes for 30% lower capex and 10% lower fuel consumption.

Reformer management

Several papers tackled the subject of management of steam reformers, including controlling temperature fluctuations in down-fired reformer furnaces, by BD Energy Systems; balancing production and reliability in a steam reformer, by Quest Integrity; internal and external 306 degree reformer tube inspection, by Reformer Services; and reducing stress and increasing reformer tube throughput by IKR Richter Technology. Several of these are described in far greater detail in our article on reformer stresses on pages 32-49.

Urea technology

Urea technology papers covered topics including the installation of a *MicroMist* Venturi acid scrubber in a urea granulation plant, which reduced urea dust emissions to less than the stringent 5mg/Nm³ target. Entechmach described the modernisation of a CO₂ centrifugal compressor train in a urea plant.

Materials

A number of papers dealt with the subject of construction materials – always a con-

cern in some of the high stress environments of ammonia, urea and nitric acid plants. Giovanni Rinaldi of Belleli Energy described a quality assurance approach to handling duplex materials, from education and training, through advanced design studies, to proper monitoring and procedure validation in post weld heat treatment.

Barinder Ghai of Sandvik Materials Technology discussed the importance of reformer pigtail material selection. Pigtail creep rupture can be a common cause of plant downtime and potential risk to plant personnel. Sandvik's *Sanicro 31HT* is an alloy designed for high creep strength and good resistance to oxidation and combustion gases at high temperatures (up to 1100C), especially suitable for outlet pigtails.

Sho Kubota of Toyo Engineering also took material selection as a topic, this time in urea plants, to guard against carbamate corrosion. Toyo has developed a series of modelling programs which simulate corrosion in different areas of a plant under different plant operating conditions, validated against real world data, and augmented by sensor packages which can provide real time data from operating plants. This can assist with optimum deployment of passivation air as well as predictive maintenance and selection of the best materials for the job.

Product finishing

The final session on Wednesday looked at product granulation and finishing. Barbara Cucchiella of Stamicarbon showed the evolution of Stamicarbon's urea granulation technology, from its initial application, through the addition of MMV Venturi scrubbing technology, to re-working the system to handle urea ammonium nitrate and more recently urea ammonium sulphate, as recently installed at Eurochem's Novomoskovsk site, and 'multi-product' granulation, with macro- and micro-nutrient additions.

Dan Kuttentkuler of Koch Agronomic Services also took up the cause of enhanced efficiency products, including the addition of nitrification or urease inhibitors, coatings for slow release and controlled release, and the addition of these technologies to existing urea granulation plants.

Finally, Dr Theodora Kouloura and Evangelos Petkos of New Karvali Fertilizers in northern Greece described their company's 35 years of experience with AN and CAN granulation using a high temperature pan granulator. ■

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Strategies for ammonia and methanol co-production

IMAP Methanol unit at the Shchekinoazot site, Tula, Russia.

PHOTO: HALDOR TOPSOE

Table 1: Ammonia and methanol co-production plants

| Location | Methanol capacity t/d | Ammonia capacity t/d | Start-up |
|--------------------------|-----------------------|----------------------|-------------|
| Middle East | 72 | 286 | 1993 |
| USA | 363 | 600 | 1994 |
| China | 120 | 600 | 1999 |
| Kedah, Malaysia | 200 | 1,125 | 1999 |
| China | 136 | 314 | 2003 |
| Tatarstan, Russia | 670 | 1,382 | 2015 |
| Tula, Russia | 1,350 | 415 | 2018 |
| Middle East | 3,000 | 900 | 2022 |
| Middle East | 3,000 | 900 | 2022 |

Source: Haldor Topsoe

The ability to produce both ammonia and methanol in the same plant allows for synergies in process design as well as spreading market risk for a plant development. This article looks at some of Haldor Topsoe's most recent developments in the area.

As methanol and ammonia plants are both based on reforming or partial oxidation of a carbon-based feedstock, typically coal or natural gas, there has often been interest in using a common upstream syngas generation section to produce both chemicals, taking advantage of synergies between the processes to produce multiple product streams more efficiently than via two stand-alone plants, and spreading market risk. Haldor Topsoe have been among the companies most in the forefront of developments of ammonia and methanol co-production, and this article describes some of their process developments and the impetus behind them.

IMAP Ammonia+

The beginnings of ammonia and methanol co-production go back to the early 1990s, when changes in US vehicle fuel regulations led to the mandating of the addition of oxygenated fuel components, especially methyl t-butyl ether (MTBE), a methanol

derivative. The very high prices that methanol therefore commanded for a few years led ammonia producers in the US and elsewhere to consider adding methanol side-streams to their plant to capture some of this added value.

Traditional co-production strategies thus generally used an ammonia plant as a base with the possibility of co-producing methanol. This was achieved either by converting part of the process stream from the reformer into methanol synthesis as a smaller side stream typically carried out at low pressure or by IMAP Ammonia+ (Integrated Methanol Ammonia Process) offered by Topsoe where the methanol synthesis unit is located between the first and second casing of the synthesis gas compressor. IMAP Ammonia+ also include a methanation reactor downstream the methanol synthesis unit removing the CO from the process stream and assisting with gas clean-up prior to ammonia synthesis.¹

The ability of bypassing the shift and CO₂ removal section adds valuable production

flexibility, where the methanol production can range from zero to the design capacity of the methanol unit. Typically, the methanol unit is designed to produce 15-35% of total plant capacity.

The Petronas plant at Kedah, Malaysia and the JSC Ammoni plant in Tatarstan, Russia (see Table 1), both designed by Topsoe as grassroots units, were based on this process scheme. Since then Topsoe has been marketing this process as IMAP Ammonia+. Topsoe estimates that investment cost compared to two standalone units is around 10-25% lower, and natural gas consumption is around 4% lower.²

IMAP Methanol+

Methanation worked where the primary product desired was ammonia, but the uptake of methanol as a fuel component – either on its own or via downstream conversion to MTBE, dimethyl ether (DME) or biodiesel – led to steadily increasing methanol plant sizes in order to produce the required

volumes. Methanol plants began to be typically larger than ammonia plants, sometimes twice as large or more. Co-production of ammonia and methanol therefore might often focus on methanol, with ammonia as a side stream. In order to meet this need and also refine the process to achieve greater efficiencies, Topsoe developed what it called IMAP Methanol+; the Integrated Methanol Ammonia Process, which it launched in 2012.³

IMAP Methanol+ aims to keep the simplest process layout to minimise capital cost, and comprises a 'once-through' methanol process. As shown in Figure 1, there is typically a pre-reformer to provide higher capacity and reduce steam production, optimising the syngas for methanol production.⁴ Air inlet to the secondary reformer is low, with high methane slip. Make-up gas to the ammonia synthesis has a high proportion of inerts (up to 18%) and the steam:carbon ratio is lower than usual at 2.2, but the process layout for ammonia synthesis is otherwise typical. However, the absence of a shift converter and CO₂ removal section and no need for an air separation unit make overall capital cost and opex lower. With methanol and ammonia synthesis happening at similar pressures, a common compressor train can also be used,

giving additional savings. Topsoe estimates that overall capex cost is 20-25% lower for the IMAP unit than for standalone ammonia and methanol plants of the same size, while natural gas consumption is around 2% lower overall. Production flexibility is lower, however, as ammonia capacity is governed by excess hydrogen from the methanol plant. This is why the flowsheet in Figure 1, used at the new Shchekinoazot plant in Russia, also includes an optional CO₂ pressure swing adsorber (PSA) which boosts ammonia capacity by up to an additional 100 t/d. Off-gas from the PSA, rich in CO₂ and CO, is used as fuel gas in the reformer, while hydrogen-rich product gas is mixed with the balance synthesis gas.

Production flexibility

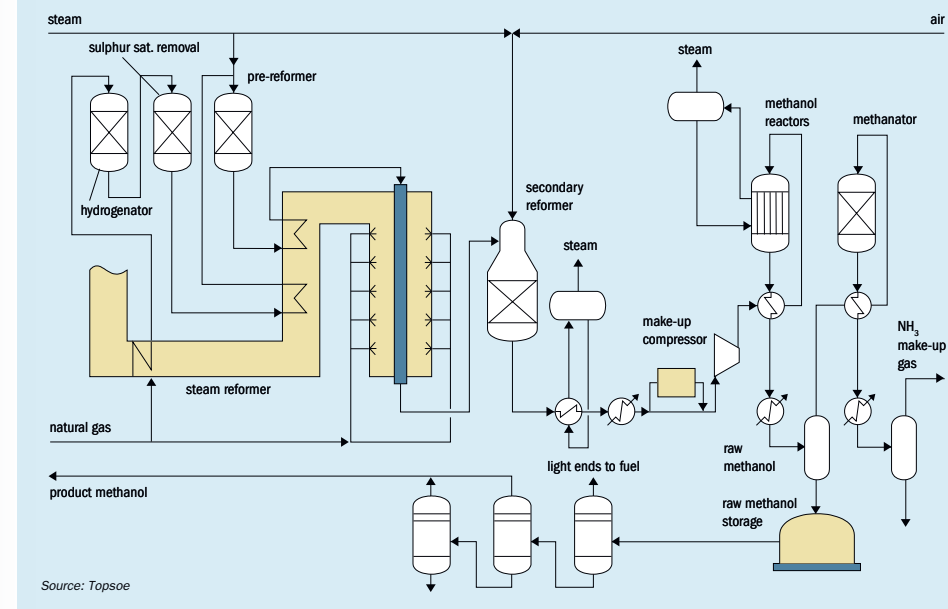
One of the striking things about the ammonia/urea and methanol industries is that in spite of the similarities in feedstock requirements and production processes, final product pricing is often equally determined by other factors – methanol prices often track global oil prices, for example, while ammonia and urea prices have closer relations with agricultural commodity markets. This means that peaks and troughs

of product prices can be at different times, as can be easily seen in our historical price graph for the three products on page 8.

The initial IMAP design was optimised for methanol and ammonia co-production with no downstream urea unit. However, ammonia production is often integrated into downstream urea production, and this necessitated a different design approach to achieve the right carbon balance, which Topsoe now markets as IMAP Urea+. The revised process flowsheet is similar to Figure 1, but puts the high temperature shift section – and, optionally, also a low temperature shift – back in downstream of the secondary reformer. The air inlet to the secondary reformer is enriched with oxygen. The pre-reformer has the same advantages as for the original IMAP process, and also ensures prolonged lifetime for the primary reformer catalyst and makes the plant less sensitive to variations in feedstock composition. Topsoe estimates capex savings for this configuration at 15-25% for the methanol and ammonia sections compared to standalone plants, and gas consumption around 1% lower.

An IMAP Urea+ plant can accommodate a wide range of hydrocarbon feedstocks,

Fig. 1: The IMAP Methanol+ process flowsheet



Source: Topsoe

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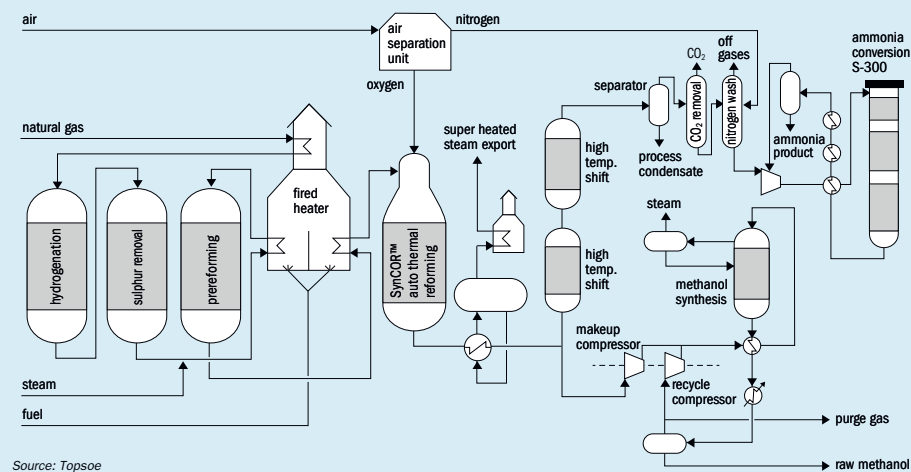
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Fig. 2: Topsoe SynCOR Plus™ simplified co-production layout



Source: Topsoe

including streams that contain CO₂. Addition of the low temperature shift section and enriched air allows the plant to have complete process flexibility between the proportions of ammonia, urea and methanol production. The proportion of ammonia converted to urea can be controlled by adjusting CO₂ levels.

SynCOR Plus™

Both ammonia and methanol industries have gradually moved to larger and larger plant sizes over the decades in order to achieve greater economies of scale. *IMAP*, being based on steam reforming technology, has an overall upper limit of around 3,000 t/d for a single stream, but it is recognised that these days producers may wish to take advantage of larger plant sizes.

Topsoe has developed a synthesis technology optimised for large scale production: *SynCOR*.⁵ *SynCOR*™ is an autothermal reforming (ATR) process, with a pre-reformer upstream of the main ATR reactor. It uses oxygen to eliminate nitrogen from the reformer inlet side and operates at a low steam:carbon ratio of 0.6, which reduces equipment size and lowers water consumption by up to 60% as well as boosting energy efficiency. The unique *SynCOR*™ ATR reactor design is based on Topsoe's experiences with low steam:carbon reforming for gas to liquids production, used in the Topsoe-designed Oryx GTL plant in Qatar, which was commissioned in 2006.

SynCOR™ produces syngas with a H₂:CO ratio of 2.0, ideally suited for methanol production.

For co-production scenarios, Topsoe offers what it describes as *SynCOR Plus*™. A typical flowsheet is shown in Figure 2, which assumes that methanol is the primary desired product, based on 5,000 t/d of methanol production, with 2,000 t/d of ammonia production, typical for a modern world-scale ammonia-urea unit. The reforming stream is split downstream of the ATR, to methanol and ammonia synthesis sections. Ammonia synthesis is inert-free, with pure nitrogen provided from the air separation unit. While no-one is likely to build a 7,000 t/d ammonia unit, the configuration allows a conventional sized ammonia plant to benefit from the upstream economies of scale of the syngas generation section.

Savings for a *SynCOR Plus*™ unit are estimated by Topsoe at: 5% in terms of natural gas consumption compared to two separate plants; 5% in terms of cooling water consumption and 60% for make-up water consumption; and up to a 25% reduction in CO₂ emissions if renewable electricity is used for powering compressors and other electricity consuming units.

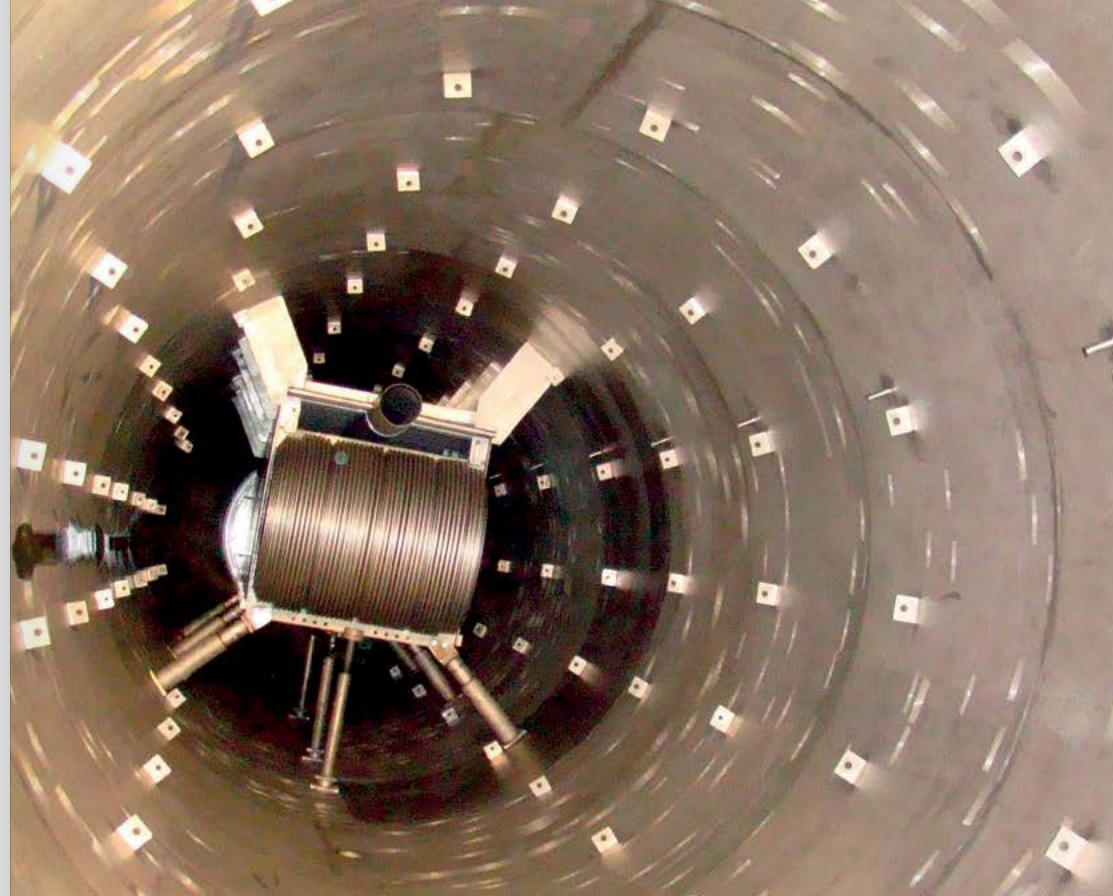
Market impetus

The development of co-production flowsheets has been a response to market interest. Topsoe says that there have been two kinds

of manufacturers interested in co-production in recent years; producers who are primarily makers of ammonia and urea who have spare cash that they want to invest in methanol production, as happened with Shchekinoazot; and project developers who are aiming primarily at the methanol market and want to achieve significant economies of scale, but who are limited by the ability of the market to cope with large new methanol plants and want to spread the product risk. With the current glut of natural gas on the US market, both kinds of developers are present, as our article elsewhere in this issue on US methanol developments testifies, and it seems that the dream of a 'syngas refinery', capable of producing multiple product streams from a single feedstock source may finally be coming to fruition. ■

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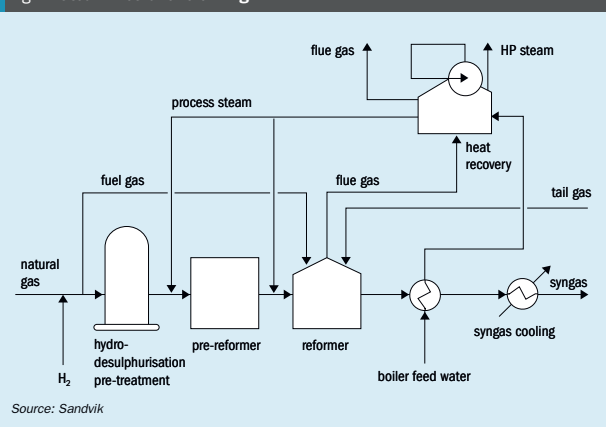
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Controlling the stresses of the primary reformer

Risk associated with the primary reformer is highly dependent on its operation. In this article we look at common problems associated with catalyst tubes, pigtails, operating close to material limits etc. and discuss latest practices and new materials to prevent these issues and allow plants to run at maximum output without unplanned outages.

Fig. 1: Steam methane reforming



Source: Sandvik

Steam reformers used in hydrogen, ammonia and methanol plants are complex, energy intensive and expensive. By nature their design is often aggressive, due to the need for harsh operating conditions and specialty materials. A failure in the primary reformer typically has large financial implications, often running into millions of dollars, as significant downtime is incurred alongside the costs of tubes, engineering and catalyst.

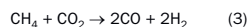
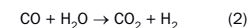
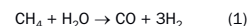
The basics

In a conventional steam reforming process (Fig. 1) hydrogen and mixture of CO/CO₂ are produced by reacting methane with steam over a nickel catalyst at high temperatures. The catalyst is contained in the reformer tubes, which are located in a box type fired

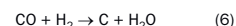
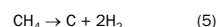
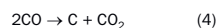
furnace (Fig. 2) that provides the large endothermic heat of reaction.

The basic reactions of the steam reforming of methane are expressed by the following chemical equations.

Desired reactions:

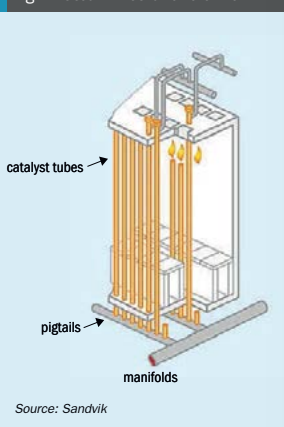


Unwanted reactions:



Reaction (1) is known as steam methane reforming, while reaction (2) is referred to

Fig. 2: Steam methane reformer



Source: Sandvik

as the water gas shift reaction. Both reactions are reversible and approach equilibrium. In addition to the desired reactions (1) and (2), other side reactions (3, 4, and 5) are under certain conditions also possible. Selection of suitable catalyst and appropriate operating conditions will promote reactions (1) and (2) and suppress reactions 4 to 5. Reaction (3) takes place in steam reformers where CO₂, available downstream of the CO₂ removal section, is recycled back to the reformer in order to increase CO formation in the syngas (methanol, oxo syngas production).

The conversion is favoured by a high steam to carbon ratio (in excess of the stoichiometric quantity), high outlet temperature, low pressure and high catalyst activity. There are restrictions and limitations for maximum conversion:

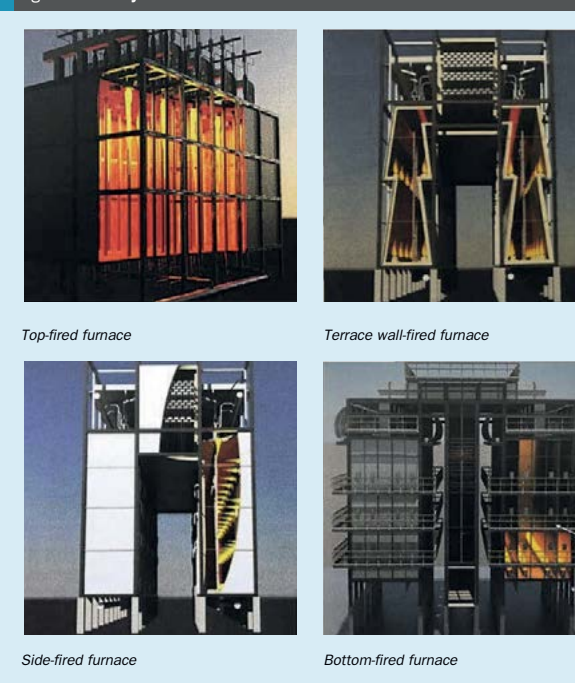
- A steam to carbon ratio that is too high will make the process less energy efficient, large quantities of excess steam have to be condensed and high volumetric steam flow will increase the equipment cost. Low steam to carbon ratio will improve the energy efficiency, but can form carbon in the catalyst pores and other undesirable byproducts.
- An operating temperature that is too high poses problems of heat transfer and lowers the mechanical strength of the reformer tube material (metal temperatures up to 960°C under pressure of about 35 bar). Low operating temperature reduces the conversion, but sometimes this offers an attractive possibility for conversion completion under optimum conditions downstream the primary reformer;
- An operating pressure that is too low increases the cost of equipment and makes the reforming process inefficient, as it is always necessary to compress the produced syngas at higher pressures for further processing (purification and synthesis). There are mechanical limits for higher reforming pressures, but in general higher reforming pressure reduces the overall operating and investment cost.
- Catalyst with too high activity could at first improve the conversion rate, but because of its sensitivity, it may easily lose activity due to feedstock impurities, or because of maloperation. Small size catalyst in a given total reformer tube volume will present a higher surface to catalyst volume ratio and thus a higher conversion rate and a better approach to equilibrium, but also gives a higher pressure drop. Loss of activity may lead to reformer tube overheating, as reduced conversion means less heat absorption for the endothermic reforming reaction.

Primary reformer configurations

Several configurations of reforming furnaces are in use today, characterised mainly by the disposition and position of the burners. The most common types are top-fired, side-fired and terraced wall-fired reformers. Bottom-fired reformers are not very common in modern syngas plants. Fig. 3 shows the overall geometry of these reformer furnaces.

The top-fired reformer uses multiple rows of reformer tubes with burners located in the arch on each side of the

Fig. 3: Geometry of reformer furnaces



SOURCE: IIR RICHTER

tubes. The heat to the reformer tubes is supplied by the radiating products of combustion. The main advantage of this configuration is the few burners relative to the reformer tubes, the higher radiant efficiency, the presence of the high heat flux zone in the "cold" inlet of the feedstock and the very large reformer tube number which can be accommodated in one radiant box. The main disadvantages are the limitation in the heat input control and the hot operating level at the top.

The side-fired reformer has multiple radiant wall burners along both side walls and one row of reformer tubes in the middle of the box. The heat to the reformer tubes is emitted from the radiant walls. The main advantage is the uniform heat distribution and the very good heat input control. Disadvantages are the large number of burners required, the lower radiant efficiency and the size limitation of the fired box (single box for 100 to 150 reformer tubes).

The terraced wall type, developed by Foster Wheeler may be regarded as an

intermediate between the side-fired and bottom-fired reformers. The reformer has inclined walls with several terraces on which upward firing burners are installed. This unique burner positioning makes it possible to adjust the heat flux in each zone.

Bottom-fired furnaces have a rather constant heat flux profile along the reformer tube with high metal temperatures on the outlet side.

The high heat flux and the high reformer tube skin temperature at the upper part of the reformer is the main characteristic of top fired reformers. In the side-fired and the terraced wall reformer the heat flux along the reformer tube and the conversion are more uniform. In Fig. 4 the respective profiles of reformer tube skin temperature, heat flux, and methane conversion are shown for the two most common reformer furnaces.

In a conventional reforming process only 40% of furnace duty is absorbed by the endothermic heat of reaction. About 35% is recovered in the form of waste heat export steam, by utilising part of the



Inspired by
The School of Athens, Raffaello Sanzio 1509-1511
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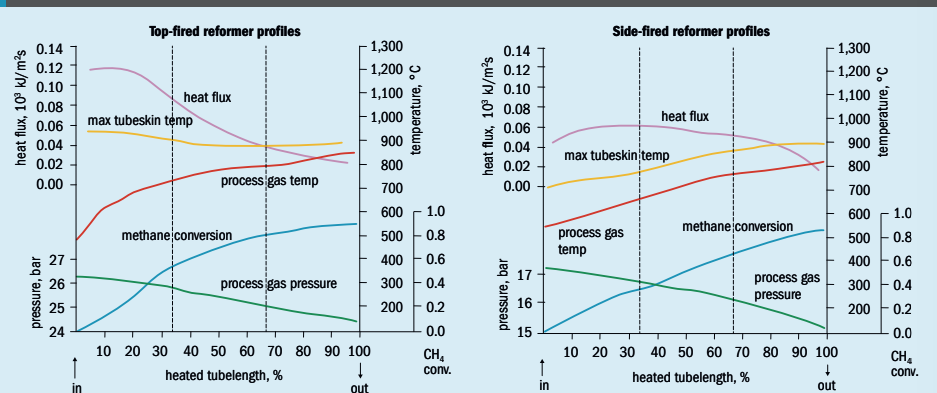
New catalyst
developments

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Fig. 4: Reformer furnace temperature and heat flux profiles



Source: IKR Richter

latent heat of the syngas for CO₂ removal and by preheating feed stock-combustion air or boiler feed water in the convection section of the reformer, where flue gas is cooled from 900 to 950°C to about 125 to 150°C. In the region of 20 to 25% of the heat applied is lost in the stack, in cooling water and in heat losses.

Overview of reformer tubes

The most critical item in a fired reformer are the reformer tubes in which the catalyst is placed. Reformer tubes constitute up to the 30% of the total reformer cost. For mechanical and process reasons, a typical reformer tube is 10.0 to 14.0 m long, with ID of 75 to 140 mm and wall thickness between 8 and 15 mm. Reformer tubes are usually centrifugally cast and machined in the internal borehole. The tubes are typically made in 3-4 sections consisting of individual castings.

The size of the primary reformer has increased step by step over the last decades due to increasing ammonia plant capacities. Whilst a primary reformer for a 400 t/d ammonia plant designed in the 1960s had less than 200 reformer tubes, a reformer for a 3,300 t/d ammonia plant designed nowadays is equipped with more than 400 reformer tubes arranged in eight rows. Although ammonia plant capacities have increased considerably the number of installed reformer tubes, i.e., the installed heat exchange area, has been reduced continuously for a given capac-

ity. A modern reformer for an ammonia plant capacity of 1,000 t/d has less than 900 m² heat exchange area. The same reformer designed more than 30 years ago had a heat exchange area of more than 1,300 m². Together with the optimisation of the reformer tube pitch, i.e., the tube-to-tube distance and the tube row distance, a very compact reformer design is available today.

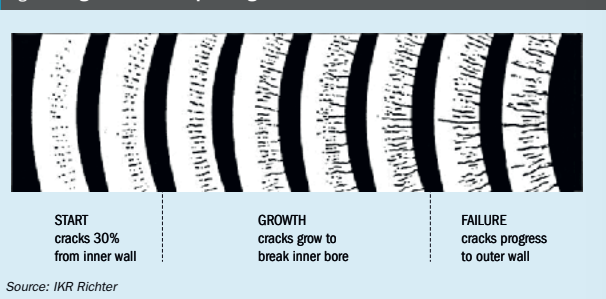
Stress to rupture of reformer tubes

The high operating temperature and pressure to which the primary reformer tubes are exposed mean that the reformer tubes are close to the metallurgical limits and therefore operate in what is commonly known as the, "creep regime". This means that reformer tubes will suffer gradual plastic deformation, resulting in micro-

voids, which develop into large cracks with time in service. Eventually the cracks will propagate throughout the thickness of the reformer tube such that process gas can leak from the reformer tube into the flue gas side of the reformer. This is illustrated in Fig. 5, which highlights the progression of creep through a reformer tube with time.

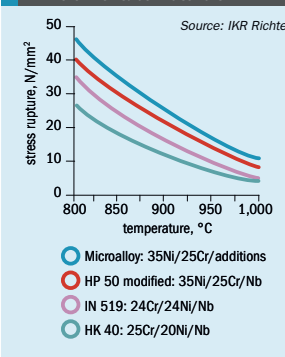
Once cracks have reached the inner wall the reformer tube can be considered to have failed. Although this will normally take many years it can, in very specific process circumstances, happen in a matter of minutes. As can be seen from Fig. 6, stress to rupture is dependent on the tube wall temperature with modern micro-alloys offering significant benefits over older materials. As a result the tube wall thickness has been reduced considerably whilst keeping the same design tube life time as before (100,000 hour).

Fig. 5: Progression of creep through a reformer tube



Source: IKR Richter

Fig. 6: Stress-to-rupture values of reformer tube materials



Source: IKR Richter

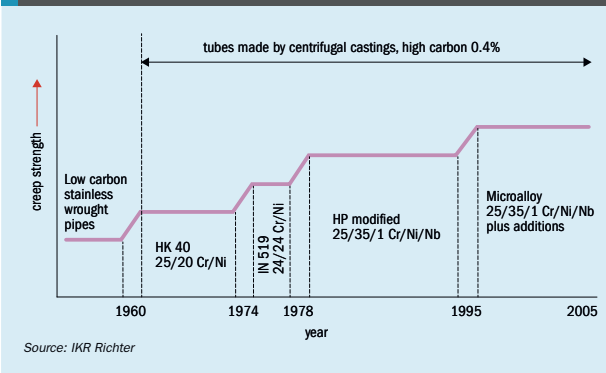
Development of reformer tube materials

The materials used for reformer tubes in recent decades are illustrated in Fig. 7. The first centrifugally cast reformer tubes were made of HK 40, a material containing 25% chromium and 20% nickel. Today microalloyed steels are used that contains 25% chromium, 35% nickel, niobium and traces of other elements like zirconium and titanium. As alloy strengths have increased, tube wall thicknesses have decreased, thus reducing the thermal stress, and process volumes have increased, whilst keeping the same design tube life time as before.

A 14 mm thick reformer tube made of microalloyed steel would have a wall thickness of approximately 17 mm if made out of HP modified and more than 30 mm if made out of HK 40. Clearly such thick reformer tubes do not represent an optimal design, and therefore reformers utilising older tube metallurgies will have a larger number of narrow diameter tubes. The reformer tube inlet pressure, the inside diameter of the tubes and the peak tube wall temperatures, i.e. the tube design temperature, can be increased without having to utilise reformer tubes with an unacceptably large wall thickness. Reformer tube inlet pressures have increased from around 20 barg up to more than 40 barg and the inner diameter of the reformer tubes has increased in steps from 97.2 mm to 127 mm over the last decades.

The strength improvement between HK 40 and later alloys is due to the increased amount of secondary carbides, which are

Fig. 7: Development of reformer tube materials



Source: IKR Richter

finely distributed throughout the parent material. They prevent the movement of dislocations through the material and hence reduce the extent of creep damage. In HK 40 only the chromium forms carbides whilst for the later alloys, niobium forms secondary carbides.

Titanium, zirconium, tungsten and caesium are all strong carbide formers and form finer carbides that last longer, therefore providing higher strengths that are retained for longer. These higher strengths allow for a reduction in reformer tube wall thickness when utilising modern alloys. By changing to an improved reformer tube material it may permit, for example, a reduction of the overall reformer tube count could be reduced or an increase to the inside reformer tube diameter.

The generally accepted methodology for designing reformer tubes is to utilise the Larson-Miller plot with the appropriate data for the metallurgy to be used. This plot can be used to determine whether the assumed reformer tube dimensions and operating conditions will deliver the required reformer tube life time. The reformer tube dimensions or operating conditions can then be varied to achieve the required design life time.

Most reformer designers or reformer tube vendors design the reformer tubes to provide 100,000 hours (or circa 11 years) of continuous operation based on the assumed design conditions. However, this steady state approach does not take into account start-ups and shutdowns, designers tend to use 75-85% of the mean stress to rupture values allowing for start-up and shutdown transients. Deviations

from these assumed design conditions will clearly affect the achievable reformer tube life time.

New alloy materials for reformer outlet systems

Outlet systems are an important part of steam methane reformers. Although these elements are typically located outside of the reformer firebox, they operate at severe conditions up to the metallurgical limits and while significant research efforts have been made over the last 30 years in improving alloys used for steam reformer catalyst tubes, no major efforts were devoted to improving outlet system materials.

Outlet manifold materials differ depending on reformer designer preferences. Typically, low temperature systems with design temperatures below 829°C use either 800 HT or cast equivalent 20Cr-32Ni, while designs targeted for higher temperatures use cast materials 20Cr-32Ni almost exclusively.

20Cr-32Ni alloy material supplied by the Schmidt+Clemens Group is named Centralloy® G4859. This alloy is a low carbon alloy designed to maintain good ductility after ageing and a good creep resistance in the range of 800°C to 1,000°C. Niobium is used as carbide forming element (20Cr-32Ni-Nb). A substantial benefit of the cast alloy with Nb is that the creep strength is about 50% higher than the wrought alloy (800 HT) with Al and Ti.

New Schmidt+Clemens materials have recently become available for outlet header components as alternatives to standard material GX10NiCrNb32-20

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Table 1: Typical composition of Schmidt+Clemens low carbon alloy materials for outlet components

| Composition, wt-% | C | Si | Mn | Cr | Ni | Nb | Ti/Zr | Fe |
|-------------------------|------|-----|-----|----|----|-----|-----------|---------|
| Centralloy® G4859 | 0.1 | 1 | 1.5 | 20 | 32 | 1 | - | balance |
| Centralloy® G4859 Micro | 0.1 | 1 | 1.5 | 20 | 32 | 1 | additions | balance |
| Centralloy® H101 Micro | 0.13 | 0.5 | 0.5 | 25 | 37 | 0.5 | additions | balance |

Source: Schmidt+Clemens

or ASTM CT 15C (20Cr-32Ni-Nb). These materials named as Centralloy® G4859 Micro and Centralloy® H101 Micro can significantly improve creep resistance and ductility after ageing over the standard alloy 20Cr-32Ni-Nb.

The main advantage for plant operators are wall thickness reduction of outlet header components, with benefits in weight reduction, and increased resistance to thermal shock. Alternatively, maintaining original wall thickness, lifetime of such components can be substantially increased keeping the same design and operating conditions.

The nominal composition of these materials is represented in Table 1.

Centralloy® G4859 Micro

A logical improvement of 20Cr-32Ni-Nb is the development of a micro alloy version – Centralloy® G4859 Micro. Addition of small quantities of elements like titanium and composition optimisation has enhanced significantly material performance. Like standard material G4859, this alloy has a maximum operating temperature of 1,000°C.

Centralloy® G4859 Micro has been available in the market since 2011. Currently more than 102 outlet manifold arms and 2950 outlet reducers have been installed in service, together with more than 40 T-pieces and transition cones. Performance of these components in operation has been regarded as excellent.

Centralloy® H 101 Micro

Low carbon versions of HP-Nb (25Cr-35Ni-Nb) were originally designed for operation under severe corrosion conditions only requiring a moderate ductility. These conditions are typical in steam cracker applications. Nevertheless, these materials were described in the literature as a potential replacement of 20Cr-32Ni-Nb materials, especially in designs requiring higher operational temperatures.

Unfortunately, lower ductility after aging performance compared with 20Cr-32Ni-Nb

has been regarded as the main drawback. Therefore, material replacement in outlet manifold components was not advisable.

Schmidt+Clemens has designed a micro alloyed version of this low carbon material, with an optimised chemical composition, capable of enhancing creep resistance and ductility after ageing over existing 20Cr-32Ni-Nb materials. Furthermore, higher chromium and nickel contents would allow outlet components to be designed for higher temperatures up to 1,050°C.

The first reference in reformer outlet components was supplied in 2016.

Characterisation and results

During the development of these new materials, Schmidt+Clemens carried out extensive characterisation of tensile properties and creep performance. Additionally, significant efforts were made on material microstructural characterisation and accelerated ageing tests in order to study the driving forces regarding material ductility exhaustion.

Tensile tests

Room temperature (RT) and high temperature tensile tests were performed on these three materials. 0.2% yield strength, ultimate tensile strength and elongation to rupture properties were measured.

Results for 0.2% yield strength (Fig. 8) showed that the addition of micro alloying elements has improved material yield strength in comparison with alloy G4859. When comparing the ultimate tensile strength (UTS) for these materials, no relevant differences could be seen between G4859 and G4859 Micro, while H101 Micro UTS values seem to be slightly inferior.

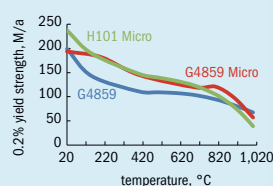
Elongation to rupture values results (Fig. 9) indicated a superior ductility of G4859 at low temperatures, while H101 Micro has a better ductility at higher temperatures. G4859 Micro alloy has a slightly lower ductility. The relevant reduction on ductility seen for alloy G4859 in the range

of 700-900°C might be related to the stability of brittle intermetallic phases like G-phase, leading to a localised embrittlement of the alloy material.

Creep tests

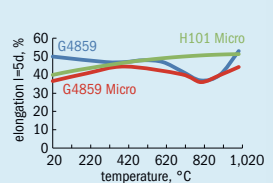
Creep resistance is one of the major requirements for these type of materials. Creep strengthening is accomplished by the formation of carbides in the microstructure. Material creep resistance is typically shown in Larson-Miller curves (parametric stress rupture strength). Minimum parametric stress to rupture values for a life time of 100,000 hr is represented in Fig. 10.

Fig. 8: 0.2% yield strength comparison



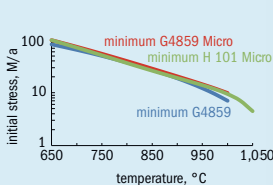
Source: Schmidt+Clemens

Fig. 9: Elongation to rupture comparison



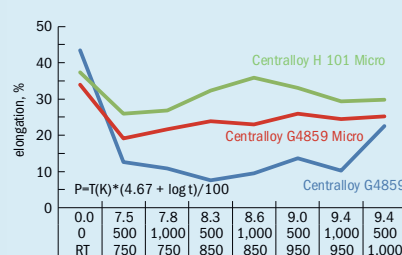
Source: Schmidt+Clemens

Fig. 10: Minimum creep resistance comparison



Source: Schmidt+Clemens

Fig. 11: Ductility after aging comparison



Source: Schmidt+Clemens

Both microalloyed materials have a superior creep resistance compared with G4859. Small additions of strongly carbide forming elements lead to the formation of stronger and more evenly distributed secondary carbides in the austenitic matrix.

Ductility after aging

Ductility after aging is a major requirement for these types of materials. Material samples are aged in a furnace (controlled temperature and time of ageing), and later aged samples are tensile tested at room temperature to measure elongation to rupture. Ageing conditions and test results are shown in Fig. 11.

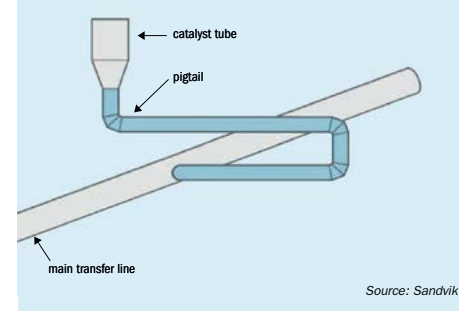
Considering all three materials, superior ductility after ageing performance is achieved with alloys H101 Micro and G4859 Micro in comparison with alloy G4859. Such superior behaviour might be explained by the formation of more thermodynamically stable primary carbides and due to delay/suppression of intermetallic phase formation.

FE modelling of outlet manifolds

Finite element analysis (FEA) provides the opportunity to test real components simulating the continuous operation in the furnace. FEA can be carried out on outlet header systems, but the model accuracy strongly depends on the quality of the creep model, boundary conditions, geometrical models and correct meshing.

Creep modelling is clearly the most complicated issue. Manufacturers like Schmidt+Clemens provide stress to rupture values parametrised in models like Larson-Miller. Such stress to rupture data is not adequate for dynamic modelling where creep elongation and stress relax-

Fig. 12: Pigtailed overview



Source: Sandvik

ation behaviour information is required. Therefore, having a good creep behaviour modelling is imperative in providing good FEA results.

Analysis results indicate that new materials are improving time to rupture compared with standard 20Cr-32Ni-Nb materials. Nevertheless, inadequate operation or maintenance of outlet header components can lead to overstressed zones that can lead to early component ruptures in operation, even if the entire header is securely designed according corresponding standards.

Simulation study results

Two simulation steps were considered for all three materials. The first step considered a static structural simulation of just one second, to evaluate stress/strain distribution on the outlet header. The second step considered a one-year simulation of the part under creep regime. Wall thickness of the component was estimated using ASME B31.3 calculations for alloy material G4859 considering a design time of 100,000 hours.

Some surprising results were obtained from the static structural simulation. Even considering that reformer tube counterweight system was compensating all weight stresses over the material, significant part deflection was observed on header tube arms due to the thermal expansion of the transfer line.

All material results showed that the outlet header tube support location has a strong impact on the stress distribution in the component. Supported areas and T-piece/arm tube zones had the highest stresses in these models. Therefore, these parts are the most susceptible to failure due to creep damage.

Life time predictions can be applied into the model considering the Larson-Miller curves for each material. Most stressed portions of the outlet header are determining the lifetime of the component in operation.

According to the simulation, material G4859 will have a time to rupture of 133,000 hours in such an area. On the other hand, more creep resistant material like G4859 Micro (255,000 hours) and H101 Micro (220,000 hours) will have a significantly higher time to rupture in operation.

Lack of maintenance or inadequate alignment of header components (like arm supports) might add additional stresses on the part and, consequently, reduce dramatically the lifetime of the outer header.

Results of these simulation efforts show that material selection is the most critical part in ensuring that the outlet system is able to achieve the required design time.

In addition, components of the entire header system like tube supports, can also have a significant impact in the outlet header performance/ life if they are not working adequately.

Pigtail material selection

Pigtails are piping systems for the connection of the catalyst tubes to the manifolds in both the inlet and outlet of the reformer are prone to different mechanical and thermal stresses and possible failures (Fig. 12). Inlet pigtails are less critical as they work at lower temperatures (550-600°C), but still require careful material selection. Outlet pigtails, on the other hand, which carry the reformed gas from the catalyst tubes to the collection manifold, must be able to

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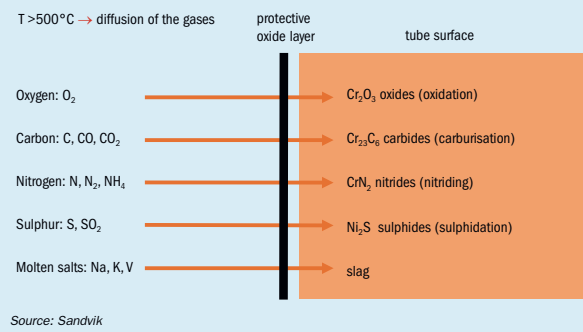
New catalyst developments

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Fig. 13: High temperature corrosion



withstand much higher temperatures (800-950°C) and are subject to harsher high temperature corrosion mechanisms that require higher alloyed grades. Materials such as 20Cr32Ni grades or UNS N08810 or UNS N08811 are typically selected due to their high creep strength.

Since most of the major components of the primary reformer have advanced over the years, pigtails are usually perceived as the weakest point, often requiring replacement much earlier than the reformer tubes or manifolds. In addition to resisting the thermal expansion from the process system, pigtails must be able to withstand creep fatigue and stress relaxation cracking. Hence, the overall objective when selecting materials for pigtails is to provide more reliable pigtails with a longer lifetime that allow the replacement of all major parts at one time with no intermediate shutdown period.

In pigtails, due to the nature of the application, which brings some mechanical fatigue to the tubes and the bended shape they have, creep resistance is the most important property. To prevent the material from cracking due to low creep strength rupture, and consequently burst into the crack itself, it is important to have a resistant material. Ruptures can lead to hydrogen leaks with risk of explosion and risk to the safety of personnel.

The properties of stainless steels are different when there is "diffusion" of gases into the protective oxide layer (Fig. 13). In these corrosive environments good resistance to creep and structure stability is required. The grain size of pigtails also has a huge influence on the mechanical behaviour of these materials.

Industry requirement for these particular materials regarding grain size is commonly found in standards and specifications as "average grain size 5 or coarser" according to ASTM E112. This specification does not, however restrict the grain size distribution. It is known that the upper and lower tail of the statistical distribution has a large influence on mechanical behaviour of materials.

There is therefore a general need for precise grain size characterisation and grain size control, which has a strong influence on creep strength. Restricted grain size is also required in the bent portion of U-bends. Cold bending followed by annealing may cause the grain size to fall outside the preferred grain size window.

Research into grain size and grain size control is ongoing at Sandvik, who can provide narrow grain size windows upon request. A commonly used pigtail material is Sandvik Sanicro 31HT, an austenitic nickel-iron-chromium alloy characterised by:

- high creep strength;
- very good resistance to oxidation;
- good resistance to combustion gases;
- very good resistance to carburisation;
- good resistance to nitrogen absorption;
- good structural stability at high temperatures;
- good weldability.

Sandvik Sanicro™ 31HT can be used at temperatures up to about 1,100°C. In order to have the best ductility, it should be used above 700°C.

Referring to industry standards and the most common specifications, an average grain size of 5 or coarser is required which can be mainly derived from ASTM B 407.

The methodology is described in ASTM E 112, however, this specification does not contain any requirement regarding the grain size distribution. Consequently, the manufacturing process of pigtails must be adjusted in a manner that the properties and hence the behaviour of these tubes lead to an increasing service lifetime.

The manufacturing process is of even greater importance when it comes to the bending of pigtails. Based on the fact that there are many different furnace designs, pigtails come in different shapes, they may be straight but may also have bends. A high amount of strain is induced during the bending process and it is important to have appropriate control of the deformation, minimise ovality and avoid scars or superficial defects. Depending on the degree of cold work induced during the bending process, this will cause the material to change its microstructure which will then have an impact on the performance during service lifetime. In order to improve pigtail performance it is recommended to perform a final annealing heat treatment.

Reformer revamping

Many critical components of the steam reformer unit, such as the catalyst tubes, pigtails, intermediate tube sheets and shield coils are inevitably forced to operate very close to their material design limits and there is a time frame, before a point of failure, when symptoms or warning signs can be identified in time and with good reliability, avoiding unplanned outages and potential risk to plant personnel.

In many cases, conditions that were already critical can be exacerbated when improvement modifications or revamping activities are carried out, particularly when the plant owner does not request a licensor assessment, which is fundamental to minimise risks and avoid any subsequent surprises on plant consumption figures.

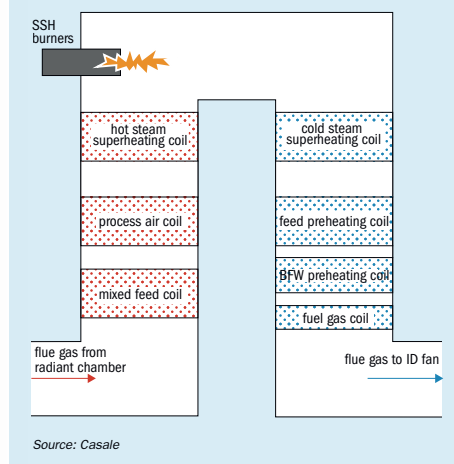
The following two cases demonstrate the importance of carrying out a detailed data analysis of the whole reformer to identify where abnormal conditions or upset operating parameters are located.

Revamp case 1

In this first case, Casale was awarded an EP project for an ammonia plant revamp to reduce energy consumption and increase plant ammonia production capacity from 1,700 to 1,900 t/d.

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Fig. 14: Original arrangement of primary reformer convection section



A detailed assessment of the plant revealed many limitations in the primary reformer convection section (Fig. 14) as it had already been revamped many times. The reformer is an induced draft top fired type with an omega convection section configuration and an external auxiliary boiler.

In the past, the client decided to replace the mixed feed coil and process air coils with new ones with the aim to reduce the fuel consumption to the reformer arch and tunnel burners which was progressively increasing. It was decided to proceed providing an increased surface on both coils of about 50%.

Following this modification, the temperature of the flue gas stream coming from the reformer hot leg dropped so much that the steam superheating burners had to be operated at their maximum heat release in order to reach the desired steam superheated temperature. However, this practice can create issues with the steam superheater coil.

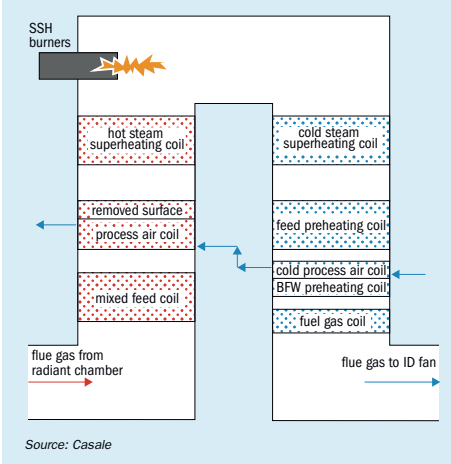
Analysis

After data collection, an overall detailed analysis of the primary reformer was performed, and the original reformer design was verified.

It was found that both the mixed feed coils and the process air coil, before replacement, were significantly underperforming and were unable to achieve the

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Fig. 15: Revamped arrangement of primary reformer convection section



desired process stream outlet temperature despite the flue gas temperature from the tunnel section being higher than required.

Based on Casale's experience, this primary reformer section is very critical and subject to mechanical degradation, accelerated by operating conditions, which normally lead to minor or major underperformance of the coils. This phenomenon is made worse by the practice to compensate for the temperature drop by increasing the tunnel combustion heat release.

The second point to be analysed was related to the new geometry of the coils which, it turned out, affected performance of the cold steam super heating coil. This solution in effect moved a problem from one section to another: the cold steam super heating coil section.

The coil was found to be operating well below the required performance and below the expected performance considering operation aging. This was demonstrated by the hard firing of the steam superheating burners.

Solution

The plant was revamped with the aim to preserve the existing mixed feed and process air coil geometries considering the project targets and at the same time solving the balance issues of the convection section.

The overall steam consumption required for the reforming reaction and

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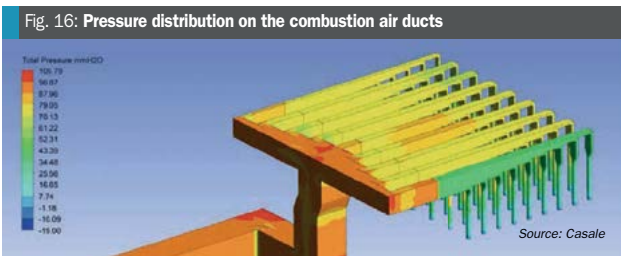
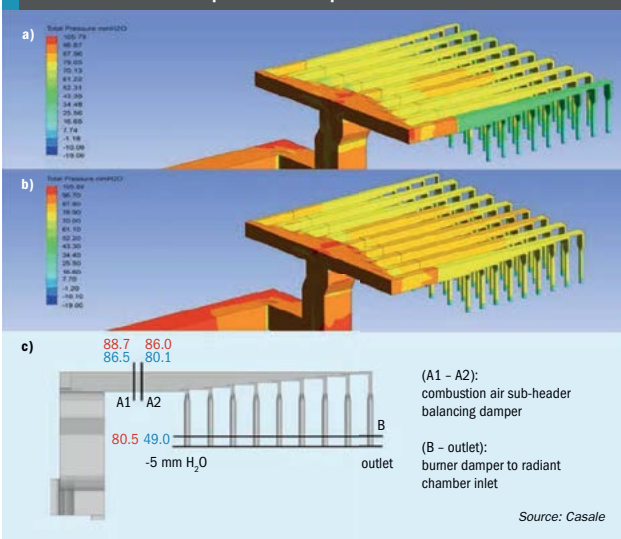


Fig. 17: Combustion system a) before modification; b) after orifice plate installation; c) pressure drop before (blue) and after modification (orange). Calibrated orifice plate located in position B.



times in the past, mainly in the convection section, without any modifications to the radiant chamber. Some years later the catalyst tubes at the end of their life were replaced by new ones manufactured with the latest generation microalloy material. During the same turnaround, it was decided to change all primary reformer original low-NOx burners with the new generation ultra-low NOx burners.

The reformer is a very big (16 tube rows) balanced draft top-fired type with a horizontal convection section.

Analysis

After data collection, an overall detailed analysis of the primary reformer was performed and the original reformer design verified.

The plant process scheme is based on pure steam reforming technology, which makes the furnace operating conditions very critical since it requires a reforming process outlet temperature of about 900°C.

From a preliminary analysis of the recorded tube skin temperatures, a temperature deviation was found ranging from 30°C for the inner tube rows to 50 °C for the outer tube rows.

Due to the use of ultra-low NOx burners it was necessary to analyse the flue gas distribution inside the radiant chamber in greater detail, since this technology limits pollutant emissions by forcing the burner to operate with inefficient combustion, staging the fuel into many zones (two or more). As a result, the flame shape is

worsened in term of dimensions, affecting both the radiant chamber efficiency and the catalyst tube skin temperature profile.

From the computational fluid dynamics analysis, it was clear that the tunnel extraction system was not adequate to mitigate the poor distribution in the radiant chamber, while the combustion air distribution was adversely affected by the ultra-low NOx burners which require a much lower pressure drop on the air side than conventional low NOx burners.

Fig. 16 shows the pressure distribution on the combustion air ducts.

During the site survey, it was found that the entire system was balanced by regulating the firing of each burner throttling the relevant combustion air damper and fuel gas valve.

Of course, this practice relied exclusively on the plant operators and is commonly applied to steam reformer units to mitigate radiant chamber maldistribution and provide a uniform catalyst tube skin operating temperature. However, although this approach is acceptable to reduce stresses of the catalyst tubes, it can lead to burners being operated with process parameters far from the operability and stability range.

From a mechanical point of view, the outlet pigtails proved to be the most critical components of the system. Despite the catalyst tubes operating at very high temperatures, the new micro-alloy material together with the low design pressure of the tubes, provided sufficient safety margin on the tube thickness which can be converted to an extended tube life. The outlet pigtails, on the other hand, were manufactured of Alloy 800 HT and were operating very close to the material design limit. In this case, the reformer outlet temperature variation had to be strictly contained within a reasonable range.

Solution

Some rectifications were proposed in order to solve the issues on the combustion system with the aim to preserve and extend the life of critical items.

On the air side, a dedicated calibrated orifice plate was designed and provided just before the burner damper to ensure the required pressure drop for distribution and the necessary air split ratio between the inner and outer burners.

It should be noted that the modification itself does not have an impact on the overall duct pressure drop since the local damper

head loss is moved to the calibrated orifice plate without affecting the combustion air fan operation (Fig. 17).

On the flue gas side, it was clear that, the uneven distribution was attributable to the geometry transitioning from the huge radiant chamber to the small cross-sectional area of the convection section, which led to some preferential pathways in the middle of the reformer. A new hole distribution pattern was provided for the tunnel walls to balance the flue gas extraction system and tighten the flow deviation.

The effect of these measure were:

- to reduce the temperature spread recorded on the skin temperatures and on the outlet pigtails by about 40%;
- to operate the burners within a safe and operable range;
- to have a straightening effect on the flames to reduce the risk of tube impingement.

Reformer tube failure mechanisms

There are two key operating conditions that must be considered in reformer tube design, the reformer tube operating temperature and the tube-side operating pressure.

Large temperature excursions reduce the residual reformer tube life time because higher temperatures increase the rate of loss of secondary carbides which reduce the strength of the parent reformer tube material. As a rule of thumb, a 20°C rise in tube wall temperature will halve the expected reformer tube life time. For example, an excursion of 200°C for six hours will reduce the expected reformer tube life time by approximately nine months. Operation at higher pressure than the design pressure, for example due to higher than expected pressure drop downstream of the primary reformer, will increase the differential pressure across the reformer tubes and therefore reduce the reformer tube life time. Transients such as start-ups and shutdowns will lead to the generation of thermal stresses within the reformer tubes. These stresses are cumulative and so will reduce the ultimate reformer tube life time. The faster the increase or decrease in reformer tube temperatures, the greater the stresses and therefore the greater the reduction in the ultimate reformer tube life time. A rapid shut-down can reduce the life time of the reformer tubes by four to six months



in comparison to a controlled shutdown. The most common failure mechanism of reformer tube is nearly always due to the creep of the reformer tube material; however, others do exist.

A typical creep failure is longitudinal with the crack extending axially from the original failure point in both directions as illustrated in Fig. 18. There are a number of different causes of reformer tube failure depending on the location of the section of reformer tube and the problems that can affect the reformer tubes in these different locations. The root cause of reformer tube failure can be broken into two discrete groups based on whether the section of reformer tube has been overheated due to a general or a local effect, i.e. generalised overheating or localised overheating.

Generalised overheating is defined as a large area of the reformer tube being overheated (typically greater than 2 m of reformer tube which affects many tubes). Generalised overheating can be caused in a number of ways, for instance:

- The normal overheating process that occurs within a primary reformer due to the operating temperature required by the steam reforming process;
- Overheating during transients such as start-ups and shut-downs where the fuel rate has not been sufficiently reduced;
- Low catalyst activity due to poisoning or carbon formation, reducing the rate of hydrocarbon reforming and hence the rate of heat absorption;

- Fouling of foreign material at the outer and inner surface of the reformer tubes

Localised overheating is defined as a small area (typically 1-2 m in length and can be isolated to 5-10 reformer tubes) of the reformer tube being overheated. Again, there are a number of different ways that this can occur due to:

- Flame impingement due to poor alignment of the burners or where the burners ports are blocked;
- Catalyst bridging which leads to void formation and hence a reduction in the rate of reforming with the associated increase in tube wall temperature;
- Point problems such as the tunnel port effect;
- Failure at welds or within the parent reformer tube material due to poor manufacturing techniques. With advances in the metallurgy of weld materials this effect has made this less common; however, there are still a large number of reformers that still utilise older weld materials and are vulnerable;
- Fouling of foreign material at the outer and inner surface of the reformer tubes.

Pinched tubes

Isolated hot spots and tube ruptures can occasionally develop on radiant tubes during operation. Rather than shutting down the furnace to replace these isolated tubes, the tubes are externally pinched by hot crimping both inlet and outlet pigtail tube ends of the damaged reformer tubes when in service. Despite good crimping procedure, there is still a possibility of some leaks at the crimped locations. A second crimping before the pigtail gets cold at 90° to the first crimping can be done if there is space in the straight leg of both inlet and outlet pigtails. Some users use a second crimping as a backup against failure of first crimped locations. If a leak persists there is no alternative but to shut down the reformer furnace for repair or replacement.

Thermal shock

Thermal shock is very damaging to tube life, it can even cause catastrophic effects to the whole reformer. After a thermal shock event it is important to perform an inspection, check for damage and have a good plan in place to deal with all inspection findings. Ideally the inspection results

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can be compared to a previous inspection. Any damage that occurred during the excursion should be evaluated carefully, due to the rapid damage all indications are of importance. After a thermal shock it is much more difficult to predict how the damaged areas will react when they are brought back online.

Overfiring protection case study

In early 2015, when Profertil was performing a hot restart of their ammonia plant, an uncontrolled and rapid increase in flue gas temperature was noticed in the primary reformer. After natural gas feed was introduced to the primary reformer, it was observed that a rupture of several catalyst tubes had occurred and the plant was tripped immediately. Profertil requested Haldor Topsoe A/S to take the lead technical advisor role in a thorough root cause analysis, performed to identify the reason(s) for the tube rupture incident.

The results of this thorough root cause investigation led to a solution that assures such incidents will not happen again. The incident with ruptured tubes not only impaired plant capacity utilisation until the re-tubing of the furnace, but more importantly, the leaked gas from the ruptured tube could have resulted in unsafe conditions. Therefore, the possibility of avoiding this type of incident is of paramount significance to all plants operating with any type of tubular reformers. Following this incident, an automated overfiring protection (OFP) management system that provides four elements of protection against overfiring of primary reformer tubes was developed.

The OFP management system addresses both 'local' and 'global' causes of primary reformer catalyst tube overheating.

OFP does not allow fuel header pressure increase during start-up and enforces a symmetric burner ignition pattern. During start-up, these two protection elements not only help to avoid catalyst tube overheating but also ensures better heat distribution inside the furnace.

Moreover, double protection elements of duty and bridge wall temperature limitation ensure parity in duty input and duty uptake by adjusting fuel flow to the burners based on maximum estimated duty for the primary reformer at a particular capacity.

OFP is suitable and highly relevant for all types of tubular reformer designs.

Monitoring tube wall temperature

Reformer tubes are highly valuable assets. A large reformer contains hundreds of tubes, at an average tube cost of approximately \$15k to \$30k each, and unplanned outages can result in significant costs of \$350k to \$1m a day, so increasing tube life and reducing tube failures is essential asset management. That means having an effective method of temperature measurement.

The monitoring of tube wall temperatures (TWT) can help optimise catalyst tube life and ensure longevity, energy efficiency and productivity. With better temperature control, operators can increase profit by increasing output and lowering operating cost, resulting in better utilised feedstock, catalyst and fuel. A 2% improvement in output has the potential to save approximately \$1 million a year.

Issues with the burner, flue gas distribution and the catalyst can all directly affect TWT and lead to premature tube failure. To prevent this, most operators tend to be overly cautious with TWTs. However, excessively cautious firing reduces the reaction rate and thus leads to lower production and/or higher energy consumption – a 10 °C drop in temperature can result in 1% decrease in productivity. Even taking a cautious approach, tube failures can still occur due to hot spots on tubes and hot areas within the convection box. Mechanical stress on the hot tubes increases exponentially, in worst cases causing tube ruptures.

Even though producers may be running at a reduced rate, they are still not guaranteed to have a balanced, reliable reformer. Reformer tube failure and process flow problems come about when temperatures are too high. Even operating at temperatures only 20°C above the design temperature can cut a tube's lifetime in half. Maintaining optimum temperatures is therefore critical.

A thermal gradient through the tube wall is more significant at the bottom or close to the bottom of the tube, causing differential creep strain, which is a primary cause of damage. A fifth of all incidents involve tube cracking. Operators are required to have an in-depth understanding of reformer behavior and must also be able to analyse data and make rapid decisions when faced with catastrophic failure.

The burners, which fire directly inside the fire box from the top, sides or both, are

also very important to tube efficiency, as the flames must not impinge on the tubes or wall. Proper alignment of the burner is very important to avoid flame impingement, gas flow restriction, burner issues, external tube scaling and afterburning (tube leaks).

Significant operator experience is necessary to fully understand basic reformer construction, process flow, heat transfer principles, background radiation, and emissivity along with the cooling effects that occur when the peep door is opened. Regularly opening a peep door can increase stress on the tubes and potentially cool those directly in front of the door by a variance of 30°C. With that in mind, operators need data on the TWT that is accurate, repeatable and reliable.

By continually monitoring readings, the operator will get an early warning of increasing tube wall temperatures, which can then be used to counteract potential catastrophic failure. Continuous monitoring, likewise, will allow the operator to safely and confidently increase temperatures, with a view to increasing production.

TWT measurement methods

In order to meet the demands for greater production, efficiency and safety, continuous 24/7 monitoring is required. Several different temperature measurement methods are available, two examples are given below:

- Handheld spot pyrometers enable users to take routine spot measurements to optimise steam reformers by maintaining operation closer to design temperatures and, in many situations, the pyrometers can provide adequate accuracy. However, with pyrometers, the operators are only able to view a local spot on the tubes and may miss hot spots in other locations.
- Fixed thermal imaging provides more accurate and repeatable results than handheld pyrometers as they are less liable to human error and enable optimisation of the TWT to ensure a long tube life. Thermal imaging cameras are inserted into the reformer, with the end of the imager ¼" from the inside reformer wall refractory. Imagers are water- and air-cooled to ensure accuracy in the hot atmosphere of the reformer. This method improves efficiency and minimises the risk of catastrophic failure.



CONTINUOUS TEMPERATURE MONITORING OF TUBE WALL TEMPERATURE

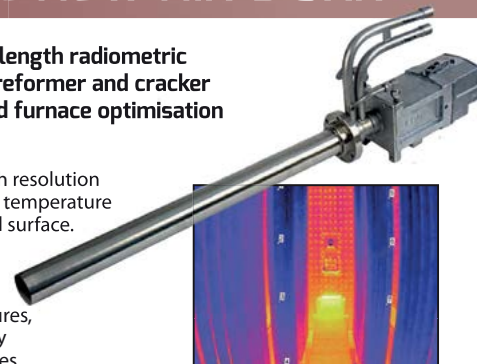


INTRODUCING THE NEW NIR-B 3XR

The NIR Borescope (NIR-B) 3XR is a short wavelength radiometric infrared borescope imaging camera for steam reformer and cracker tube continuous temperature measurement and furnace optimisation and monitoring.

ATEX and IECEx approved, the NIR-B 3XR provides a high resolution thermal image with real time continuous high accuracy temperature measurements of both the tube wall and refractory wall surface.

Producing real-time thermal data from 307,200 points across the high-resolution visual image, the NIR-B 3XR offers highly accurate measurements of high temperatures, enabling process control optimisation, energy efficiency savings and prolonging the lifetime of the reformer tubes.



OVER 70 YEARS EXPERIENCE WITH REFORMER TUBE APPLICATIONS

APPLICATIONS

- /// Hydrogen Reformer
- /// Ethylene Cracking Furnaces
- /// Syngas Production
- /// Ammonia Production
- /// Methanol Production

BENEFITS

- /// Real time continuous data monitoring
- /// Accurate tube wall measurement
- /// Removes operator from hazardous areas
- /// Optimises production throughput
- /// Reduces energy consumption

CERTIFICATIONS

ATEX and IECEx approved to Ex nA IIC T4 Gc for use in Zone 2 Gas Atmospheres

CSA Certified for US and Canada to Class I, Division 2, Groups A, B, C, D T4



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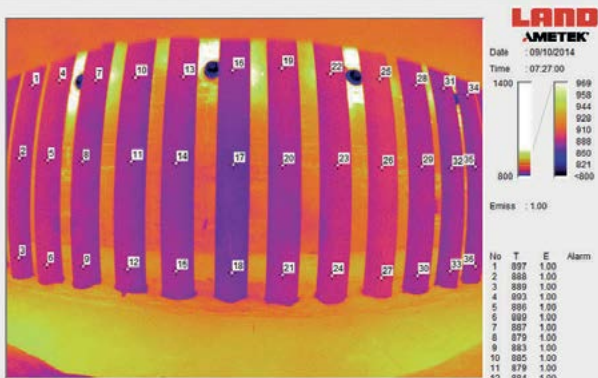
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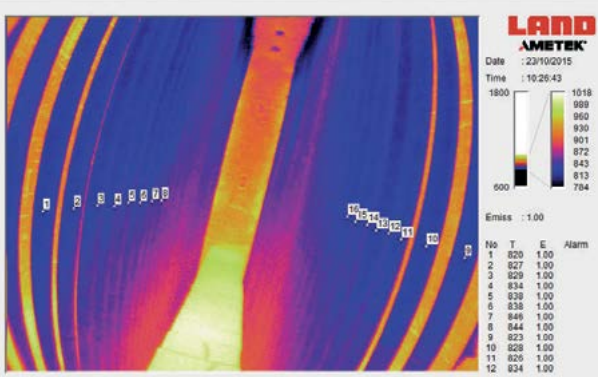
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Fig. 19: Thermal view inside and reformer tube furnace with data points



Source: AMETEK Land

Fig. 20: Thermal view inside and reformer tube furnace with data points



Source: AMETEK Land

AMETEK Land's Near Infrared Borescope (NIR-B) 3XR

Accurate temperature measurement must take emissivity into account. Within the reformer environment, several objects can reflect off the surface. Handheld pyrometers and visual inspection can wrongly interpret the reflections as real data, causing errors in temperature measurement. Thermal imaging cameras that are mounted strategically within the reformer do not allow this to happen, such as AMETEK Land's Near Infrared Borescope (NIR-B) 3XR – which

is certified for hazardous areas. The fixed thermal imager delivers a high-resolution image, with accurate real-time measurements of both the tube skin and refractory surface (Figs 19 and 20).

The image, combined with the 90° angle field of view, allows for multiple parallel tubes to be measured simultaneously. This can dramatically enhance efficiency and safety, as well as provide better asset management and furnace optimisation.

One of the major benefits of using fixed thermal imagers like the NIR-B 3XR is their rapid response time. Using the

AMETEK Land Image Processing Software (LIPS) provided with NIR-B 3XR, for example, the software will sound an alarm the moment the tube wall reaches the maximum temperature in any region, identifying the problem region and allowing the operator to take corrective measures to fix the issue.

Case study

Air Liquide, the world leader in gases, technologies and services for industry and health, understands the critical importance of managing TWT and required a solution to deliver highly accurate and more complete measurement of the equipment and process, compared to spot temperature measurements, whilst operating in a hazardous environment.

AMETEK Land recommended its Near Infrared Borescope (NIR-B) 3XR, which provides a high-resolution thermal image with real-time high accuracy temperature measurements of both the tube wall and refractory wall surface, allowing for background compensation.

With the AMETEK Land solution in place, Air Liquide is now continuously measuring the temperature of reformer tube walls.

Gonzalo Navarro, Production Manager at Air Liquide Ibérica de Gases, explains: "Our main drivers in investing in AMETEK Land's NIR-B 3XR were to extend tube and catalyst life, which we are achieving as a result. We are continuously learning about our reformer, which enables us to balance it correctly and follow online our main and critical asset."

He adds: "Now, our teams can monitor the temperature of the tubes continuously, they are able to make more informed and confident decisions implying greater plant reliability".

Air Liquide's Research and Development team has since approved the NIR-B 3XR thermal imager for potential installation in additional steam methane reformers.

Clariant TWT monitoring

Clariant offers various technologies for monitoring the tube wall temperature. The simplest of these, the pyrometer, allows reliable single-point readings of the tube wall temperature by measuring through peepholes. As it is designed for ease of use, pyrometer measurements are limited to tubes which can be accessed through the peepholes. In addition, readings should be corrected for background radiation.

A more advanced solution is Clariant's Thermal Scan, a high-resolution thermal imaging borescope which measures temperatures from 600 to 1,100°C at a short, accuracy-enhancing wavelength. The instrument presents a real-time, three-dimensional heat profile of all tube rows in the furnace, allowing easy detection of uneven heat distribution or hot spots. Plant operators benefit from a comprehensive temperature survey, which includes thermal images as well as recommendations for burner adjustments.

Alternatively, the Thermal Scan Plus Gold Cup has been developed for measurements using a golden reflector. This method provides superior precision due to its near-perfect reflectance. The data is used to calibrate the standard Thermal Scan, thus providing an extremely accurate temperature profile of the entire furnace ($\Delta T < \pm 5^\circ\text{C}$). These instruments enable more effective troubleshooting, and help operators achieve maximum reformer performance and lifespan, without unnecessary and costly outages.

360° tube inspection

With today's economy plants are pushing their reformers harder than ever to keep up with production needs, this can lead to many issues such as flame impingement, flue gas distribution, catalyst damage and pinching tubes online. All of these can lead to overheating of the reformer tubes around the complete circumference and in the past, the focus has always been on inspecting just the fired side of tubes. These issues are also affecting the non-fired sides of tubes and the industry has seen failures from overheating of these areas in the past.

A new method from Reformer Services is now available for detecting damage mechanisms affecting the complete 360° circumference of the reformer tube wall, as well as the full volume of the tube wall thickness simultaneously. The focus is the detection of damage mechanisms in the tube and the ability to size the damage on the equipment being inspected. The state-of-the-art technology proprietary crack detection system provides a full body examination of tubes and is able to detect the earliest stages of creep and bulging to the most severe stage of creep to prevent catastrophic failure. This inspection technology is fast and very repeatable using multiple lasers. On-site reporting software

Fig. 21: Tube scan 360-OD

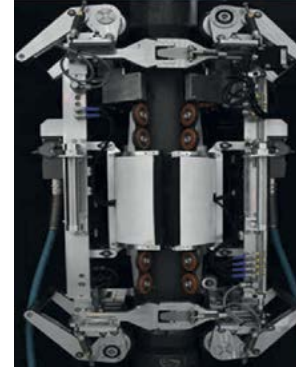


PHOTO: REFORMER SERVICES

Fig. 22: Tube scan 360-ID



PHOTO: REFORMER SERVICES

is integrated from the computer-controlled data acquisition system.

The new inspection technology consists of two reformer tube scanner types. The outer diameter reformer tube scanner, Tube Scan-360-OD, (Fig. 21) volumetrically inspects 360° circumferentially as it advances along the length of the tube producing real time data with two different technologies while identifying the damaged areas. Only 50 mm clearance is required between tubes. It provides 100% OD coverage of each reformer tube and 360° crack detection.

The internal diameter reformer tube scanner, Tube Scan-360-ID, (Fig. 22) also uses two different inspection methods running concurrently to provide a full 360° examination of the tubes. It provides 100% laser ID coverage and 100% crack detection coverage of each reformer tube.

Both reformer tube scanner types are equipped with a powerful proprietary eddy current technique for sensitive crack detection in reformer tubes up to 23 mm wall thickness. Measurements for both

strain and crack detection are carried out simultaneously. Cracks can be detected in both the longitudinal and circumferential direction. Both scanner types offer repeatable accurate and fast inspection results, based on the collection of millions of data points during each tube inspection. All recorded data is used for remaining life assessment.

Fouling of reformer tubes

Fouling has been described as the major unresolved problem in heat transfer. Fouling is generally defined as the accumulation and formation of unwanted materials on the surfaces of processing equipment, which can seriously deteriorate the capacity of the surface to transfer heat under the temperature difference conditions for which it was designed.

In the production of the syngas, fuel combustion in the primary reformer can lead to dust deposits on the outer surface of the reformer tubes and prevent proper heat transfer which diminishes the overall performance of the primary reformer which is the main energy consumer in syngas production.

Major detrimental effects of fouling at the reformer tubes in any primary reformer include loss of heat transfer as indicated by charge outlet temperature decrease and the lower value of emissivity which consequently increase the energy consumption. Where the heat flux is high, as in primary reformers, fouling can lead to local hot spots resulting ultimately in mechanical failure of the heat transfer surface. Such effects lead in most cases to production losses, higher energy consumption and increased maintenance costs. Loss of heat transfer and subsequent charge outlet temperature decrease is a result of the low thermal conductivity of the fouling layer or layers which is generally lower than the thermal conductivity of the fluids or conduction wall. Reformer tubes continuously degrade due to the harsh environment of the furnace box from the moment they are commissioned. The upper limit of the reformer tube wall temperature is primarily governed by the reformer tube design temperature. If the temperature is too high, there is a high risk of premature creep damage and coke formation, resulting in the reformer tube failure and process flow restriction. The performance of the primary reformer is of crucial importance to plant efficiency and production because of the

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reformer's role as the single largest consumer of energy.

As a result of this lower thermal conductivity, the overall thermal resistance to heat transfer is increased and the effectiveness and thermal efficiency of the reformer tubes are reduced. The total thermal resistance to heat transfer is decreased during the first stages of fouling due to the surface roughness resulting from initial deposition. After that and with deposits building up, the thermal resistance returns to increase again. Fouling affects approximately 50 to 90% of reformer tubes, but multiple complex variables make it difficult to foresee. Scaling or corrosion from particulates can limit the performance of primary reformer tubes, as can unfavourable process conditions or malfunctioning upstream equipment.

Due to all mentioned and taking into consideration complexity of steam reforming operation it is therefore extremely valuable to conduct regular primary reformer assessments that result in solutions aimed at optimising parameters for peak primary reformer performance. Whether the catalyst is replaced or not, the reformer tubes should be physically measured for creep growth during the last production run to back up the results of the temperature monitoring in terms of whether any reformer tubes need replacement or a cleaning procedure. If the catalyst is being changed out, it is always recommended to conduct an internal inspection of the reformer tubes using a different technique to determine the diametrical growth of the reformer tubes with subsequent reformer tube cleaning technology of the outer or inner surface. If the catalyst is not being removed, again reformer tube cleaning technology can be utilised to improve the condition of the reformer tubes and enhance energy consumption with insuring higher reliability of the same. The cleaning technology can reduce stress which is even more pronounced in case of fouled reformer tubes with improvement of the process conditions in the terms of better throughput. Cleaned reformer tubes will not suffer due to higher temperature regime to reach the needed heat flux which is necessary for achieving proper level of steam reforming reaction, while the energy consumption will stay at the same level as is predicted in design case.

Simple regular cleaning procedure of reformer tubes will have beneficiary effect

to prevent creep damage and in the same time reduce the energy consumption which will have direct impact to financial savings.

Reformer tube cleaning

Poor design or operation of reformer tubes can lead to premature tube failure. This is very costly in terms of reformer tube replacement and lost production due to the downtime to replace failed reformer tubes. In the worst case, a complete reformer burn down, the cost can be as high as \$18 million based on the lost production plus the cost of the catalyst and reformer tube replacement. If a failed tube is nipped (isolated on line), the production rate may need to be reduced if the front end of the plant is pressure drop limited; for example if 5% of the reformer tubes are out of service the plant rate will be reduced by approximately 2% decreasing the plant profitability by \$650,000 per year for a 2,000 t/d (420 reformer tubes) ammonia plant.

To prevent this, a very simple cleaning procedure of the reformer tubes can be conducted by applying proprietary cleaning technology which will not only prolong the lifetime of the reformer tubes, but also result in financial savings due to the direct impact it will have on subsequent energy consumption.

To illustrate the benefits of the reformer tube cleaning technology IKR Richter Group provides two examples showing the impact of IKR reformer tube cleaning technology in an ammonia plant and a methanol plant. In both cases the financial impact of cleaning reformer tubes with different degrees of fouling, namely a fouling thickness layer of 1.0 mm, 1.75 mm and 2.0 mm, are shown.

An engineering methodology for understanding risk

Quest Integrity has a widely-used method for determination of remaining life in reformer tubes based on inspection data, entitled LifeQuest™ Reformer. This program is based on over 20 years of research and creep testing of common reformer tube alloys. In particular it is designed to capture the effect of material aging, which causes significant reduction in creep strength during service independently from the accumulation of creep damage. The major advantage of this approach is that it is strain-based, as opposed to tempera-

ture-based, and therefore it is not subject to errors in temperature measurement.

Within the program, the operating temperature is back-calculated from the strain. This allows the effects of changes in operating conditions to be analysed. In effect, the program can be used to develop integrity operating windows (IOWs) depending on requirements in the future. These IOWs may be based on corrected IR temperatures in conjunction with a temperature correction program such as CorrectIR™, or based on relative changes in uncorrected measurements provided the same tools and measurement techniques are used.

Historically the program has been primarily used in order to determine remaining life and fitness for service of reformer tubes. Recently however, the program has been utilised more and more in engineering decisions regarding the operation of the reformer. These decisions fall into two categories: (1) intended changes in the operation to influence production, or (2) non intended changes in operation, for example analysing the effect of tube hotspots caused by flame impingement or local catalyst deactivation.

A case study from category (1) is described in the following section.

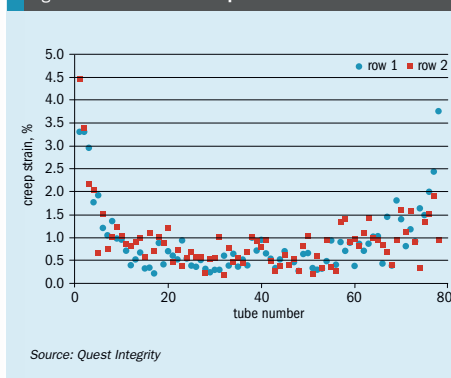
Case study – intended changes in operation

This case study relates to a steam reformer operating in South East Asia, with 156 tubes in two rows of 78. The plant is currently hydrogen-constrained, and so there is significant advantage to be gained in increasing its hydrogen output. The reformer was commissioned in 2009 and first inspected internally using the Quest Integrity LOTIS™ tool in 2016. At that time, significant diametric expansion was found, however the damage was seen to be very localised. In particular, the damage was restricted to only a few tubes at either end of each row. The majority of the tubes showed very little damage. The strain distribution from 2016 is shown in Fig. 23.

With reference to the balance described in the introduction, this is obviously not an ideal scenario. The reliability in this case is controlled by the end tubes, which showed high damage, whereas the majority of the tubes were working beneath within their limits, thereby limiting production.

The first decision which was made related to the end tubes. Remaining life assessment performed at the time of

Fig. 23: Distribution of creep strain within furnace



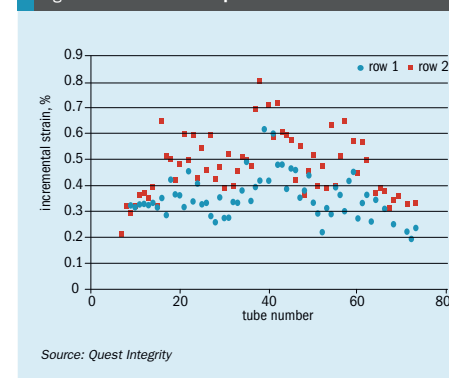
Source: Quest Integrity

inspection showed that there were a few tubes which were not fit for service through the next operating period. These tubes were predicted to exceed 80% calculated life during that time. It was therefore recommended that some tube replacements were made. However, due to turnaround time constraints, this was not possible. It was decided instead to continue to operate these tubes but with reduced operating conditions for the next period, i.e. it was necessary to calculate IOWs. As the critical tubes were grouped together at the ends of the tube rows, it was decided that this could be achieved through local adjustment of burners (in fact, just the burners at each end).

In order to calculate the allowable operating conditions for these tubes, LifeQuest™ Reformer, was utilised. The simulated operating temperature for the next operating period was varied until it was deemed that no tubes would exceed 80% life before the next major turnaround. The allowable limit corresponded to a reduction of 30°C compared to the previous period. As a consequence, the reformer was returned to service with a reduction of 30°C in the allowable tube metal temperature (TMT) limit on the end tubes only. The allowable TMT for the remainder of the furnace was very slightly increased to maintain production. Note that these changes were reviewed as part of a Management of Change (MOC) program.

Despite the significant damage in 2016, the unit ran without failure for two years until 2018, when it was shut down again for its scheduled turnaround. The LOTIS inspection was repeated and this

Fig. 24: Incremental creep strain distribution 2016-2018



Source: Quest Integrity

time the incremental strain (i.e. strain between 2016 and 2018) was calculated. This is shown in Fig. 24. Note the end tubes had been replaced prior to the inspection.

Three findings are important here:

- No tubes showed significant damage, indicating that the risk of online failure was very low. All tubes subsequently passed a fitness-for-service remaining life assessment for the next two year period.
- The damage profile has been essentially inverted compared to the previous profile. This has ensured that the tubes with lower damage as of 2016 have been asked to work slightly harder in the following period (and vice versa). This was seen to be an effective method for maximising production with negligible added risk.
- All tubes showed some damage. This may seem a counter-intuitive statement. However, when it is considered that both life consumption and production are tied to temperature, it in fact is an excellent finding. The vast majority of reformer tubes inspected in furnaces globally show zero damage, indicating that they are fully capable of higher production (of course this is not always needed). The fact that in this case the entire furnace showed low, but not zero damage, indicated that the operating conditions between the last two inspections were optimised for production at no significant cost to reliability. In effect the furnace was well balanced and all tubes had contributed equally to hydrogen production.

Following the inspection, another engineering decision had to be made concerning the next operating period (2018-2020):

- continue operation as per the 2016-2018 period, or
- increase the allowable TMT by 18°C.

It was found that continued operation at the 2016-2018 limits resulted in four replacements being required in 2020. Increasing the allowable TMT was permissible in terms of fitness-for-service until 2020, however the result was that over 60 tube replacements would be required in 2020. This allowed the plant management to consider the economic impact of each scenario and tailor the operation of the furnace with good information. ■

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Science inspiring better catalysts

Catalysts are a crucial part of every syngas and ammonia production unit. Catalyst performance is directly linked to the profitability of a plant. A robust catalyst that is easy to start-up and tolerant towards varying process conditions is also decisive for improving the on-stream factor of a plant. In this article Johnson Matthey discusses its inspiring science to extend purification and LTS catalyst life and Clariant reports on its latest catalyst developments for pre-reforming, reforming and HTS.

Johnson Matthey purification and LTS catalysts

Johnson Matthey (JM) seeks to improve the efficiency, effectiveness and sustainable impact of its products, enabling JM customers to achieve high productivity by making more for less. One of the most critical duties in an ammonia plant which can force the timing of outages is the low temperature shift (LTS). The outages caused by the LTS are typically either due to lack of conversion (high CO slip) or pressure drop. To provide long life and maximum conversion, management of trace levels of S and Cl poisons, which are known to be a major factor in the achieved LTS life, is important. For decades JM has been known for offering the market leading self-guarding LTS catalysts that are robust, retaining high strength meaning increased lives can be achieved with reliability.

As market leaders in the field of syngas purification the two products featured here are examples of inspiring science from JM which extend the life of LTS catalyst.

Many ammonia plants are fed with light natural gas feeds containing a relatively low level of sulphur impurities, for these Johnson Matthey's KATALCO 33-1 is ideally suited as a 3-in-1 total sulphur removal product, the multi-functionality of the product results from a bulk ZnO phase with controlled physical properties to maintain a high sulphur capacity and a sharp sulphur profile into which low level catalytically active components have been

incorporated providing the HDS and ultra-purification activity.

KATALCO 33-1 has now been deployed in a number of plants with the technology well proven and now widely adopted, especially in the industrial gas market where operators have significant expertise analysis and understanding of gas quality.

KATALCO 33-1 is a granulated product that has been designed to offer optimised hydrodesulphurisation (HDS) activity for conversion of organic Sulphur species to H_2S , in combination with high saturation sulphur capacity and a narrow H_2S absorption front.

This is achieved by the materials science in the granules where both ZnO promotion and product density have been optimised to give a high capacity whilst retaining a high porosity structure, as shown in the SEM image in Fig. 1. The structure is very porous with highly developed number of accessible active sites.

The electron probe micro analysis (EMPA), of discharged KATALCO 33-1 granules (Fig. 2), shows how the full structure is accessible to sulphur, with a uniform S distribution throughout the granules.

In operation KATALCO 33-1 offers enhanced protection against COS slip. This is because the H_2S formed by reaction over the HDS function of KATALCO 33-1 is immediately captured by the H_2S absorption function of the product. This prevents subsequent reaction of H_2S with CO_2 so that COS is not generated. KATALCO 33-1 can be designed to additionally provide ultrapurification in the bed – both of these

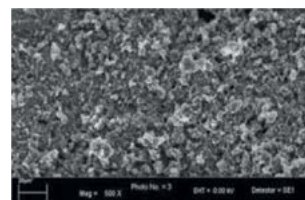


Fig. 1: SEM image showing porous surface of KATALCO 33-1

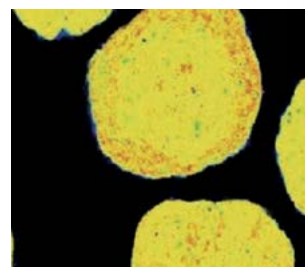
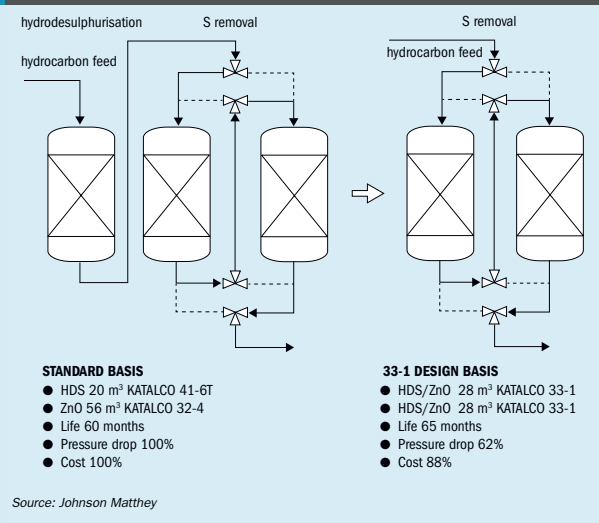


Fig. 2: EMPA elemental map of KATALCO 33-1 granule – S specific.

aspects stop S which escape a traditional purification and end up being captured in the LTS. As a 3-in-1 solution in addition to ease of loading of one product rather than multiple products there are capex benefits, as KATALCO 33-1 allows simplification of plant designs. Conventional designs may use a two stage (HDS + H_2S removal) or three stage (with ultrapurification) system, both of which could be arranged in either a lead-lag or single bed configurations.

Fig. 3: Standard vs KATALCO 33-1 design for 2,200 t/d N America ammonia plant



The following case studies illustrate the use of KATALCO 33-1 in large modern ammonia plants.

Case study 1

Design for a North American 2,200 t/d ammonia plant shows the benefits gained from the use of KATALCO 33-1 product (Fig. 3). By using a smaller volume of product both capex savings and opex savings have been made.

Capex savings are achieved as a 20 m³ HDS is no longer required, saving

capital and on-going maintenance costs. opex savings are achieved as the 56 m³ KATALCO 33-1 loading offers a longer run length with 38% lower pressure drop through the run and this smaller volume of product saves overall cost.

Case Study 2

A European 2,000 t/d plant was operating with a level of incoming sulphur that was less than 10 ppm S. It had been using a standard CoMo/ZnO system in a single vessel containing beds of KATALCO 41-6

Fig. 4: Standard vs KATALCO 33-1 design for 2,000 t/d European ammonia plant

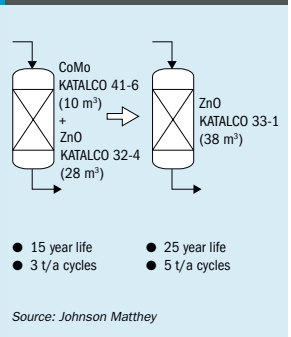
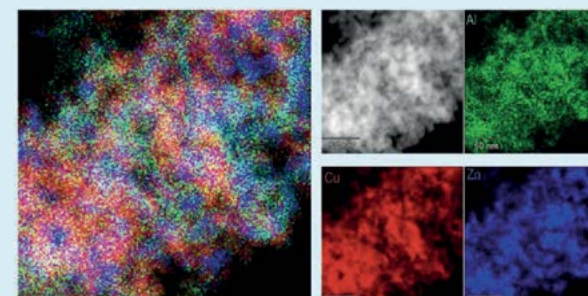


Fig. 5: EDX analysis of KATALCO 83-3X showing elemental mapping of catalyst structure



Source: Johnson Matthey

and KATALCO 32-4. The operator changed to KATALCO 33-1 (Fig. 4).

The benefit for the operator was a significantly longer life with the absorption life of the purification system. The system changeout interval increased from 15 to 25 years, lasting five rather than three turnaround cycles.

Due to the ultra-purification function from KATALCO 33-1 throughout the long life the achieved purification quality is improved, with an exit sulphur level below 10 ppbv, compared to around 50 ppbv achieved by conventional ZnO, helping downstream catalysts and particularly the LTS last longer.

LTS catalyst

JM's LTS catalyst is copper (Cu) distributed on a mixed support of zinc oxide (ZnO) and alumina (Al_2O_3). The LTS catalyst is supplied as a mixture of oxides, and the copper oxide (CuO) is in a form that can be easily and quickly reduced into the active form. The Cu crystallites formed in this way must not sinter and lose activity during service, the active Cu phase and catalyst structure should also be unaffected, as far as possible, by traces of poisons in the process gas stream.

The properties of the LTS catalyst are critically dependent upon the formulation and manufacturing process rather than on the bulk chemical analysis. The importance of the correct control of the formulation and preparation conditions is key in obtaining the correct LTS structure, to produce a catalyst that offers long-term, stable activity and mechanical properties, thus avoiding a pressure drop increase. Fig. 5 shows JM analysis structures in detail using EDX analysis.

To achieve a long and active life the copper metal crystallites (red) must be small and well separated from each other by even smaller, yet thermally stable, zinc/alumina refractory oxide crystals (blue/green). To obtain the necessary catalytic behaviour the scale of this science is at a nanometer scale. Through this leading science JM can manage the formulation and manufacture of the LTS catalyst with stringent controls to achieve the optimum structure balancing good activity, thermal stability and the ability to withstand the effect of poisons hence enhancing life.

The formulation of KATALCO 83-3 series LTS catalysts is a careful balance between poisons resistance, stability, selectivity and activity that is manufactured to achieve a high dispersion of Cu crystallites within the ZnO/Al₂O₃ structure. The ZnO/Al₂O₃ refractory crystallites add strength to the catalyst while providing a stable support maintaining the high dispersion of the active Cu sites and therefore inhibit the Cu crystallites from sintering, therefore maintaining activity and life.

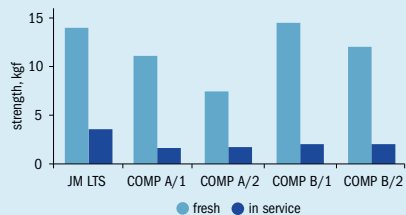
After stabilising in-service, the LTS catalyst needs to display stable performance throughout its working life – meaning uniform activity, retained strength and good capacity for poisons. The relative effects of increasing poisons resistance and activity of LTS are shown in Fig. 6.

Although increased catalyst activity is desirable, improved poisons resistance has a more significant effect on LTS catalyst life.

Considering what this understanding of catalyst science and LTS composition means in operation, typical use of LTS catalyst comprises of three stages:

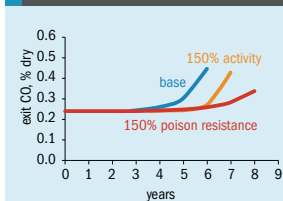
- catalyst is loaded, reduced and started-up without incident;
- catalyst is operated with trace levels of poisons as would be expected with a normally operating purification system;

Fig. 7: Relative strengths of LTS catalyst for both fresh and in-service conditions



Source: Johnson Matthey

Fig. 6: Increasing poisons resistance or activity – effect on LTS performance



Source: Johnson Matthey

- after many years of stable operation with CO at equilibrium levels and low pressure drop, the catalyst is discharged. During the operation of an ammonia plant there are trips, boiler leaks, and catalyst poisons that are an unavoidable part of plant operation, and the LTS catalyst must be designed to survive these.

KATALCO 83-3 catalyst series have an excellent reputation of doing this. The catalyst structure retains a high in-service strength which is especially critical to the operator as this is the strength of the catalyst in the in-service condition, once reduced and used in plant conditions. The attached benchmark data (Fig. 7) shows the in-service strengths measured on reduced catalyst using a crush machine housed in an inert atmosphere.

These results show how for all LTS catalysts the reduced strength of pellets is lower than for fresh oxidic. For JM LTS the in-service pellet strength is higher than competitive LTS pellets. This increased strength helps provide stable performance without increasing in-service pressure drop.

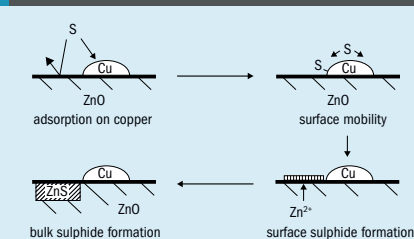
A further operational difference from the structural science of KATALCO 83-3

catalysts is the tolerance to catalyst reduction process conditions. The catalyst reduction itself is a transient process in which the CuO in the LTS is reduced to the active Cu metal, often in a recirculation loop. When a recirculating system is used there needs to be a continuous purge from the system to prevent the level of contaminants from building up within the system. The oxidic LTS catalyst contains some complex copper-zinc basic carbonates and these decompose during reduction and release carbon dioxide (CO₂). The amount of CO₂ in the recirculating carrier gas is one of the key parameters that determine the level of purging from the recycle loop.

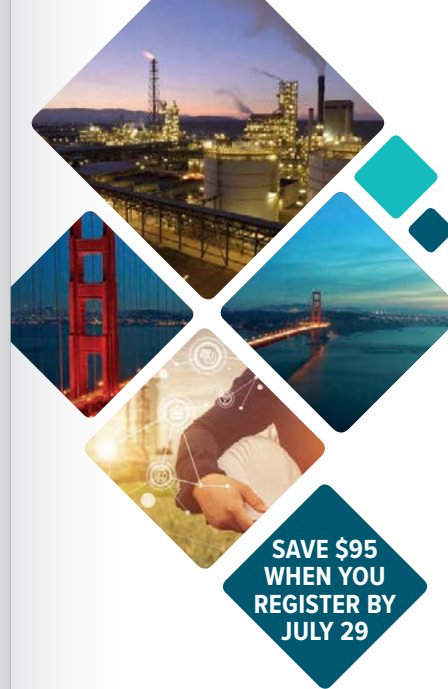
There is a potential for the CO₂ in the recirculating gas to react with oxides in the LTS catalyst and damage its microstructure. The damage occurs primarily in the support phase of the catalyst, resulting in a weakening of the catalyst pellets. This is often observed as a higher than expected LTS pressure drop as soon as the plant is started up, which then increases rapidly during ongoing operation. Therefore, limits on the CO₂ partial pressure have been applied during some LTS catalyst reductions, with a figure of circa 1bara (15psia) being typical for some products. By optimising the catalyst formulation of KATALCO 83-3 series JM has engineered a rugged stable support phase for the active sites, meaning it is a LTS catalyst less sensitive to the level of CO₂ in the reduction gas.

This has the economic benefit of reducing the cost of nitrogen or natural gas used during the LTS catalysts reduction, however, the main benefit is that it provides a larger operational envelope for catalyst reduction without risk of achieving a low catalyst activity. During LTS reduction, monitoring of the gas composition is often undertaken with temporary instrumentation and manual

Fig. 8: Schematic mechanism for S capture within LTS



Source: Johnson Matthey



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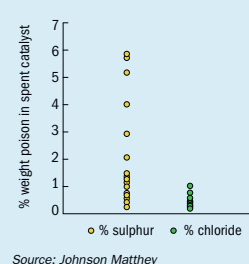
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Fig. 9: Levels of sulphur and chloride measured in spent LTS catalysts



control of the purge flow. Therefore, a wider operating envelope within the period of less than ideal control is especially useful.

The two most virulent poisons for an LTS charge are sulphur and chlorides. They are the major source of LTS deactivation. Sulphur covers the active copper surface and chlorides promote copper crystal growth. Possible sources of sulphur include hydrocarbon feedstock, lubricating oil, air to the secondary reformer and new HTS catalyst. Possible sources of chlorides include quench water, lubricating oil and air to the secondary reformer.

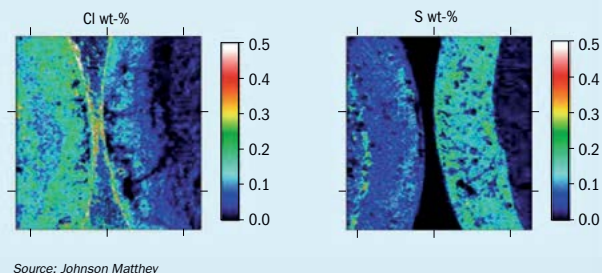
LTS catalyst poisons

Catalysts start to be poison whenever an impurity in the process gas alters the surface structure or composition of the active metal. Sulphur, which is the most common of these poisons, deactivates LTS catalyst by a process of chemisorption onto the active copper surface followed by crystallite growth.

Hydrogen sulphide (H_2S) can be absorbed as a layer onto the active Cu surface at much lower partial pressures than required for bulk sulphides. As such Cu in LTS catalyst is very active for absorbing a surface layer of H_2S if present in the reacting process gas. However, since thermodynamic data predicts H_2S will react preferentially with ZnO rather than Cu it is essential that the LTS catalyst is designed such that sulphur is rapidly transferred from the active Cu metal to ZnO before the Cu sinters (Fig. 8).

In a well formulated LTS, there is an excess of free ZnO meaning that H_2S presence is absorbed quickly at the top of the bed leaving the rest of the catalyst to operate satisfactorily. Absorption capacities of around 6 wt-%, have been measured in

Fig. 10: EMPA analysis showing analysis for S/Cl on KATALCO 83-3 pellet surface



KATALCO 83-3 series LTS catalysts in plant use. The sulphur capacity relates directly to the surface of free ZnO present in a catalyst. Those containing less available ZnO can allow a given quantity of H_2S to penetrate deeper into the bed causing greater deactivation. As described, by using upstream ultra-purification, e.g. KATALCO 33-1, a lower quantity of H_2S reaching the LTS will help prevent deactivation.

Chloride as a poison presents more of a challenge in the LTS reactor because of the low melting point and high solubilities in water of zinc, copper chlorides. Chloride can be redistributed through the catalyst bed by dissolution in condensed water or by vapour phase transfer of volatile chloride. Consequently, the absorption profile for chloride in the catalyst bed is not as stable as for sulphur and chloride can be distributed deeper into the bed. So, although the levels of chloride reaching the LTS bed are generally lower than sulphur the damage can be more harmful. The levels of S and Cl vary from plant to plant depending on the prevalent conditions of the poisons. Ranges seen on inlet LTS catalyst samples taken at the top of the bed over a wide range of over 150 plant samples are shown in Fig. 9.

High surface coverages are often seen of both sulphur and chloride on discharged samples, often above 1 wt-% at the top of the bed. A long-standing feature of JM LTS technology is that it is self-guarding in terms of both S and Cl. Fig. 10 shows an EMPA (electron probe micro analysis) of spent KATALCO 83-3 series LTS showing the distribution of both S and Cl captured on the surface of the pellets.

Although typical levels of chloride in spent LTS are much lower level than sulphur, even these low Cl-levels have the

potential to be much more damaging, for two reasons:

- **Cl-solubility:** both copper and zinc chloride are soluble in water, hence condensation on the catalyst during start-up, shutdown or normal operation can move chlorides further down the bed.
- **Cl-induced sintering:** low levels of chlorides can have a significant effect on LTS catalyst activity since they promote sintering.

Temperature is the dominant factor in controlling the rate of sintering of metallic and oxidic species. Tamman temperature is calculated (in absolute units) as one half of the melting point of the metal or oxide. This gives an indication of the temperature at which metal or metal oxide atom lattices experience mobility, physically in terms of the driving forces for dissociation and diffusion of surface atoms.

Sintering rates of a metal or metal compounds are significant and very high near the Tamman temperature; thus, the relative thermal stability materials can be correlated in terms of the Tamman temperatures, Table 1 lists these for the LTS metals and their compounds.

It can be seen why sintering of LTS catalysts is strongly promoted by traces of chlorine in the feed, copper chlorides having a Tamman temperature of only 79-174°C and zinc chloride a Tamman temperature of only 9°C meaning at LTS operating temperatures the formation of copper and zinc chlorides provide a mechanism for loss of activity and poisoning by sintering, which is shown schematically in Fig. 11.

As well as sintering, chlorides can be a problem due to their mobility in the case of wetting as this case study illustrates showing the impact a wetting incident can have on LTS performance.

Table 1: Melting point and Tamman temperatures for LTS metals/compounds

| Compound | T_{mp} (Melting point) | | $T_{Tamman} (= 0.5 T_{mp} K)$ | |
|----------|--------------------------|-------|-------------------------------|-----|
| | K | °C | K | °C |
| Cu | 1,356 | 1,083 | 678 | 405 |
| $CuCl_2$ | 893 | 620 | 447 | 174 |
| CuCl | 703 | 430 | 352 | 79 |
| CuO | 1,599 | 1,326 | 800 | 527 |
| Zn | 693 | 420 | 347 | 74 |
| ZnO | 2,248 | 1,975 | 1,124 | 851 |
| $ZnCl_2$ | 563 | 290 | 282 | 9 |

Source: Johnson Matthey

Case study 3: LTS wetting damage

This case study shows an ammonia plant using a competitive product strategy, including a Cl-guard layer (5% bed depth) over the main bed catalyst. After less than two years on-line the performance was good with low CO slip (<0.2%) and the reaction exotherm showed little signs of poisoning.

However, following a plant trip which resulted in the LTS being wetted, the CO slip increased to end of run (EOR) conditions. Consequently, the reaction exotherm moved much deeper into the bed becoming less sharp.

After the wetting damage the inefficient LTS performance significantly increased production costs. The plant therefore made an unplanned shutdown to change the LTS catalyst. An estimate of the production costs for this event was in the range \$1,000,000 – \$5,000,000.

PURASPEC 2272: a new Cl-guard trap

JM has used its expertise in purification science along with its proven STREAMLINE engineering skills to develop PURASPEC

2272 – an innovative new product which combines the functions of a low pressure drop support with that of a chloride trap. PURASPEC 2272 is a low pressure drop active adsorbent support media that replaces the inert support media at the bottom of the high temperature shift (HTS) reactor and captures chloride which would otherwise poison the low temperature shift (LTS) catalyst downstream.

The development of PURASPEC 2272 was made in JM's research facilities in Billingham, UK, where the effectiveness of the alkali-promoted adsorbent was tested using a reactor temperature of 430°C, a pressure of 30 bar, and a steam to dry gas ratio of 0.5, for a short-term, 25 day, high GHSV test to determine its effectiveness as a Cl-guard at typical HTS exit test conditions. The process gas used was representative of plant conditions: 55% H_2 , 4% CO, 16% CO_2 and 25% N_2 containing only a low level of HCl at 9 ppbv. During the test no chloride was detected in the exit gas. After the test was completed the PURASPEC adsorbent was recovered and analysed for C content. The inlet portion

contained 330ppm similar to the level of Cl levels that would be found at the top of the LTS bed in a similar duration test. In long term operation within plants where saturation capacity of PURASPEC 2272 is well above 1% chloride it is expected to more than match %w/w Cl capture that takes place normally within the LTS bed.

PURASPEC 2272 is a patented solution which provides protection by helping to stop chlorides from reaching the LTS catalyst. Chlorides are very soluble and so are mobile when wetted. This means that condensation on an LTS catalyst can distribute chlorides throughout the bed and have a severe impact on catalyst performance.

Wetting risk – dewpoint consideration

To achieve the lowest CO slip LTS catalysts are run close to dewpoint. Hence as shown in Fig. 12, dewpoint at the top of the LTS traditional location for a dedicated Cl-guard above catalyst (B) is typically below <25°C. The location for PURASPEC 2272, at the bottom of the HTS vessel (A), gives a much greater safety margin.

Fig. 12: Locations for a Cl-guard in the shift section

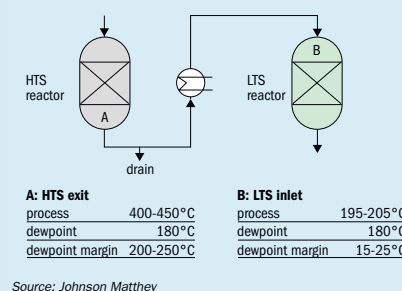


Fig. 13: Case study – improvements to HTS/LTS loadings

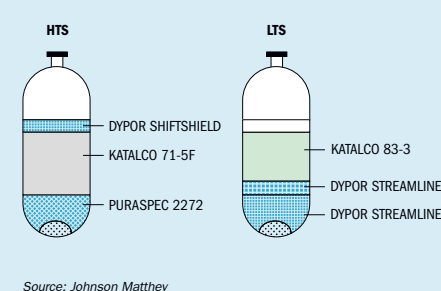
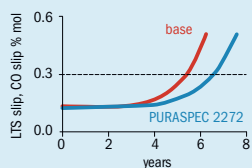


Fig. 14: Expected performance of LTS with PURASPEC 2272



Source: Johnson Matthey

The use of PURASPEC 2272 at location (A) below the HTS gives several benefits:

- dewpoint margin is above 200°C;
- chlorides are kept out of the LTS reactor;
- should wetting occur, chlorides can leave from a drain rather than enter LTS.

Case Study 4

The technology was in use in a 1,360 t/d Kellogg ammonia plant, operating at 120% of design capacity with parallel design HTS and LTS vessels in each vessel. The catalyst was supported via a conventional arrangement of ceramic balls above a semi-elliptical outlet collector.

JM was able to analyse the pressure drop profile through the catalyst bed and support media using their proprietary STREAMLINE software, JM was able to analyse the flow regime through the catalyst support balls.

From this analysis the following improvements were developed for both the HTS / LTS reactors (Fig. 13).

HTS reactor:

- DYPOR as SHIFTSIELD
- KATALCO 71-5F as the catalyst bed
- PURASPEC 2272 support as Cl absorbing STREAMLINE media.

LTS reactor:

- KATALCO 83-3 as the catalyst bed
 - DYPOR support as STREAMLINE system.
- The anticipated improvement in LTS performance and life extension from using PURASPEC 2272 is shown in Fig. 14, based on steady state operation.

In addition to life extension, by keeping Cl safely guarded outside the LTS reactor in the event of unexpected transient conditions in which condensation may occur at the top of the LTS bed the use of PURASPEC 2272 provides significant protection against potentially damaging wetting events which could easily cause losses of \$1,000,000 – \$5,000,000.

Clariant catalyst developments

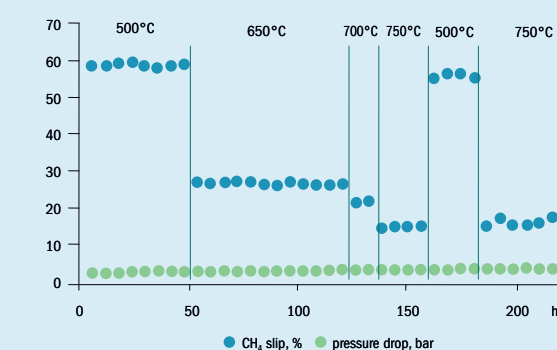
New catalyst developments from Clariant to increase plant profitability, reliability and safety include a new high temperature pre-reforming catalyst, a low pressure drop primary reforming catalyst and a chromium VI free high temperature shift catalyst.

High temperature pre-reforming

The adiabatic pre-reformer converts higher hydrocarbons to methane, hydrogen, carbon monoxide and carbon dioxide before the feed gas enters the primary reformer. This setup offers several advantages. Conversion of heavy hydrocarbons allows the utilisation of a more diverse feedstock while minimising the risk of coke formation in the primary reformer. Also energy savings can be achieved with a reduction of the overall steam to carbon ratio and a better heat integration. In addition, since the reforming reaction partially takes place already in the pre-reforming section, the primary reformer can either be reduced in size to minimise capex or the throughput of the unit can be increased.

Standard operating temperatures in the industry for the pre-reforming reaction vary in the range of 420°C to 530°C. The upper limitation is currently given by the thermal stability of the catalyst. Elevated temperatures over prolonged time cause sintering of the active sites on the catalyst surface and therefore an activity loss. Higher operating temperatures for the pre-reformer however would result in a better methane conversion and therefore allow further shift of the reforming duty from the primary reformer to the pre-reformer.

Fig. 15: Activity of pre-reforming catalyst ReforMax 100HTP



Source: Clariant

Clariant's new high temperature pre-reforming catalyst ReforMax 100 HTP has been designed to deliver outstanding performance at temperatures beyond the current standard pre-reforming conditions. Compared to the pre-reforming catalyst ReforMax 100 with an operating temperature limit of 570°C, the ReforMax 100 HTP allows a wide operating range up to 750°C while retaining its activity and superior coking resistance (Fig. 15). Installation of ReforMax 100 HTP therefore offers the possibility to minimise capex by further reducing the size of the primary reformer for new plants or to increase the throughput in revamp projects.

Low pressure drop primary reforming

The primary reformer is the most delicate unit in natural gas based syngas plants. High operating temperatures close to the material limit of reformer tubes combined with the endothermic steam reforming reaction require a highly active and stable catalyst to prevent overheating of the reformer tubes. In addition, the primary reformer typically has the highest pressure drop of installed catalyst beds, which can increase costs due to additional natural gas compression and in some cases can limit the throughput of a plant.

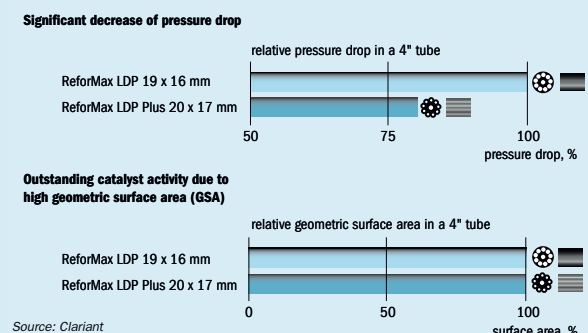
To enhance plant operations and efficiency, Clariant has developed the new steam methane reforming catalysts ReforMax® 330 LDP Plus (standard) and ReforMax® 210 LDP Plus (lightly alkaliized). Chemically based on the industry proven ReforMax LDP series, the size, aspect ratio and inner channels of these new catalysts have been designed to optimise geometric surface area, pressure drop and crush strength (Fig. 16).

Fig. 16: ReforMax LDP shape (left); optimised LDP Plus shape (right)



Source: Clariant

Fig. 17: Comparison of ReforMax LDP and LDP Plus pressure drop and surface area



Source: Clariant

Fig. 18: Chromium VI visible in ShiftMax 120 (L); absent in ShiftMax 120 HCF (R)



Source: Clariant

The catalysts' unique 8-hole flower-like shape not only provides highest activity and selectivity, but also drastically reduces the pressure drop in the reactor tubes compared to previous catalyst generations (Fig. 17), thus allowing for higher gas throughput and/or energy saving due to reduced compressor load. Furthermore, the catalysts' large holes support a highly efficient heat transfer in the reformer. Overall, the new catalysts substantially reduce energy consumption in the production of synthesis gas.

The catalysts have already demonstrated these performance advantages in

commercial use. Since the introduction in 2017, several units have been loaded with ReforMax LDP Plus, including hydrogen units in the United States and two major ammonia plants in Europe.

In 2018, ReforMax® 330 LDP Plus was installed in a world-scale ammonia production plant in Europe, where it has been delivering the expected improvements since start-up. The facility has benefitted from a 17% reduction in pressure drop across the catalyst bed, leading to a significant increase in the plant's energy efficiency. The customer reports high

satisfaction, and recommends ReforMax® 330 LDP Plus for all plants experiencing pressure drop limitations in the primary reformer.

Chromium VI-free high temperature shift

The high temperature shift (HTS) section increases the hydrogen yield by enabling the reaction of carbon monoxide with water to form carbon dioxide and hydrogen. A good HTS catalyst needs to offer stable performance in terms of activity and pressure drop even at elevated operating temperatures. Furthermore, it should withstand occasional upsets e.g. wetting due to waste heat boiler leakages.

Clariant's well proven ShiftMax 120 is based on iron/copper oxide and chromium (III) oxide. While iron and copper are mainly necessary for the catalytic activity, chromium (III) is an integral part to achieve the necessary stability and longevity of the catalyst. However, residual amounts of chromium (VI) were always an issue for HTS catalysts. First, reduction of chromium (VI) during the initial HTS start-up leads to a significant exotherm which has to be controlled. Even more important, the use of chromium (VI) has been banned by the European Union in 2017 due to its toxic and carcinogenic properties. Also in other regions of the world, chromium (VI) is increasingly being seen as a serious safety hazard.

Clariant's new ShiftMax® 120 HCF delivers the same outstanding and reliable performance which is known in the industry from ShiftMax 120 for more than 30 years. However, chromium (VI) levels are reduced to hardly detectable trace levels that fully comply with the new REACH regulations. There are now over 30 references operating the new ShiftMax 120 HCF all over the world. Fig. 18 shows an easy test to check for Chromium (VI). When HTS catalyst is placed in boiling water after five minutes the yellow, soluble chromium (VI) is visible for ShiftMax 120 (left) but is absent in the case of ShiftMax 120 HCF (right).

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